BOTANY LAB MANUAL



Maria Morrow
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College of the Redwoods

Botany Lab Manual

Maria Morrow

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TABLE OF CONTENTS

Licensing

Preface

ProgramPage

1: Long term Experiment - Nutrient Deficiency in Wisconsin Fast Plants (Brassica rapa)

1.1: Introduction

1.2: Preparing for the Experiment

1.3: Before the experiment

1.4: The Experiment

1.5: Suggested Rubric

2: Introduction to Ecology

2.1: Formative Questions

2.2: Introduction

2.3: Modeling a Food Web

2.4: Nutrient Cycling in Ecosystems

2.5: Mycorrhizal Networks

2.6: Community Interactions

2.7: Coevolution and Natural Selection

2.8: Summative Questions

3: From Prokaryotes to Eukaryotes

3.1: Formative Questions

3.2: Introduction

3.3: Using the Dissecting Microscope

3.4: Prokaryotic Cells

3.5: Using the Compound Microscope

3.6: Eukaryotic Cells

3.7: Primary Endosymbiosis

3.8: Cell Structures and Organelles

3.9: Summative Questions

4: Plant Cell Types and Tissues

4.1: Formative Questions

4.2: Introduction

4.3: Identifying Cell Types and Tissues

4.4: Summative Questions

5: Multicellularity and Asexual Reproduction

5.1: Formative Questions

5.2: Introduction

5.3: Anatomy of a Chromosome
5.4: Mitosis
5.5: The Cell Cycle
5.6: Meristems and Tissues in the Root
5.7: Multicellularity and Clonal Reproduction
5.8: Summative Questions

6: Roots and the Movement of Water - How is water moved through a plant?

6.1: Formative Questions
6.2: Introduction
6.3: The Behavior of Water
6.4: Transpiration and Cohesion -Tension Theory
6.5: Summative Questions

7: Roots and the Movement of Water - Root structure and anatomy

7.1: Formative Questions
7.2: Introduction
7.3: Root Structure and Anatomy
7.4: Types of Root Systems
7.5: Summative Questions

8: Shoot Anatomy and Morphology

8.1: Formative Questions
8.2: Introduction
8.3: Shoot Development
8.4: Monocots
8.5: Eudicots
8.6: Shoot Morphology
8.7: Summative Questions

9: Leaf Anatomy

9.1: Formative Questions
9.2: Introduction to Leaf Anatomy
9.3: Leaf Anatomy
9.4: Process of Science - Predicting Drought Tolerance in Leaves
9.5: Summative Questions

10: Plant Adaptations

10.1: Formative Questions
10.2: Introduction
10.3: Organ Modifications
10.4: Determining Plant Modifications and Function
10.5: Color-coded Organs
10.6: Summative questions

11: Secondary Growth

11.1: Formative Questions

11.2: Introduction

11.3: Secondary Tissues in the Root

11.4: Flowcharts of Development

11.5: Secondary Tissues in the Shoot

11.6: Dendrochronology

11.7: Summative Questions

12: Photosynthesis and Plant Pigments

12.1: Formative Questions

12.2: Introduction

12.3: Part 1 - Pigments

12.4: Pigments and Evolutionary Adaptations

12.5: Part 2 - Photosynthesis

12.6: C4 and CAM Photosynthesis

12.7: Summative Questions

13: Cellular Respiration and Fermentation

13.1: Formative Questions

13.2: Introduction

13.3: Cellular Respiration

13.4: Concept Mapping - Connecting Ideas Visually

13.5: Summative Questions

14: Meiosis, Fertilization, and Life Cycles

14.1: Formative Questions

14.2: Introduction

14.3: The Production of Genetic Diversity

14.4: Fertilization

14.5: Life Cycles

14.6: Life Cycle Diagram Fold Out

14.7: Summative Questions

15: Microfungi - Slimes, Molds, and Microscopic True Fungi

15.1: Formative Questions

15.2: Introduction

15.3: Fungus-Like Organisms

15.4: Kingdom Fungi - The True Fungi

15.5: General Morphology

15.6: The Fungal Phylogeny

15.7: Summative Questions

16: Macrofungi and Lichens - True Fungi and Fungal Mutualisms

16.1: Formative Questions

16.2: Introduction

16.3: Macrofungi

16.4: Fungal Ecology

16.5: Summative Questions

17: Heterokonts

17.1: Formative Questions

17.2: Introduction

17.3: Oomycota -- The Water Molds

17.4: Photosynthetic Heterokonts - Descendents of Secondary Endosymbiosis

17.5: Phaeophyta - The Brown Algae

17.6: Fucus Life Cycle

17.7: Bacillariophyta - The Diatoms

17.8: Summative Questions

18: Red and Green Algae

18.1: Formative Questions

18.2: Introduction to Red and Green Algae

18.3: Phylum Rhodophyta - The Red Algae

18.4: Phylum Chlorophyta and Phylum Streptophyta

18.5: Pond Ecosystem Relationships

18.6: Design an Experiment

18.7: Summative Questions

19: Evolution of the Embryophyta

19.1: Formative Questions

19.2: Introduction to the Evolution of the Embryophyta

19.3: Major Evolutionary Lineages

19.4: Summative Questions

20: Bryophytes

20.1: Formative Questions

20.2: Introduction to Bryophytes

20.3: Selection Pressures and Drivers

20.4: Anthocerotophyta - Hornworts

20.5: Marchantiophyta - The Liverworts

20.6: Bryophyta - Mosses

20.7: Summative Questions

21: Seedless Vascular Plants

21.1: Formative Questions

21.2: Introduction to Seedless Vascular Plants

21.3: Lycophytes (Class Lycopodiopsida)
21.4: Ferns (Class Polypodiopsida)
21.5: Summative Questions

22: Gymnosperms

22.1: Formative Questions
22.2: Introduction to Gymnosperms
22.3: Selection Pressures and Drivers
22.4: Cycads and Ginkgos
22.5: Gnetophytes and Conifers
22.6: Using a Dichotomous Key
22.7: Summative Questions

23: Angiosperms I - Flowers

23.1: Formative Questions
23.2: Introduction to Angiosperms
23.3: Selection Pressures and Drivers
23.4: Specialized Vascular Tissue
23.5: Anatomy of a Flower
23.6: Stimulating Pollen Tube Growth
23.7: Pollination Syndromes
23.8: Inflorescence Types
23.9: Summative Questions

24: Angiosperms II - Fruits

24.1: Formative Questions
24.2: Introduction
24.3: Selection Pressures and Drivers
24.4: Angiosperm Life Cycle
24.5: Fruits
24.6: Using a Dichotomous Key to Identify Fruit Type
24.7: Dispersal Syndromes
24.8: Summative Questions

25: Glossary

25.1: Key to Common Local Tree Genera (Written for Humboldt County, California)
25.2: Dichotomous Key to Common Fruits
25.3: Evolutionary Profile - Photosynthetic Groups
25.4: Glossary of Terms and Root Words

Glossary of Terms and Root Words
Evolutionary Profile - Photosynthetic Groups
Dichotomous Key to Common Fruits
Index
Glossary
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Preface

Introduction to the Study of Botany

The term botany refers to the study of plants. However, as you will undoubtedly experience more during your scientific career, a name is often reflective of something that was once believed to be accurate but no longer is. So, what is "botany"?

As a course, botany is the study of plants and many of the other non-animal groups in the tree of life. With regard to organisms, this course begins with the Cyanobacteria, winds through several groups of unrelated organisms that were all once categorized as fungi, picks apart pieces of the "protista," and finally emerges into Kingdom Plantae. With regard to scientific disciplines, we begin with ecology, transition to a bit of chemistry and cell biology, assemble these building blocks to learn anatomy and physiology, use these characteristics to discuss evolution and systematics, classify our organisms into related groups based on organismal biology, then discover their interrelatedness by returning back to ecology--all with a sprinkle of physical geography to give us some historical context.

Notice that I did not say plant identification. The (upper division) botany course you are thinking of is called Plant Taxonomy. To take that course, you must first learn to speak the language of botany. It is difficult to determine whether the vestiture on the pedicels of a raceme is glabrous, glaucous, or glochidiate if you do not yet know what a pedicel **is**.

Speaking of languages, botany is a language-intensive course. As with any language, only speaking it for a few hours a week will not be sufficient to attain any kind of fluency. You will need to learn, memorize and apply a vast array of new terms throughout the course of this semester (there are 528 terms in the glossary). You will need to speak botany outside of class. You will need to speak botany to others and interpret botany being spoken to you. You will need to read, write, and draw botany. If you start to dream in botany, you know you are doing it right.

How to Use This Manual

Before You Get to Lab

Each lab has a section that is intended to be completed prior to the start of the lab. This section includes formative questions, content and skill objectives, and an introduction to the topic. **Formative questions** are not intended to be graded for “correctness” and often lack any correct way to answer. Instead, these questions are intended to see what you might already know or think about the topic you are going to learn about. **Content objectives** list what you are expected to learn during the lab, while **skill objectives** list what you should be able to do after the lab. The **introduction** frames the lab content in context of larger topics within the field of science and highlights specific concepts that will be covered within the lab. Later labs focused on learning different organismal groups also contain a section called **selection pressures and drivers** that explains what conditions this group of organisms evolved in response to.

Vocabulary

Any new terms that you will be expected to know are **bolded**. These bold terms can also be found in the glossary, which also includes the definitions for root words frequently used in botany.

Diagrams

Most diagrams are intended to be colored in. You should have colored pencils, crayons, or pens to fill in these diagrams. In the organismal group labs, there are life cycle diagrams. Each of these should have a color-coded key for distinguishing between haploid and diploid tissues. You can choose the colors. Most of the diagrams are also unlabeled. The intention is that you will interpret the text, interact with the material, and learn from your instructor how to label the structures. If all of the answers are laid out for you, there isn’t much investigation to be done and your opportunities for learning are diminished. Don’t know if you labeled the life cycle correctly or identified the correct root system? Use the vast amount of resources you have at your disposal at any college to check your work: your textbook, your classmates, your instructor, Google, Youtube, and Wikipedia. As is always

the case in science, it is good to check multiple sources of information.

Summative Questions

Summative questions are at the end of the lab and are intended to gauge your understanding of the material. These may be collected and graded or not, depending on your instructor's preference. However, the questions address concepts that are fundamental to understanding the topic and are intended to help you prepare for exams and quizzes.

Additional Resources

This lab manual was produced as an open educational resource under the Open Educational Resources Initiative. In an effort to make all materials available to anyone who would like access, there is a Google Drive folder that contains the following resources, all of which can be downloaded, edited, and adapted (for non-commercial purposes). All materials are licensed CC BY-NC:

- All 23 labs contained in this manual
- All ancillaries in this manual, including dichotomous keys, experiments, a template for evolutionary profiles, the glossary, table of contents, and this introduction!
- A growing database of hundreds of images of prepared slides and specimens
- A folder of diagrams and figures used in the manual
- A folder titled "Updates" where updated or additional materials will be made available

You can access the Google Drive folder here.

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1: LONG TERM EXPERIMENT - NUTRIENT DEFICIENCY IN WISCONSIN FAST PLANTS (BRASSICA RAPA)

Learning Objectives

Content Objectives

- Research the roles of macro- and micronutrients in plant life cycles
- Connect characteristic symptoms to specific nutrient deficiencies

Skill Objectives

- Use the process of science to investigate questions about nutrient deficiency
- Develop a testable, falsifiable hypothesis
- Collect data on a variety of plant characteristics and organize this data in a meaningful way
- Summarize and communicate your findings in a report

1.1: Introduction

1.2: Preparing for the Experiment

1.3: Before the experiment

1.4: The Experiment

1.5: Suggested Rubric

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1.1: Introduction

Throughout this course, you will learn about the requirements for plant survival. One of these requirements is nutrients--elements without which a plant could not complete its life cycle. There are currently 17 known essential nutrients for plants. These include macronutrients, needed in large quantities, and micronutrients, needed only in trace amounts. The dry weight of a plant is 96% carbon, oxygen, and hydrogen, macronutrients that plants can get from air and water. Nitrogen, phosphorus, and potassium are three that you will often see reported on bags of soil (NPK ratios). Calcium, magnesium, and sulfur are the final three macronutrients.

The purpose of this experiment is to familiarize you with the process of science and observe plant nutrition in action! This process often requires a few key components: detailed observation, asking a question, doing some background research, developing a hypothesis/prediction, experimental design, collection of data, and analysis of results. To do this, we will use plants that have been bred to go through their entire life cycle in a single month: Wisconsin Fast Plants. These plants require 24 hours of light each day and do best around $70^{\circ}F$ (see the seed packet for details).

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1.2: Preparing for the Experiment

In this experiment, you will be investigating the effects of different nutrient deficiencies. To do this, you will first need to do some background research on the role of different essential nutrients within the plant. Use your background research to develop a question about plant nutrition.

Examples of questions

What is the effect of nutrient deficiency on vertical growth?

What effect did nutrient deficiency have on the biomass?

How does nutrient deficiency differentially affect roots vs. shoots?

Feel free to be creative with your questions!

Next, you'll need to form a hypothesis about how plants grown in the absence of a particular nutrient will respond. A hypothesis should be a statement that predicts some influence of the independent variable on the dependent variable. Because it includes the dependent variable, your hypothesis should include measurable terms. For example, "plant health" is not measurable, but plant height and biomass are.

Hypothesis

Your statement or prediction concerning nutrient deficiency in Brassica rapa is based on what you know about plants, on your observations, from literature we have in lab, or from information you can glean from the internet, books, nursery fertilizer boxes, etc. If the data you collect does not support your hypothesis, it is okay. In fact, that is often the case in science. We are using science to test your hypothesis, not to prove it right. Here is a brief checklist I like to use when making a hypothesis:

Hypothesis checklist:

- It is a statement, not a question
- It does NOT use the phrase "I think..."
- It makes a prediction
- It is falsifiable (it is possible to collect data that proves it incorrect)
- It includes terms that I can measure
- It is specific enough that someone else could read it and know the parameters of the experiment

Next, you will need to decide what data (evidence) you will need to collect to test your hypothesis. Review the description of the experimental design on the following page to get some ideas.

Data collection

During each lab meeting your group will measure/observe **at least** 5 plant characteristics and record them. These data will then be included in your final written report. Be sure that your data collecting is consistent. Terms like small or large mean very little. However, smaller or larger compared with the control (complete fertilizer) may tell us something about the treatments you are using. Below are some examples of variables you might choose to measure, but do not feel restricted to this list.

Some characteristics that can be observed in comparison with the control and without the use of measuring instruments are basically **qualitative**:

- Leaf size – use terms like smaller, larger, same size, thicker, thinner
- Leaf appearance – terms might include darker, lighter, rougher, smoother, more hairy
- Leaf number – more, fewer, similar
- Height – taller, shorter

- Form – bushier, more elongated, more squat
- Speed of maturity – faster, slower, similar
- Disease Symptoms/Abnormalities – chlorate (yellowing), pale, spotted, blotched, wilted, curling, rotting, crinkled

Some characteristics that require measuring are basically **quantitative**:

- Leaf size
- Plant Height
- Leaf length
- Amount of fertilizer added/used
- Number of leaves
- Number of flowers
- Final biomass

You can take pictures to aid in cataloguing your results.

Analysis of results

We will discuss in class a few ways to analyze your results. Often obtaining averages for collected data and comparing to the control is an effective method.

If you have any questions, bring them up in class—you are probably not the only one! We will spend some time during each of the following labs making observations and discussing what we see.

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1.3: Before the experiment

Before you begin the experiment, record the following information:

Hypothesis (H1):

Independent variable:

Dependent variable:

Standardized variables:

Positive control(s):

Negative control(s):

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1.4: The Experiment

Materials (per group)

- 6 bottles, label with group name, date, time, solution type: -P, -N, -K, -Fe, -Mg, or C for control, and a number (1-6)
- 24 seeds (Wisconsin fast plants, Brassica rapa)
- Vermiculite
- Planting medium (recommend coco coir or other nutrient-free medium)

Procedure

Planting seeds. Make 6 of the following bottle growing systems (BGS)

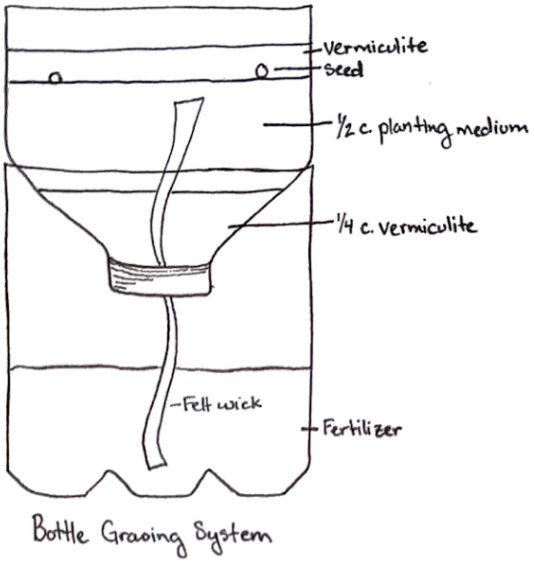


Figure 1.4.1: Bottle Growing System

1. Put your wick (a strip of felt) through the hole in the cap. The wick should be 1/2 inch from the bottom of the bottle.
2. Layer approximately 1/4 cup of vermiculite into the funnel portion of the BGS.
3. Layer approximately 1/2 cup of your planting medium on top of the vermiculite so that it fills the funnel to the rim. Tap the funnel to help the soil settle loosely, then level off the excess. Do not press or compact the planting medium.
4. Gently soak the soil and vermiculite with tap water, letting it percolate through the soil until it drips from the wick at the bottom of the growing funnel. It is important to go slowly, or planting medium can splash out. This is called the run-off. The layer of planting medium should shrink down in the funnel about 0.5 - 1 cm from the rim.
5. Uniformly distribute 2*Fast Plants seeds on the surface of the moist planting medium around the perimeter of the funnel about 5 mm from the clear wall. *Seed arrangement may change, depending on the number of seeds available.
6. Cover the seeds and planting medium with a layer of vermiculite (1 cm) so that the vermiculite is level with the rim of the growing funnel.
7. Gently moisten the vermiculite with tap water until water again drips from the wick at the base of the funnel.
8. Pour off the water remaining in the reservoir, replace it with the liquid fertilizer (-P, -N, -K, -Fe, -Mg, or C). about 2 inches from the bottom – be sure that the wick is at least 1/2 inch into the fertilizer.
9. Clearly label each bottle of the six with the name of your group and which fertilizer solution you are using.
10. Place all BGS in the light rack in the back of the botany lab. Keep light on 24 hours a day.

Procedure: Weekly Data Collection

Each week replenish your fertilizer solutions in the appropriate BGS. You may also need to stake your plants to help support them and adjust the height of the lights. Try to keep your plant tops approximately 10 cm from the light, if possible.

Keep a log of your activities with the plants:

- Did all of your seeds germinate?
- Dates plants are lowered from light source or any other changes are made
- Date, type, and amount of fertilizer added
- Any observed differences in the plants within each BGS. Here are some examples
  - Color changes (which colors and where on the plant)
  - Growth patterns
  - Flower production
  - Leaf production (#, color, shape, etc...)
  - Patterns of chlorosis or necrosis

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1.5: Suggested Rubric

Introduction (11 pts)

( ) A brief description of the experimental design 2 pts

( ) Your question 2 pts

( ) Your hypothesis 2 pts

( ) Which variables you chose to measure 2 pts

( ) Background information to justify your hypothesis and variable selection 3 pts (no need to cite)

Data (5 pts)

( ) A presentation of your collected data (tables, graphs, etc...) 3 pts, clearly labeled! 2 pts

Analysis (9 pts)

( ) A written interpretation of your data/findings. Connect your results to plant nutrition.*(see below) 4 pts

( ) A discussion of the results in relation to your hypothesis: How do these findings relate to your hypothesis? Do they support your hypothesis or not? 2 pts

( ) A brief analysis on improvement: How you could make this experiment better? Was there anything that you think impacted your results? Are there data that you wish you had collected? etc...3 pts

This should be 1-2 pages, not including tables and graphs. Your grade will be based on inclusion of necessary components. As you write your report, use this guide as a checklist! It is also posted to Canvas.

*In this section reiterate the importance of these nutrients to the plant, their function, if they are components of any molecules (micro or macro) that we discussed in this class. This is very important – it shows me that you can apply your knowledge. Relate lecture material regarding nutrients/molecules to the appearance of your plants – how/why the lack of these nutrients/molecules might have affected the plant structure, color, flowering ability, growth, etc . of your plants.

For example: Don't just state "phosphorus provides energy to the plant" –Tell me that phosphorus is a component of nucleic acids, of which ATP is one, and ATP is the energy molecule of the cell – driving chemical reactions.

Don't just list the nutrients and a general description of their function – relate them to the health of your plants. Explain why the deficiency in these nutrients might explain the appearance of your plants. What role do these nutrients play in the processes like photosynthesis, mitosis, cell communication, etc.

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2: INTRODUCTION TO ECOLOGY

Learning Objectives

Content Objectives

- Become familiar with different ecological roles organisms can have, including feeding strategies, nutrient cycling, and symbioses
- Get an introduction to some of the diversity of life covered under the umbrella of botany

Skill Objectives

- Describe the flow of energy through a community of organisms
- Ascribe ecological roles to organisms in an ecosystem

2.1: Formative Questions

2.2: Introduction

2.3: Modeling a Food Web

2.4: Nutrient Cycling in Ecosystems

2.5: Mycorrhizal Networks

2.6: Community Interactions

2.7: Coevolution and Natural Selection

2.8: Summative Questions

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- Thuymbnail: Wasp Pollination

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2.1: Formative Questions

Complete before lab.

1. How are plants different from other organisms? What traits would you use to classify an organism as a “plant”?
2. The first law of thermodynamics states that energy cannot be created or destroyed. Instead, it is transferred and transformed into other types of energy. In a food web, how is energy transferred between organisms? How is the energy transformed in this process?

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2.2: Introduction

Read the following sections before lab.

This lab manual begins by looking at the microscopic, working its way up the organization of organisms through cells, tissues, organs, and organisms, until it arrives at large-scale evolutionary groups. For many, this series of content will only make sense if it is first situated into a larger context. This can be accomplished in a variety of ways -- perhaps a field trip looking at interacting pieces of an ecosystem, designing and building a terrarium, or a survey of samples from the different organismal groups covered in botany. How you experience this introduction will be dependent upon the resources (and weather) available to you! The content in this first lab is designed to supplement multiple methods of approach by explaining the foundational principles of ecology and allowing you the flexibility to apply them to any context.

Ecosystems

An ecosystem includes both the **biotic** (cellular) and **abiotic** (non-cellular) components in a given environment. Though every ecosystem will be composed of a unique assemblage of interacting factors, we can classify the organisms in them by the roles that they fulfill. For example, all ecosystems require a primary producer. A **primary producer** is an organism that uses some external, abiotic energy source (e.g. electromagnetic or chemical energy) to build organic molecules.

In many ecosystems, plants act as the primary producers, using energy from sunlight to build sugars from the carbon atoms in carbon dioxide through a process called **photosynthesis** (photo- meaning light, synthesis- meaning to form or put together). However, we often overlook the other organisms who share this role: algae and photosynthetic bacteria.

Energy Flow Through Ecosystems

Collectively, we can refer to plants, algae, photosynthetic bacteria, and chemosynthetic bacteria as **autotrophs** (auto- meaning self, troph- meaning feeding), because they all use an abiotic energy source to form organic molecules: they make their own food. Organisms who cannot make their own food must consume other organisms to survive, obtaining energy by breaking down the complex molecules built within those other organisms. These are referred to interchangeably as **heterotrophs** (hetero- meaning other) and **consumers**.

In any given ecosystem, there may be a hierarchy of who eats whom. **Primary consumers** eat primary producers and can also be called herbivores. **Secondary consumers** eat primary consumers, while **tertiary consumers** eat secondary consumers. Rarely is ecology quite so clear cut, and any of these levels might also consume “lower” levels of the food chain, which is why it might be more accurate to refer to this transfer of energy as a **food web**.

There is another important category of organisms that aids in the completion of this network--the decomposers. **Decomposers** break down dead organic matter, transforming the molecules that made up those organisms into forms that are released into the environment and reabsorbed by primary producers. These organisms have a multitude of names that they may be referred to as, including detritivores, saprotrophs, saprophytes, and saprobes (sapro- meaning death or decay). Some important decomposers studied under the umbrella of botany are the true fungi and Oomycota (water molds).

> **Note**
>
> This is the end of the material that you should have completed reading prior to lab. In future labs, this won’t be explicitly stated, it will be your responsibility to keep up with the pre-lab information.

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2.3: Modeling a Food Web

Draw a food web. If you are on a field trip, include organisms that you see in the same area, interacting together. If in the lab, try to include organisms that you have seen or learned about. Make sure to include a **primary producer**, at least **two levels of consumers**, and a **decomposer**. Label which organisms are **autotrophs** and which are **heterotrophs**. Use arrows to show how energy is transferred and lost throughout this web.

What is the ultimate source of energy for your food web?

What happens to this energy as it moves through the food web? Where does it end up?

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2.4: Nutrient Cycling in Ecosystems

In drawing your food web, you depicted a combination of the flow of energy and the cycling of nutrients through an ecosystem. Where as energy has an input and an output, nutrients are continually recycled. These elements often cycle between the biotic and abiotic components in an ecosystem.

For example, water is composed of hydrogen and oxygen atoms. Water molecules precipitate from the atmosphere and fall as rain, saturating the soil. A plant absorbs those molecules through its roots, transporting them up to its leaves. Some of these water molecules will be broken apart during the process of photosynthesis, the oxygen exiting the plant as O_2 gas that you will breathe in while the hydrogen might be used to form molecules of glucose that you will eat. The rest of the water exits the plant through its stomata, evaporating back into the atmosphere in a process called **transpiration**, the evaporation of water from plant tissues. The oxygen atoms that you breathed in will be used for cellular respiration and be joined back to hydrogen molecules to once again form water. This water might exit your body as vapor on your breath or as perspiration and return directly to the atmosphere. It might also soak into your clothes as sweat or exit as urine, be processed in a wastewater facility, then sent out to the ocean where it will evaporate back into the atmosphere.

The atoms of hydrogen and oxygen are broken apart and reassembled into other molecules multiple times in this process, but the overall outcome is a cycle, with atoms traveling between the atmosphere, hydrosphere, lithosphere, and biosphere, but rarely ever exiting our Earth system.

> In the space below, diagram the flow of water through the ecosystem around you.
>
> What is the role of plants in the global cycling of water?

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2.5: Mycorrhizal Networks

A **symbiosis** (sym- meaning shared, bio- meaning life) is when two or more organisms of different species live in close proximity to one another, sharing some aspect of their life cycle. A **mutualism** is a type of symbiosis in which both partners get a net benefit from the interaction. In other types of symbiosis, only one partner benefits and in a **parasitic** symbiosis, it is to the detriment of the other partner.

Most plants form a mutualistic symbiosis with fungi called a **mycorrhizal** relationship (myco- meaning fungus, rhiz- meaning root). In this particular partnership, the fungus enters the plant through the roots and takes sugars from the plant. In exchange, the plant takes water and dissolved nutrients (particularly nitrogen and phosphorus) from the fungus. Though both of these organisms lose something in the exchange, it is something that they tend to have a surplus of, while the thing they get in return is one that they would not have access to alone.

> The fungus obtains its sugars from the living plant tissue. What terms could you apply to this organism?
>
> The plant synthesizes its own sugars during photosynthesis. What terms could you apply to this organism?

Somewhat recently, a researcher named Suzanne Simard began tracking the exchange of nutrients through mycorrhizae. Not just from tree to fungus, but from tree to tree via connections to the same mycorrhizal partner. By providing certain trees with carbon dioxide containing a heavier isotope of carbon (C14), Dr. Simard could track the sugars formed from those heavy carbon atoms as they moved from tree to tree. What she found was that the connections extended beyond just one tree to another, but that almost all of the trees within her plot were connected through a network of different mycorrhizal fungi. Trees of different species and fungi of different species could exchange nutrients with each other. Further study revealed that the exchange was not limited to nutrients and water, but also included transfer of plant defense compounds that worked like raising an alarm, cuing the other plants to start producing defensive chemicals.

> How might this information change the way we study ecosystems?
>
> Sketch a few of the above ground plants that you can see (or imagine) and connect them below ground via a mycorrhizal network. Use arrows to indicate the flow of sugar through this network. Add in some disturbance that would set off a plant's immune system (attack of the caterpillars, fungal infection, etc...) and depict the movement of the signal throughout the plant community.

Some plants have evolved to be parasitic by taking advantage of the mycorrhizal network. These plants no longer photosynthesize. Instead, they form relationships with mycorrhizal fungi that are attached to other plants, siphoning sugars from those plants through the fungal connection. For example, the parasitic plant *Allotropa* parasitizes the Matsutake mushroom, which is mycorrhizal with tanoaks and a few other trees.

> Add a parasitic plant into your ecosystem above and use arrows to depict the movement of sugars.
>
> Are these parasitic plants autotrophic or heterotrophic? How would you classify them, using ecology terminology? Explain your reasoning.

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2.6: Community Interactions

Each species in an ecosystem is considered a **population**. This represents a group of actually or potentially interbreeding organisms and is an important area of study for both ecologists and geneticists. When multiple species in an ecosystem are considered together, this is called a **community**. For example, a forest could be composed of a single population of redwood trees, but it is more likely to be a community, including other tree species like Sitka spruce and Douglas-fir, and animals like the Northern spotted owl or Coho salmon. All living organisms are considered to be a part of the community in a given ecosystem.

What is the difference between a community and an ecosystem?

Pollination

One important community interaction we study in botany (in addition to mycorrhizae) is **pollination**. This is the transfer of pollen from one plant to another and can be mediated by animals, water, wind, or another mechanism. Since we are talking about community interactions, we will focus on animal pollination. Many flowering plants have evolved over time to attract a specific animal pollinator. Because the plant often provides food in the form of nectar or pollen, the pollinator often relies on this relationship as well and coevolves with the plant. One interesting example of this coevolution is the pollination of figs by parasitic wasps.

The Story of the Fig and the Wasp

Figs are made of many small flowers in an inside-out inflorescence called a syconium. How, then, are these flowers pollinated to develop into fruits? Figs are pollinated by tiny chalcid wasps known as fig wasps. In the spring, female fig wasps laden with pollen and fertilized eggs enter into the fig syconium through a small opening called the ostiole. As she enters, her wings are ripped off, making her unable to leave again. She has reached her destination.

As she walks along the tops of the flowers, which are in their female stage, she lays her eggs inside the ovaries by inserting a long tube called an ovipositor down through the style.

Pollen either falls off of her body or she actively deposits it onto the female flowers and travels down the styles as well to fertilize the ovaries. Each flower she deposits an egg into will develop into a wasp instead of a fruit. However, some of the styles are longer than others, and in these she will not be able to lay her eggs. These flowers will develop into the fig fruit, while the others will serve as nurseries for the fig's strange pollinators.

The male wasps hatch first. Blind and wingless, they roam around the enclosed inflorescence, impregnating their still-sleeping sisters. As carbon dioxide builds up within the chamber, they begin to suffocate and burrow out through the sides of the figs, allowing oxygen to flow back in.

After their brothers have died, the females hatch, climbing over the flowers that are now in their male stage, collecting pollen and stuffing it into pouches on their bodies. The young female wasps, laden with pollen and fertilized eggs, leave the fig through the tunnels their brothers made and fly off to find a developing fig to lay their eggs and pollinate the enclosed florets. The timeline of a fig wasp's life is intricately interwoven into the phenology of the fig tree.

View the diagram on the following page and identify the stages in the connected life cycles of these organisms. If available in lab or on your field trip, cut open a fig to view the florets developing inside the syconium.

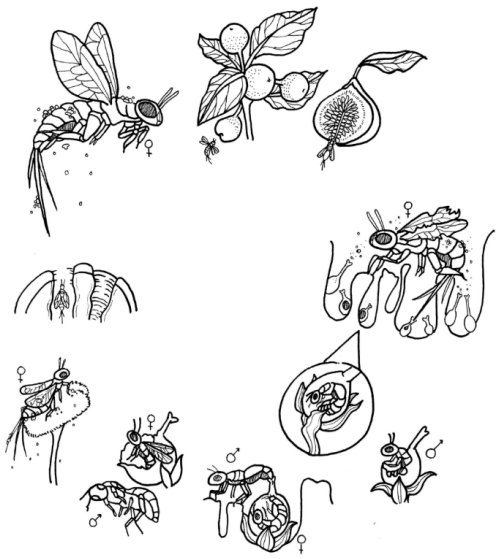


Figure 2.6.1: Fig Wasp Pollination Diagram

Is this relationship a parasitism or mutualism? Explain your reasoning.

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2.7: Coevolution and Natural Selection

In the pollination story above, you saw the product of a long history of **coevolution**. Coevolution is driven by the slow accumulation of changes in organisms (mutations) that are then acted on by a process called natural selection. For example, a purple daisy could have a mutation that caused it to produce a sugary substance. All sorts of animals would be attracted to this -- ants, bees, birds, flies, beetles, and mammals. This might help the flower get its pollen spread around, passing the sugar-production gene on to its offspring, but a lot of pollen would be wasted in the process.

Generations down the line, its offspring could have another mutation that caused it to produce a red pigment instead of purple. Birds are drawn to the color red and might visit the flower to investigate it, discovering and drinking the sugar, and picking up pollen during their visit. However, other animals would still be drawn to the sugar. If some of this flower's offspring were to (completely by chance) develop a deeper place within the flower to store the nectar, then maybe only birds could reach it. If only birds were visiting the flowers, it is more likely that the pollen is being transferred directly to another flower of the same species.

If so, the deeper flowers with sugar and red pigment would be more likely to reproduce and pass on their genes, perhaps resulting in even deeper flowers in future generations. Birds would need to keep up with these changes if they were to continue to access the sugary food source. Offspring with longer beaks would be able to access the sugar more easily, spending less work finding food and perhaps more energy could be devoted to mating, resulting in the longer beak genes passing on to future generations. In this way, flowers and their pollinators can coevolve through a mutual codependence and the accumulation of random mutations. Individuals with mutations that result in more successful pollination for the flower and (usually) more reliable food for the pollinator are more likely to reproduce and pass these genes on to future generations.



Figure 2.7.1

How does the diagram on the right illustrate the process of natural selection? Circle the moths that will survive to pass on their genes.

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2.8: Summative Questions

1. What roles do plants fill in an ecosystem?
2. How are plants involved in nutrient cycling?
3. What organisms play complementary roles to plants with regard to nutrient cycling? Explain your answer.
4. Explain how Allotropa, Matsutake, and tanoaks are connected within an ecosystem. Which of these organisms are producers and which are consumers?
5. Symbioses often result in coevolution of the organisms involved. In the lab, you saw coevolution from mutualistic symbioses. Describe how a parasitic symbiosis could result in coevolution of both organisms.
6. Make a concept map using the following terms. The terms below should go into bubbles. Arrange these bubbles in a way that helps communicate relationships between the terms, then connect the bubbles with lines that have a verb or action phrase attached to them. It might help to start by organizing the words into related groups. You can use words more than once. For example, I could connect the bubbles “Autotroph” and “Photosynthesis” with a line that said “makes food via”. The concept would be “an autotroph makes food via photosynthesis.”
    - Autotroph
    - Photosynthesis
    - Chemosynthesis
    - Heterotroph
    - Primary producer
    - Primary consumer
    - Secondary consumer
    - Tertiary consumer
    - Decomposer

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3: FROM PROKARYOTES TO EUKARYOTES

Learning Objectives

Content Objectives

- Get an idea of what the earliest life forms on Earth looked like.
- Know some of the roles of cyanobacteria in ecosystems, including primary production, nitrogen fixation, and mutualisms.
- Differentiate between prokaryotic and eukaryotic cells.
- Understand how cells can increase in complexity through endosymbiosis.
- Familiarize yourself with plant cell structure and function.

Skill Objectives

- Successfully use the dissecting and compound microscopes to view specimens.
- Prepare a wet mount of a specimen.
- Differentiate between prokaryotic and eukaryotic cells based on size and cellular composition.
- Select the appropriate stain to view specific aspects of a cell.

3.1: Formative Questions

3.2: Introduction

3.3: Using the Dissecting Microscope

3.4: Prokaryotic Cells

3.5: Using the Compound Microscope

3.6: Eukaryotic Cells

3.7: Primary Endosymbiosis

3.8: Cell Structures and Organelles

3.9: Summative Questions

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- Thumbnail: Anabaena colony

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3.1: Formative Questions

1. What do you think the first organisms on Earth looked like?
2. What sort of ecological roles must they have been able to fulfill?

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3.2: Introduction

The Earth formed around 4.54 billion years ago. As of 2019, our first evidence of life appears in fossils somewhere around 3.77-4.22 billion years old. The particular date is still much debated, as the Earth's crust had not cooled enough to form continents until about 2.5 billion years ago and there was a rapid turnover (melting and reformation) of rocks up to this point. Additionally, these early life forms were so small and simple that some argue the fossils are likely complex mineral structures, not organisms at all.

The earliest fossils are interpreted to be unicellular organisms similar to modern day cyanobacteria, sometimes referred to as blue green algae. The most widely accepted of these fossils dates back to 3.4 billion years ago from the Strelley Pool Formation in Western Australia. These particular fossils are called **stromatolites** and are composed of alternating layers of fossilized cells and calcium carbonate. We can use evidence from modern day stromatolite formation in Western Australia to infer that these fossilized cells were doing a process called **photosynthesis**, using dissolved CO_2 in the water to form sugar molecules. This causes calcium to precipitate out of the seawater, forming hardened layers of calcium carbonate on top of the colony of organisms. Because they need access to light to continue photosynthesizing, living cells begin forming a new layer on top of the calcium carbonate. This process continues, making a ringed pattern as the formation grows, much like we see in trees and corals.

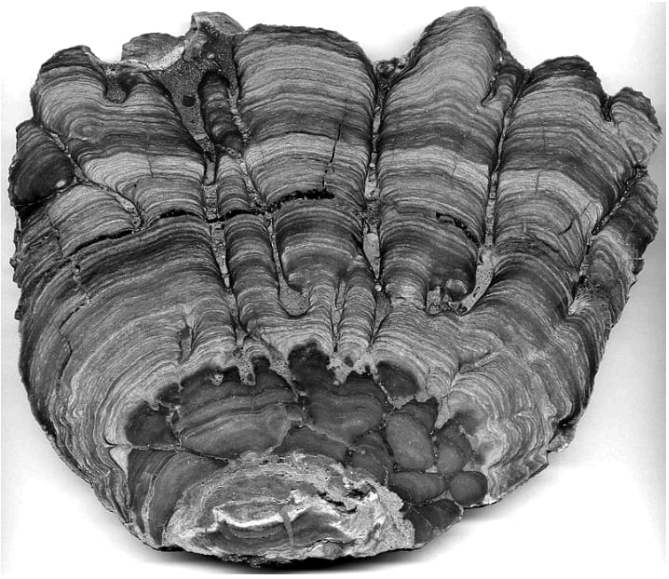


Figure 3.2.1: The image shows the rings of growth on a fossil stromatolite. Stromatolite Fossil from Wyoming by James St. John via Wikimedia Commons. CC-BY 2.0

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3.3: Using the Dissecting Microscope

A dissecting microscope is a useful tool for viewing small features or fine details. Usually the range of magnification is around 10x to 50x. This type of microscope uses what is called incident lighting, where the light is shone onto the specimen (rather than through it, as you will see later).

View a specimen from today's lab under the dissecting microscope. Position your lighting so that it creates as few shadows as possible, then look through the ocular lenses. You will have two knobs on the side of the microscope. One of these is a coarse focus that determines your overall magnification. Use this knob to decide on how closely you'd like to view features of your specimen. You'll notice that it gets quite blurry very quickly. Once you have the magnification you want, use the fine focus to resolve the image (de-blur it).

Draw an interesting feature from your specimen below.

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3.4: Prokaryotic Cells

Photosynthesis is one of the major ecological roles cyanobacteria currently have in modern day ecosystems. Another is **nitrogen fixation**. Nitrogen is an essential nutrient for plants, yet it is difficult to obtain in many ecosystems. Though it is abundant in our atmosphere, this form a nitrogen (N_2) is triple-bonded to itself, a bond which most organisms cannot break. However, certain bacteria have an enzyme called nitrogenase that can break the triple bond and convert nitrogen into usable forms for plants, such as ammonia (NH_3). These bacteria can be found free-living in the environment or in **mutualistic** relationships with certain plants.

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3.5: Using the Compound Microscope

Prepare a Wet Mount

Place a drop of water onto a glass slide. Obtain a tiny piece of the water fern, *Azolla,* and place it on the water droplet. You are looking for a cyanobacterium, *Anabaena*, that lives inside the leaves of the water fern. Using a razor blade, chop the sample into small pieces, much like you would mincing garlic, to release the bacteria. Hold a glass coverslip at an angle, touching the base of the coverslip to the water droplet on your slide. Slowly lower the coverslip over the drop of water until it is flat against the slide.

Observe your Specimen

Place the slide you have prepared onto the microscope stage, holding it in place with the arm, and use the stage controls to place your specimen directly above the light source. Rotate the revolving nosepiece to the scanning objective (4x), adjust the light intensity (it should not hurt your eyes), and look through the ocular lenses (10x).

Checkpoint

Are there black crescents obstructing your field of view? If so, you need to adjust the ocular lenses to match your interpupillary distance (the distance between your eyes). As you look through the ocular lenses, adjust the distance between them until the image resolves into a single white circle.

Anatomy of a Compound Microscope

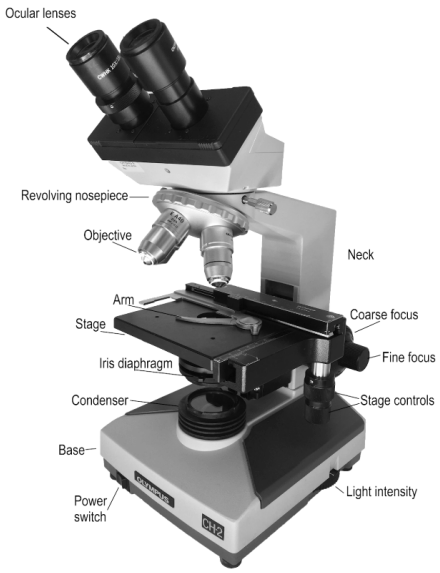


Figure 3.5.1: Adapted from Compound Microscope by Sarah Greenwood via Wikimedia Commons. CC BY 4.0

As you look through the ocular lenses, rotate the coarse focus knob away from you until your specimen comes into focus. You are viewing your specimen at 40x its actual size. What you are looking for are small strands of cells that look similar to a chain of tiny green beads. These are colonies of Anabaena that live inside the leaves of the water fern, fixing nitrogen in exchange for a safe place to live. The colonies will appear a slightly darker green than the pieces of the water fern cells.

Scan your specimen, using the stage controls to move the slide around, until you find a cluster of these dark green chains. When you find some, rotate the nosepiece to the low power objective (10x) and use the fine focus knob to adjust the focus on your specimen.

Note

If you lose your specimen when moving to a higher magnification, go back to the lower magnification and find it again.

Anabaena

When looking at the colonies of cyanobacteria, you should be able to see three different types of cells: vegetative cells, heterocysts, and akinetes.

Note

The image below shows only vegetative cells and heterocysts.



Figure 3.5.2: Anabaena colony

Vegetative cells are the “normal” smaller, darker green cells. These cells are doing photosynthesis and making sugars for the colony.

Heterocysts are larger, round, thick-walled cells that can appear yellow and have two polar bodies, one on each end where they attach to other cells in the colony.

Individual cyanobacteria that have converted into heterocysts are not photosynthesizing because photosynthesis produces oxygen. Instead, these cyanobacteria are fixing nitrogen -- the enzyme nitrogenase will not function in the presence of oxygen. This individual relies on the colony to make it food and, in return, it supplies the colony (and the landlord, Azolla) with nitrogen.

Akinetes are larger, football to nearly rectangular-shaped, thick-walled cells that tend to be more granular in appearance. These individuals still perform photosynthesis, but also function as a sort of failsafe. Akinetes store large amounts of lipids and carbohydrates so that they have enough energy to begin a new colony if conditions become too cold or too dry for survival. Their formation is triggered by these conditions (dry or cold), so you may not see them from a fresh water fern leaf, as this is a relatively stable, comfortable environment. If you left this slide out overnight and allowed the water to evaporate, you might see akinetes forming when you rehydrated it the following day.

> Draw a colony of Anabaena, including all three cell types, labelling each with its name and function. Draw a cell of the water fern next to the colony for a size comparison.

Cyanobacteria belong to Domain Bacteria, one of two large groups of organisms called **prokaryotes**. Prokaryotes are **unicellular**

organisms that have relatively simple cellular makeup. The cell is surrounded by a structure called the **cell wall** that protects the organism from desiccation (drying out) and other external stressors. In bacteria, this cell wall contains a compound called **peptidoglycan**. Inside the cell wall is a semi-permeable membrane called the **plasma membrane** (also called the cell membrane), which controls what enters and exits the **cytoplasm** of the cell. Prokaryotes have no nucleus or organelles, instead bundling their circular DNA into a compact structure called a **nucleoid**.

> In your drawing of the Anabaena above, label the **cell wall, plasma membrane,** and **cytoplasm** of one of the vegetative cells.

The diagram below is a generalized prokaryote. There is a large circle of DNA, the circular chromosome, and a small circle of DNA, a **plasmid**. On the exterior, there is a long projection called a **flagellum** which is used for movement. The smaller projections are called pili (**pilus**, singular) and are used for interacting with other cells. Label these structures in the diagram below, as well as the **cell wall, cytoplasm,** and **ribosomes**.

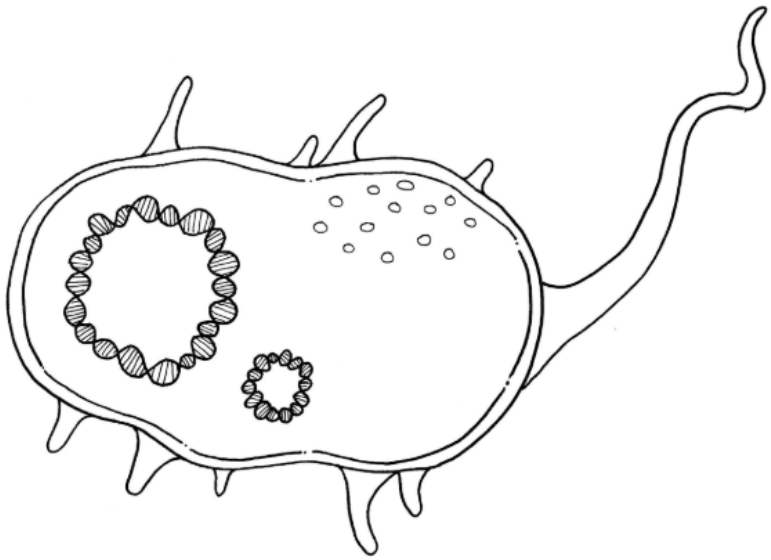


Figure 3.5.3: Prokaryotic cell

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3.6: Eukaryotic Cells

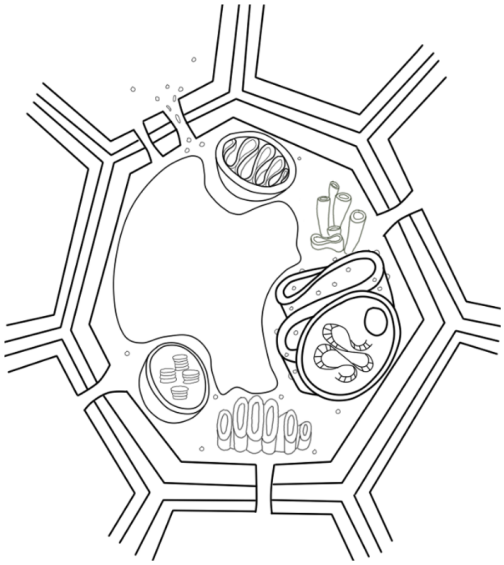


Figure 3.6.1

Label the following features in the diagram above:

1. Nucleus
2. Nucleolus
3. Rough endoplasmic reticulum
4. Smooth endoplasmic reticulum
5. Tonoplast
6. DNA
7. Nuclear envelope
8. Central vacuole
9. Golgi apparatus
10. Chloroplast
11. Mitochondrion
12. Ribosome
13. Cytosol
14. Cell wall
15. Middle lamella
16. Plasmodesma

*Add the cell membrane!

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3.7: Primary Endosymbiosis

The water fern, *Azolla*, belongs to a different domain of life, Domain Eukarya. **Eukaryotes** have a more complex cellular makeup and can be either unicellular or **multicellular**. Eukaryotic cells get their name from the **nucleus** (eu- meaning true and karyo- meaning seed). In addition to the nucleus, eukaryotic cells contain other membrane-bound organelles. The DNA stored inside the nucleus is linear, as opposed to circular.

Around 1.56 billion years ago, a heterotrophic eukaryote engulfed a cyanobacterial ancestor in an attempt to eat it, a process called **phagocytosis** (phago- meaning to eat, cyto- meaning cell). Instead of being digested, this photosynthetic prokaryote remained inside the cell and continued to photosynthesize. The eukaryotic host must have benefited from the sugars produced by the prokaryotic captive and this relationship developed into a **symbiosis** (sym- meaning shared, bio- meaning life), much like the *Anabaena* and the *Azolla*.

Overtime, the captive prokaryote evolved into the **chloroplasts** and other plastids that we see in plant cells today. This process of converting a free-living organism into an organelle is called **endosymbiosis** (endo- meaning inner) and is also the way eukaryotes evolved mitochondria. All plants, such as the water fern you are looking at, descended from this primary endosymbiosis event that led to the first chloroplasts.

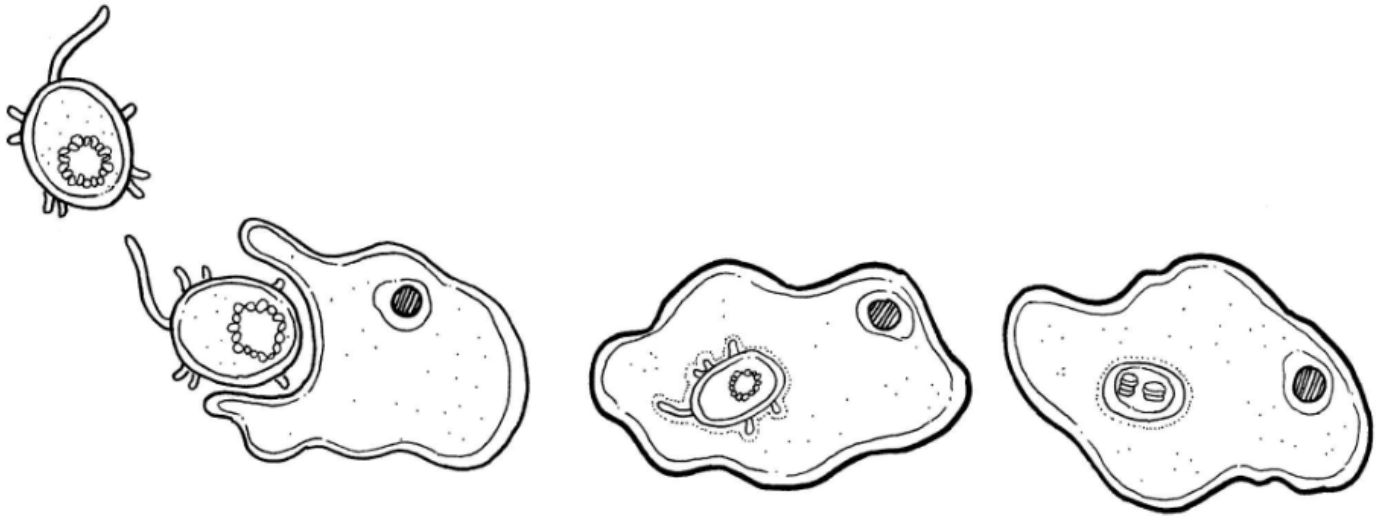


Figure 3.7.1: Primary endosymbiosis

In the diagram of endosymbiosis above, label the **cyanobacterium**, the **eukaryote**, **nucleoid**, **nucleus**, and **chloroplast**.

What evidence could we look for in a chloroplast that would indicate evolution from a bacterium?

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3.8: Cell Structures and Organelles

Because *Azolla* is a plant, its cells are surrounded by a rigid **cell wall containing cellulose**. Like the bacteria, the plasma membrane is located just inside the cell wall and contains the cytoplasm. The cell wall tends to give plant cells a boxy, rigid structure.

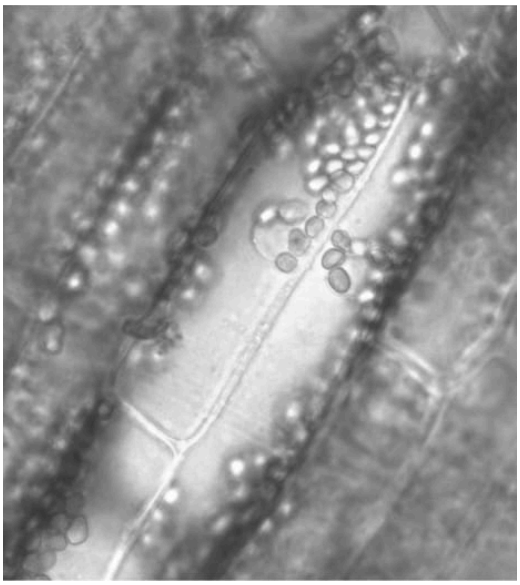


Figure 3.8.1: Elodea leaf cells

The most obvious of the membrane-bound organelles you will see are the **chloroplasts**. These numerous, green, disc-like structures are responsible for doing photosynthesis, making food for the plant. Their color is derived from the presence of **chlorophylls**, green-pigmented molecules involved in harvesting light for photosynthesis. You might also see that these chloroplasts are pushed toward the edges of the cell. This is because the majority of the cell is taken up by a large, liquid-filled structure called the **central vacuole**, surrounded by a membrane called the **tonoplast**. The central vacuole contributes to the plant's overall structure by drawing in water, inflating the cell to a turgid state (more on this in lab 5).

Above is a cell from the aquatic plant Elodea. The cell wall, nucleus, and chloroplasts are visible.

> Draw a cell from the Azolla in the space below. Label the cell wall, plasma membrane, cytoplasm, chloroplasts, nucleus (if you see it), central vacuole, and tonoplast.

The layers in an onion bulb are fleshy leaves that have been modified to store starches for the plant. At the base of the bulb, you will see a short stem with roots emerging. The part of the onion that you will be observing is the epidermis (outermost layer) of the leaf.

Cut a small section of an onion leaf. Carefully peel off a section of the epidermis--not the pigmented side, but the paler side that faces the interior of the onion. It should come off as a translucent sheet. Prepare a wet mount of onion epidermis using a drop or two of IKI solution.

This iodine solution increases the refractivity of the light and makes the nucleus visible. You should also be able to see at least one dark dot in the nucleus. This is the **nucleolus** (plural, nucleoli), a region of the nucleus where **ribosomes** are assembled.

View your specimen with the compound microscope. Draw an onion cell and label the **cell wall**, **plasma membrane**, **cytoplasm, nucleus, nucleolus, central vacuole**, and **tonoplast**.

> Why are there no chloroplasts in this plant cell? Consider where an onion bulb would be located in a garden setting.

Plant cells are static within the plant (they do not move from place to place) and are surrounded by a cell wall. Adjacent cells are

“glued” together by a pectin-rich layer called the **middle lamella**. As you saw above, the onion cells did not contain chloroplasts, meaning they are not producing their own food, yet they are used to store large amounts of sugars in the form of starch. How then do these cells communicate with each other and exchange nutrients? When plant cells divide, the division is incomplete, leaving small channels through the cell wall and middle lamella. These channels are called **plasmodesmata** (plasmodesma, singular). You can look for these in the epidermal cells of a red pepper (or similar fruit).

Peppers are fruits whose function is to attract animals to disperse the seeds of the pepper plant. To do this, the pepper goes through a ripening process. Pectins (a form of starch) in the middle lamella begin to break down into simple sugars, making the pepper both sweeter and softer. The color of the pepper also begins to change as chloroplasts are converted to **chromoplasts**. These organelles contain pigments called **carotenoids** that produce yellows, oranges, and reds, the last of which is highly attractive to animals like us.

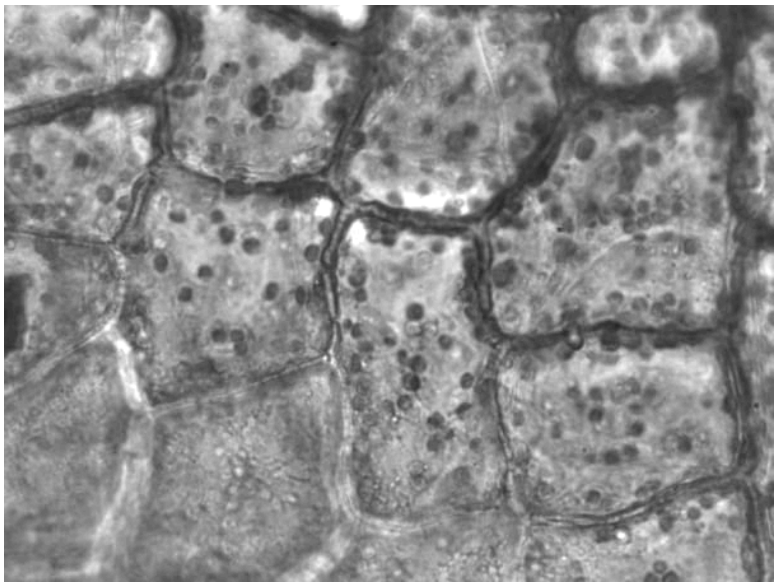


Figure 3.8.2: Red pepper epidermal cells

The image above shows epidermal cells in a red pepper. They are filled with small, red, disc-like plastids. These are chromoplasts filled with carotenoids.

In the cell walls, you can see tiny gaps that look more like constrictions. These are the plasmodesmata.

Peel off a small piece of red pepper epidermis and make a wet mount with water. Using the compound microscope, look for small, red chromoplasts within the cells. Next, look for breaks in the regions between the cells. These are the plasmodesmata.

> Draw two adjacent pepper epidermal cells. Label the **cell wall, middle lamella, plasmodesmata,** and **chromoplasts**. You are encouraged to identify and label other cell components, such as the nucleus and nucleolus, if they are visible.

A potato is a modified part of the plant called a tuber. Much like an onion, a tuber is a part of the plant--this time the stem--adapted for storing starch. Potatoes synthesize and store these starches in organelles called **amyloplasts** (named for the starch amylose). In other cases, similar organelles are used to store lipids or other complex molecules. In general, these organelles are called **leucoplasts** (leuco- meaning white), because they lack pigments.

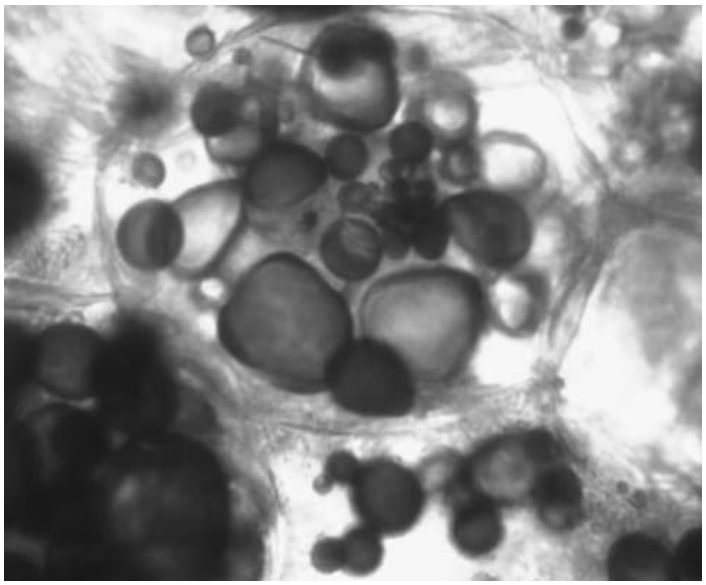


Figure 3.8.3: A potato cell with amyloplasts stained with iodine

Using a razor blade or sharp probe, scrape a small amount of the interior of a potato (not the skin) onto a slide. Make a wet mount using one drop of IKI followed by one drop of water. The iodine in the IKI solution will surround the starch molecules, causing starches to appear to stain blue to purple. This will help you locate the amyloplasts within the potato cells, as they will absorb the IKI and the entire organelle is colored purple.

Draw a potato cell and label the **cell wall, plasma membrane, cytoplasm,** and **amyloplasts**.

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3.9: Summative Questions

1. What were the earliest life forms on Earth and how did they obtain food?
2. What evidence do we have of this?
3. Explain how endosymbiosis influenced the evolution of eukaryotes.
4. Describe the relationship between *Anabaena* and *Azolla*. What type of symbiosis is this?
5. What is the difference between a chloroplast, chromoplast, and amyloplast? Where in plants would each of these different plastids most likely be found? Consider the function of each of these organelles in your answer.
6. Compare and contrast prokaryotes and eukaryotes. What features do they share? What sets them apart from each other?

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4: PLANT CELL TYPES AND TISSUES

Learning Objectives

Content Objectives

- Learn the primary cell and tissue types found in plants (the -enchymas)
- See how tissues are composed of cells that work together to perform a similar function
- Understand how different tissues can work together to perform a united function as an organ

Skill Objectives

- Differentiate between parenchyma, collenchyma, and sclerenchyma
- Use Toluidine Blue stain to locate cell types in different plant tissues
- Identify the function and cell type of specialized cells
- Make a thin section of plant tissue where you can clearly see cell types

4.1: Formative Questions
4.2: Introduction
4.3: Identifying Cell Types and Tissues
4.4: Summative Questions

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- *Thumbnail: Phloem Tissue*

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4.1: Formative Questions

1. Can unicellular organisms have tissues? Explain your answer.
2. Why would a nucleus be required for an organism to be multicellular? What does this organelle allow cells to do?

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4.2: Introduction

Plant cells can be classified into three major categories based on their cell wall structure. Most plant cells are **parenchyma cells** (par- meaning equal), with an evenly-thickened primary cell wall. Some areas of a plant, particularly in young shoots, will require more flexibility, allowing them to bend without breaking. In these regions, you will often find **collenchyma cells** (coll- meaning glue), cells with strange, unevenly-thickened primary walls. Both of these cell types are alive at maturity. A third cell type, **sclerenchyma cells** (scler- meaning hard), develops a rigid **secondary wall** that is composed of lignin. This secondary wall provides structural support, but it also cuts off the exchange of water and other molecules permitted by the plasma membrane. Ultimately, this results in the death of the cell at maturity and loss of internal cell components.

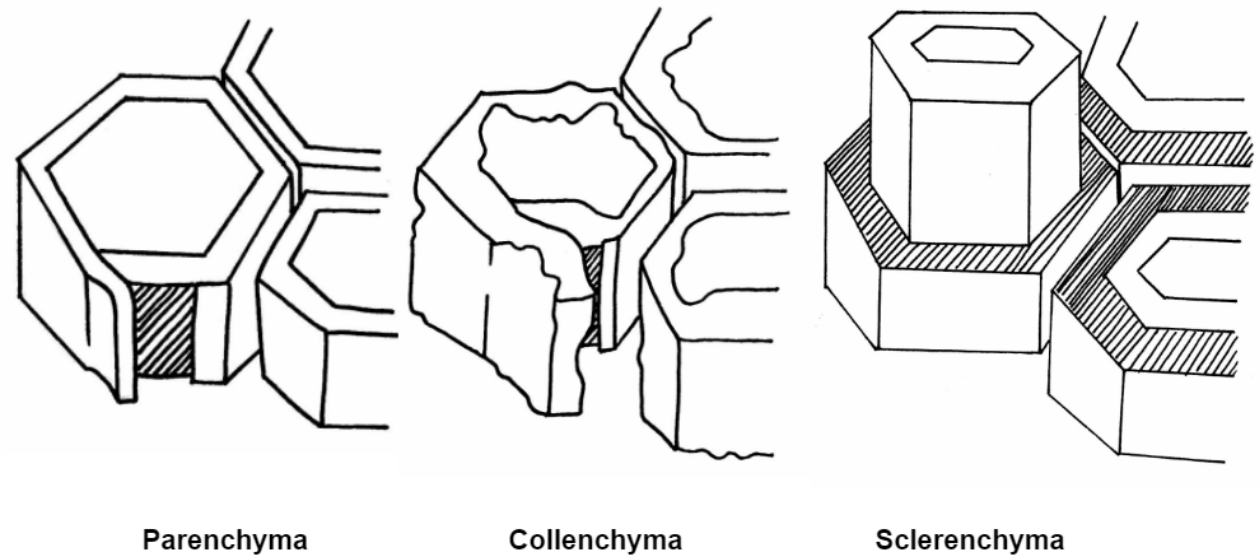


Figure 4.2.1: Collenchyma cell

Parenchyma Collenchyma Sclerenchyma

Plant cells performing a similar function can be assembled into tissues. This lab will introduce you to the three primary cell types found in plants, the tissues where you can find these cell types, and specialized cells that they can differentiate into. Specialized cells covered in this lab will be either parenchyma, collenchyma, or sclerenchyma (referred to as the “cell type”) and will have evolved for a specific function, such as conducting water. At the end of the lab, you will complete a table with the cell types, specialized cells, and functions of the major tissues within a leaf.

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4.3: Identifying Cell Types and Tissues

Cell Types

Make a thin section of a celery petiole or the main celery stalk. This needs to be very thin to see the features you are looking for, so make a few samples to look at! If you would like to stain your specimen, place the specimen on a slide and add a small drop of Toluidine Blue. Wait a few seconds for the dye to penetrate into the sample, then rinse by adding water to the slide and either soaking up or draining off the excess liquid. When the water is mostly clear, add another drop or two of water and a coverslip.

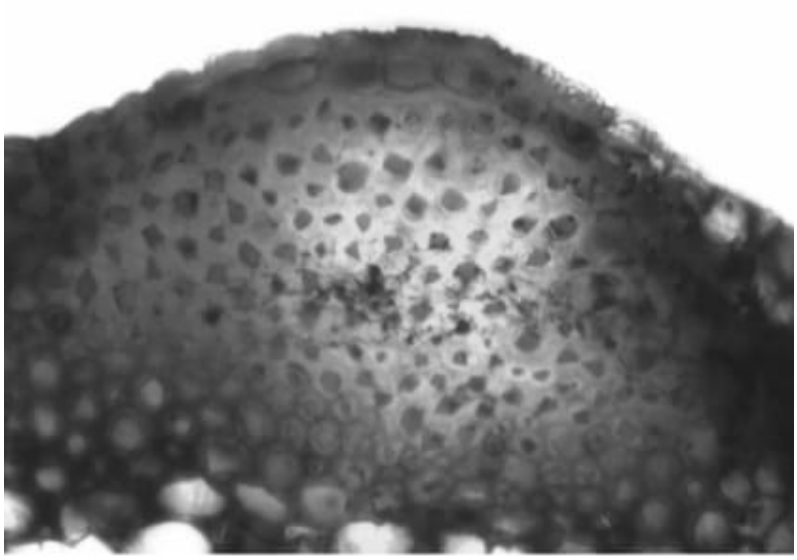


Figure 4.3.1: A cluster of collenchyma cells in the celery petiole

View your specimen under the compound microscope.

You should be able to see several cell types in your specimen. Most of the cells will be parenchyma. A great place to look for textbook parenchyma cells is the outermost layer of the plant, the **epidermis**.

You will find collenchyma cells in dense clusters near the epidermis in a region called the **cortex**, forming the strings that you would find in your celery. They appear to have an almost checkerboard-like pattern, due to the unevenly thickened primary walls. In Toluidine Blue, primary walls stain purple.

Some specialized cells can be found in the **vascular tissue**, organized regions of cells that are transporting water, sugars, and other chemicals throughout the plant body. The **xylem** is the tissue responsible for conducting water. Specialized cells in the xylem tissue called **tracheids** and **vessel elements** have evolved specifically for this ability by forming hollow tubes with lignified secondary walls. Tracheids evolved first and are narrow with tapered ends. Vessel elements evolved in the most recent group of plants, the Angiosperms, and are usually much wider than tracheids. In Toluidine Blue, the lignin in the secondary wall stains bright aqua blue.



Figure 4.3.2: Sclerenchyma cells from wood pulp

The image above shows three different types of cells with secondary walls found in wood pulp. A vessel element is shown in the center with a tracheid running parallel just above it. Note the pits in the walls of both of these cells and the large holes (**perforation plates**) on the ends of the vessel element only. Criss-crossing the rest of the slide are many thin fibers. All of these cells are dead at maturity and provide structural support due to the lignin in the cell walls.



Figure 4.3.3: Tracheid

In the image above, you can see the pits in the walls of a tracheid.

Unlike the xylem, conducting cells in the **phloem** tissue are alive so they may transport sugars and communication signals in any direction. These cells, **sieve tube elements** and **companion cells**, are more similar to parenchyma. The sieve tube elements conduct sugars and have specialized to do this by having reduced cytoplasm contents: sieve tube elements have no nucleus (or vacuole)! These cells are controlled by small, adjacent cells called companion cells. If you look closely, you can also see some sclerenchyma bunched together in the phloem. These are the **phloem fibers**. Their thick secondary walls should stain the same color as the tracheids and vessel elements.

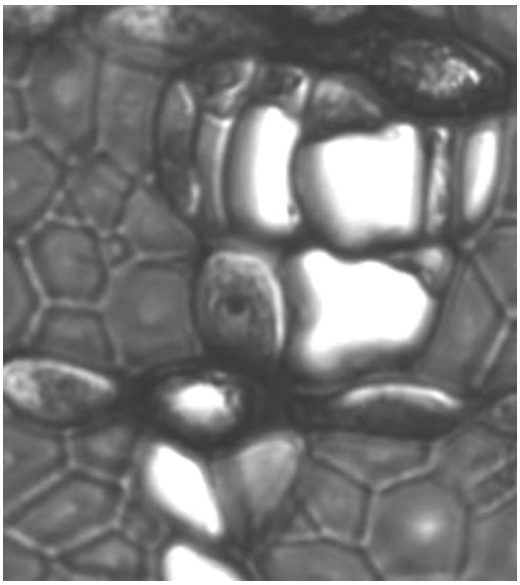


Figure 4.3.4: Phloem Tissue

In the image above, you can see clusters of thick walled fibers, large open sieve tube elements, and small companion cells containing nuclei.

> Draw a cross section of the celery petiole, labeling **parenchyma** in the epidermis, **collenchyma** in the cortex, and **sclerenchyma** in the vascular tissue. Make notes about the differences in the cell wall for your future study.
>
> The central region of the celery petiole is called the **pith**. What type of cells are present in this region?

While collenchyma tissue tends to have one job--flexible support--parenchyma and sclerenchyma can fill a diverse set of roles. In a developing pear, there is a high density of a second type of sclerenchyma cells called **sclereids** (the first type of sclerenchyma cells were fibers)**.** These cells cause young pears to be tough and unpalatable, as the seeds inside are still developing. As the seeds mature, the pear ripens, making more parenchyma cells for storing large amounts of sugar, while the tough sclereids are slowly outnumbered by the larger, juicier cells. The grit that you feel when eating a pear are these remaining sclereids.

> What other cellular changes might occur to signal that a pear is ripe?

Make a squash mount of the flesh of a pear (not the skin) by scraping off a small amount with a razorblade. Do not take a slice or a chunk, just a tiny bit of pulp (consider chopping it up on the slide). Again, I recommend staining with Toluidine blue, as this should make the thick secondary walls of the sclereids appear a bright aqua blue. Sclereids tend to occur in clusters, surrounded by large parenchyma cells. You may need to gently squish your coverslip down a bit to help disperse these clumps. Coverslips are fragile, so ask your instructor what they recommend before doing anything that might result with glass in your fingers.

When you find a sclereid, you should see lines running through the secondary wall. These are channels where the plasmodesmata extended through to connect to other cells. After the cell dies, only the empty channels (called **pits)** remain.

> Draw a sclereid, located in the **ground tissue** of a pear. Label the **secondary wall**, **pits**, an adjacent **parenchyma cell**, and the **primary wall** of that parenchyma cell.
>
> Is this sclereid alive or dead? What about the parenchyma cells around it?
>
> What is the compound in the secondary wall that stains differently from the primary wall?

Tissues in the Leaf

When cells of the same type work together to perform a collective function, the collection of cells is called a **tissue**. For example, the epidermis is a collection of parenchyma-like cells working together to separate the internal environment of the plant from the exterior. The epidermis also contains specialized cells. **Trichomes** are outgrowths from the epidermis that look like hairs. These

can protect the plant from sun damage by being white and reflective, trap evaporating moisture on the plant's surface, secrete sticky substances, and be unpleasant for herbivores.

A second type of specialized cell in the epidermis is the guard cell. **Guard cells** are shaped like parentheses and flank small pores in the epidermis called **stomata** (sing. stoma). When the plant has adequate water, the guard cells inflate and the stoma is open, allowing water vapor to escape through transpiration. When the plant is low on water, the guard cells collapse, closing the stoma and trapping water inside. However, for the plant to perform photosynthesis, it must have access to carbon dioxide and be able to release oxygen. Both of these gases are exchanged through the stomata.

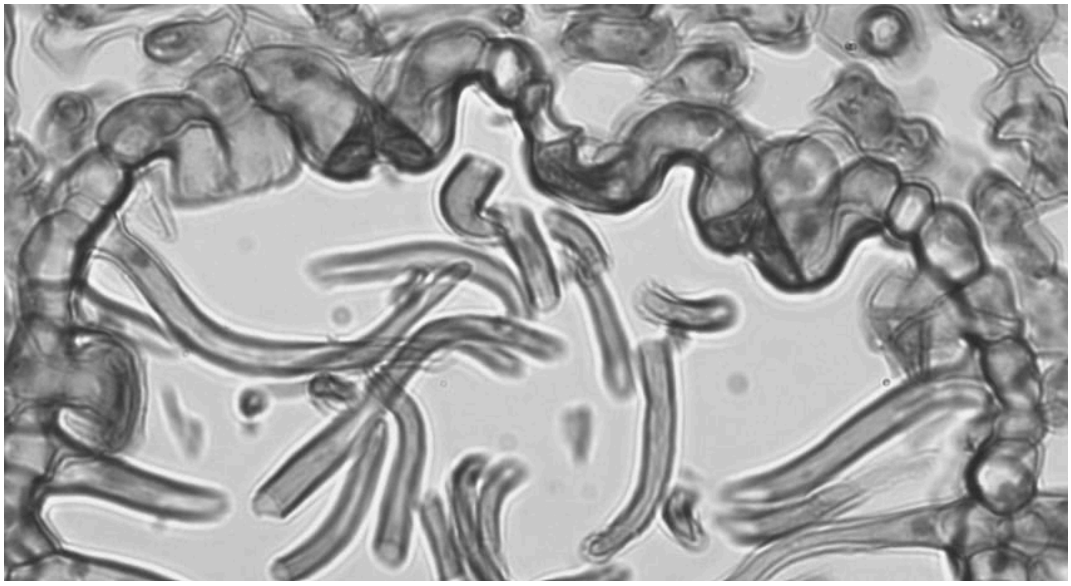


Figure 4.3.5: Stomata in a stomatal crypt

The image above is from the lower epidermis of a Nerium leaf. These plants live in harsh, dry environments and have many adaptations to prevent water loss. This is a pocket on the lower side of the leaf where stomata are located. You can see three different sets of guard cells, currently closed, appearing slightly darker than the other epidermal cells. Surrounding these stomata and filling the pocket are trichomes.

> How does the location of the trichomes relate to prevention of water loss?
>
> View a leaf under the dissecting scope. Can you find trichomes, guard cells, or other specialized epidermal cells?
>
> *Peel off the lower epidermis of the leaf, similar to how you removed it from the onion.* It may help to break the leaf slowly, hopefully getting a piece of the epidermis that you can peel off. It will look like a transparent layer of skin. Make a wet mount of the epidermis and view it under the compound microscope. Draw what you see below, labeling any specialized epidermal cells.
>
> What cell type (-enchyma) are these cells most similar to?

When multiple tissues work together to perform a collective function, this collection of tissues is called an **organ**. While we are familiar with the concept of organs in animals, it can sometimes be surprising to consider this aspect of plants.

An example of an organ in a plant is the leaf. A leaf is surrounded by epidermal tissue, protecting the interior environment, and allowing for the exchange of gases with the environment. The xylem tissue, found in the veins of the leaf, provides the water needed for specialized parenchyma, **mesophyll cells**, to carry out photosynthesis. Phloem tissue runs alongside the xylem tissue, transporting sugars made during photosynthesis to other areas of the plant for either immediate use or storage. Together, these tissues allow the leaf to function as an organ specialized for photosynthesis.

> *View a prepared slide of a leaf cross section.* Draw what you see below. Identify and label as many tissues, cell types, and specialized cells as you can.

Summary Table of Cells and Tissues in the Leaf Organ

A **simple tissue** contains only a single cell type, while a **complex tissue** contains multiple cell types. The leaf organ is composed of both simple and complex tissues. In the table below under Tissue Type, try to identify whether it is a simple or complex tissue. If it is a simple tissue, identify which cell type it is composed of.

Tissue	Specialized Cells	Tissue Type	Function
Epidermis	1. Guard cell 2. Trichome		
Mesophyll	Mesophyll cells		
Xylem	Tracheids & vessel elements		
Phloem	1. Sieve tube elements 2. Companion cells 3. Phloem fibers		

Why didn't I include a stoma among the specialized cells in the epidermis?

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4.4: Summative Questions

1. What is the function of the xylem tissue and which specialized cells are involved in this function? Was this a simple or complex tissue in the specimens you viewed?
2. What is the function of the phloem tissue and how do the specialized cells in this tissue contribute to this function? Was this a simple or complex tissue in the specimens you viewed?
3. What is the function of the epidermis and how do the specialized cells in the epidermis contribute to this function? Was this a simple or complex tissue in the specimens you viewed?
4. One of the characteristics of living things is a hierarchical (nested) organizational structure. Organize the following terms into a nested structure: specialized cell, organ, organism, tissue, organelle.
5. Do the same with the following terms: chloroplast, leaf, guard cell, epidermis, plant.
6. Compare and contrast the function and appearance of parenchyma cells in the cortex of a plant.

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5: MULTICELLULARITY AND ASEXUAL REPRODUCTION

Learning Objectives

Content Objectives

- Learn the process of mitosis and how this type of cell division is used for growth, repair, and asexual reproduction
- Understand that mitosis is a type of cell division that results in clones of the original cell
- Learn the two phases of cell division: mitosis is the division of the genetic material, while cytokinesis is the division of the rest of the cytoplasm and the cell wall
- Understand that prokaryotes cannot undergo mitosis because they lack a nucleus

Skill Objectives

- Differentiate between chromatin and chromosomes in a prepared slide
- Locate and identify important cell structures, including the nucleus, nucleoli, nuclear envelope, and cell wall
- Identify cells in different stages of mitosis based on chromosomal organization

5.1: Formative Questions

5.2: Introduction

5.3: Anatomy of a Chromosome

5.4: Mitosis

5.5: The Cell Cycle

5.6: Meristems and Tissues in the Root

5.7: Multicellularity and Clonal Reproduction

5.8: Summative Questions

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- Thumbnail: A cell in anaphase

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5.1: Formative Questions

1. What is the difference between growth and reproduction?
2. How would you determine whether an organism is multicellular or a colony of unicellular organisms? What information would you need to make this determination?

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5.2: Introduction

The first organisms on Earth were likely unicellular prokaryotes. These organisms could reproduce themselves by increasing the amount of cytoplasm, making a copy of their single loop of DNA, and forming a new cell wall to divide the original cell into two identical cells. This form of cell division is called **binary fission** (binary meaning two, fission meaning to split apart). This is a form of **asexual reproduction**, where an organism reproduces an exact genetic copy of itself. This is also sometimes called clonal reproduction.

In binary fission, one cell enlarges and the DNA is replicated, dividing into two cells.

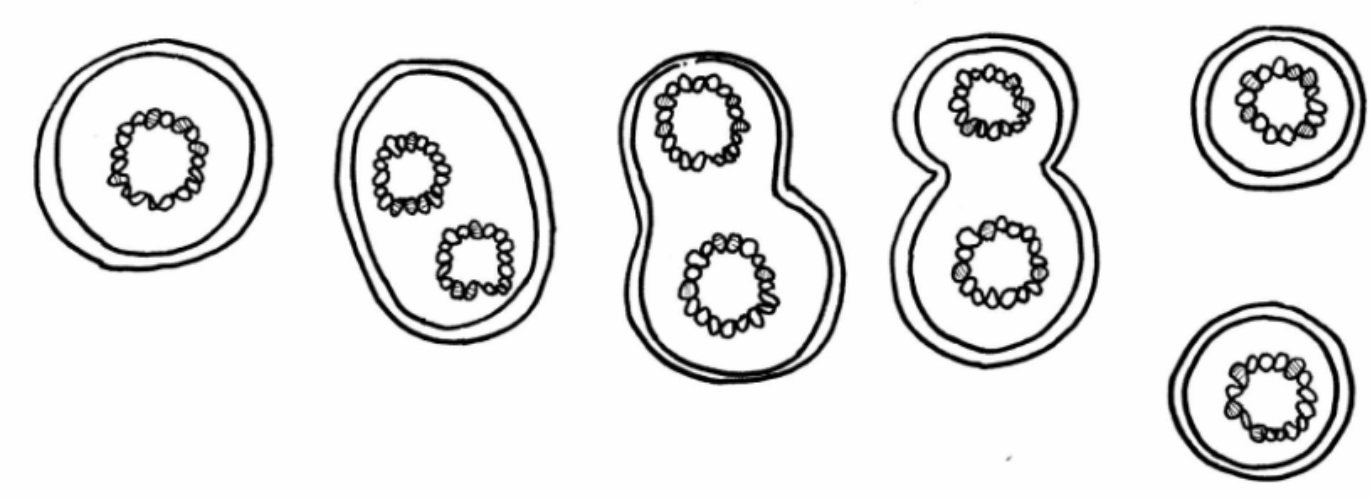


Figure 5.2.1: Binary fission

As eukaryotic cells evolved, cell division became more complex. There were now organelles to replicate and organize. Perhaps more importantly, division of the DNA became more complicated. Instead of a single loop of DNA, eukaryotic DNA occurs in linear strands that are then wound around histone proteins. This combination of DNA and proteins is called **chromatin**, because it appeared dark when stained. When eukaryotic cells divide, they further condense the chromatin into tightly wound complexes called **chromosomes**. This organizational structure is necessary, as eukaryotic cells need instructions to make and maintain all of the new cell components, often resulting in large amounts of DNA. For example, there are approximately six feet of DNA that need to be contained within the nucleus of each cell in your body. Six feet! If you lined up all of the DNA from each of your trillion or so cells, it would stretch across the solar system...twice! How to organize this massive amount of DNA so that it can be replicated and divided into two identical sets as a cell divides?

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5.3: Anatomy of a Chromosome

Chromosome literally means “colored body”. These densely packed structures are composed of highly organized DNA and have distinct regions we can make reference to. An unreplicated chromosome looks a bit like a cucumber that has been constricted in the middle (or two breakfast links, still connected). The central constricted region is called the **centromere**. When the chromosome is replicated, it will become two identical **sister chromatids** that are attached at the centromere region. You can count the number of chromosomes present by counting the number of centromeres. Two attached sister chromatids are one chromosome, but the instant they separate, two centromeres are visible and the sister chromatids each become individual chromosomes. This will become important later.

The main body of the chromosome above and below the centromere are called **arms** and the end of each arm is the **telomere**. Telomeres are of interest to many scientists studying aging, as it is possible that the degeneration of telomeres during replication eventually leads to the suite of symptoms we connect with the aging process.

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5.4: Mitosis

Mitosis is the division of the nucleus in eukaryotic cells to make two identical nuclei. This is accompanied by **cytokinesis** (cyto- meaning cell, kinesis meaning movement), division of the cytoplasm, to result in division of the entire cell into two identical daughter cells.

A unicellular eukaryote might do mitosis to reproduce asexually, making an identical copy of itself. This is common practice in many groups of organisms. For example, molds are fungi that are reproducing asexually--each mold spore is genetically identical to the others. Many unicellular algae will also reproduce this way.

Multicellular eukaryotes also do mitosis -- that is how they became multicellular! Multicellular eukaryotes primarily use mitosis for growth and repair of damage, though some also reproduce asexually (such as strawberries and mint). To see mitosis occurring in a plant, the best place to look are the growing tips, as most plants experience **apical growth** (growth from the tips).

Obtain a prepared slide of an onion root tip (Allium cepa). Cells toward the apex (pointed end) are likely to have been caught in a stage of active division.

Prophase

Mitosis begins with **prophase**. During this portion of mitosis, the chromatin condenses into a more organized state -- the chromosome. The nuclear envelope begins to break down and any nucleoli dissolve. The cell begins to produce a network of microtubules called the **spindle** (in animal cells, the production and organization of the spindle is organized by a set of organelles called centrioles that assemble together into a centrosome). These networks begin to form on opposite sides of the cell.

You can identify cells in prophase by looking for the following:

1. The nuclear region has expanded and moved to the center of the cell
2. DNA appears as distinct structures (sausage-like), still contained in the center of the cell
3. At the end of prophase, no nucleolus is present

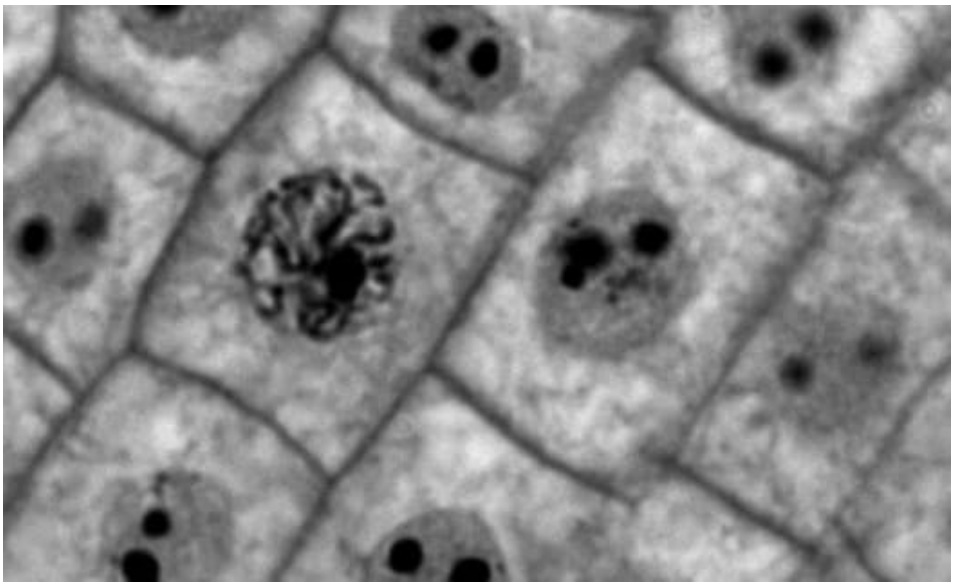


Figure 5.4.1: A cell in prophase

The image shows a cell in early prophase, surrounded by cells in interphase. The nucleoli are still visible in all of these cells as dark dots, but the cell in early prophase has condensed its chromatin into darkly stained chromosomes, whereas the cells in interphase still have the lightly staining grey chromatin. The circular organization of the chromosomes indicates that the nuclear envelope has not finished breaking down yet.

Compare the cell in early prophase (left) to a cell in late prophase (right). As the nuclear envelope finishes breaking down, the chromosomes become more spread out. Additionally, no nucleolus is visible. During this time, the spindle fibers attach to the kinetochores and are about to start pushing and pulling the chromosomes into the middle of the cell.

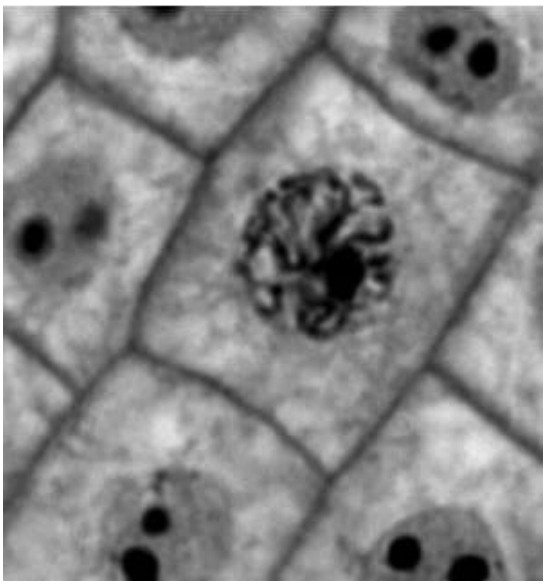


Figure 5.4.2: A cell in prophase

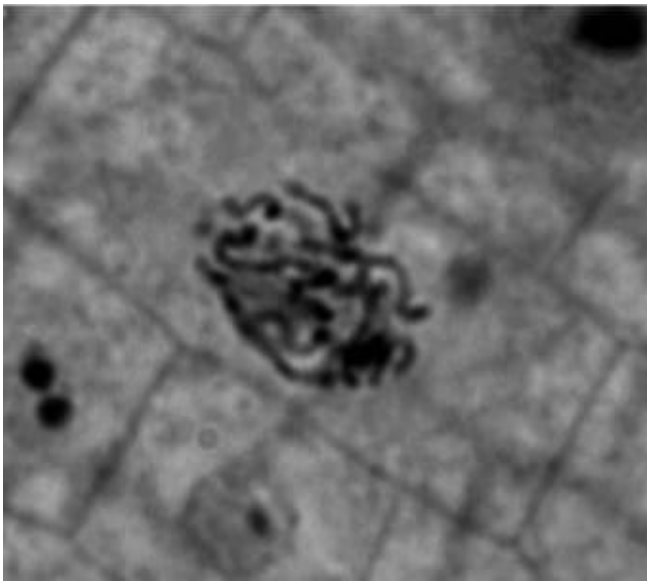


Figure 5.4.3: A cell in late prophase

Draw an onion cell in prophase. Label the cell wall, plasma membrane, nuclear envelope (or where it would be), and chromosomes. If a nucleolus is still present or you can distinguish a forming spindle, label these as well.

Metaphase

As the cell transitions into **metaphase**, referred to as prometaphase, the spindle fibers attach to sticky regions called **kinetochores** that flank the central region of the chromosome, the **centromere**. The centromere holds the two identical pieces of the chromosome, the sister chromatids, together. The spindle fibers contract and expand to push and pull the chromosomes into a line in the center of the cell, the **metaphase plate**. This is where the new cell wall will form

You can identify cells in metaphase by looking for the following: Chromosomes are found in the center of the cell, they appear to be connected, often forming a straight line.

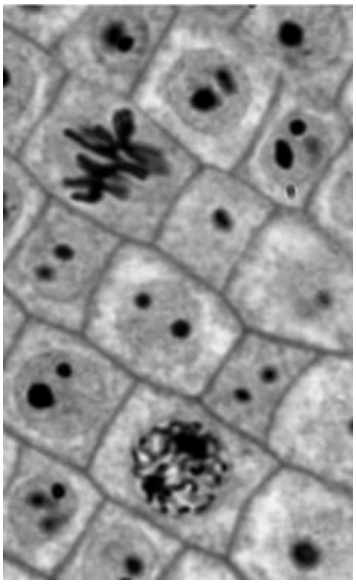


Figure 5.4.4: Cells in mitosis, metaphase section

There are two cells in this image not currently in interphase. The cell on the top is in metaphase.

Which stage of mitosis is the cell on the bottom in? How can you tell?

Draw an onion cell in metaphase. Label the cell wall, plasma membrane, chromosomes, spindle, and metaphase plate.

Anaphase

Anaphase begins when the two networks of spindle fibers start to contract. During this process, sister chromatids of each chromosome are pulled apart, each becoming an individual chromosome the moment they are separated. These chromosomes are pulled to either side of the cell in preparation to form two new nuclei.

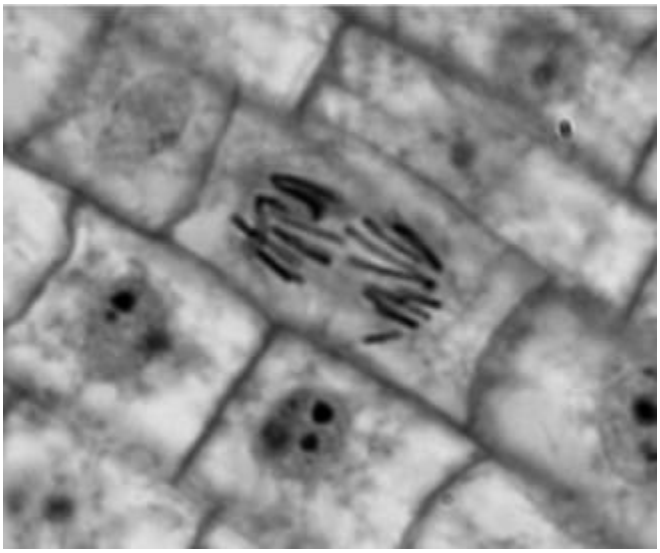


Figure 5.4.5: A cell in anaphase

You can identify cells in anaphase by looking for the following:

1. There should be two distinct groups of chromosomes
2. individual chromosomes can still be distinguished.

This image depicts a cell in anaphase. Are the dark lines in this cell chromatids or chromosomes? How can you tell?

Draw an onion cell in anaphase. Label the cell wall, plasma membrane, chromosomes, spindle, and metaphase plate.

Telophase

The final stage of mitosis is **telophase.** During this stage, a nuclear envelope begins to reform around each group of chromosomes and the chromosomes decondense into chromatin. The spindle fibers begin to break down and any nucleoli reform.

You can identify cells in telophase by looking for the following:

1. There should be two distinct darkened regions, but individual chromosomes cannot be distinguished.
2. The formation of the new cell wall, which occurs during cytokinesis, is still incomplete and the area between the two forming nuclei appears blurry.

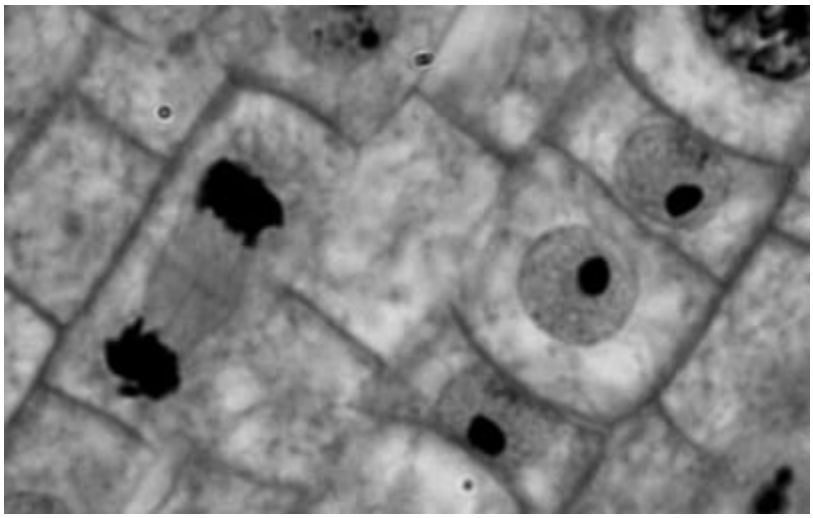


Figure 5.4.6: A cell in telophase

This image shows a cell on the left that is currently in telophase, forming two new nuclei. On the right side of the image there are three cells that have probably recently finished dividing and have entered interphase.

Draw an onion cell in telophase. Label the cell walls, plasma membranes, forming nuclear envelope, and chromatin. (It is likely that the DNA is in a transitional state between chromosomes and chromatin)

Cytokinesis

The formation of the new cell wall and division of the cytoplasm is called **cytokinesis**. This stage of cell division happens concurrently with telophase, but is not part of mitosis, as that refers strictly to the division of the nucleus.

In the image below, label the new cell wall that is forming during cytokinesis.

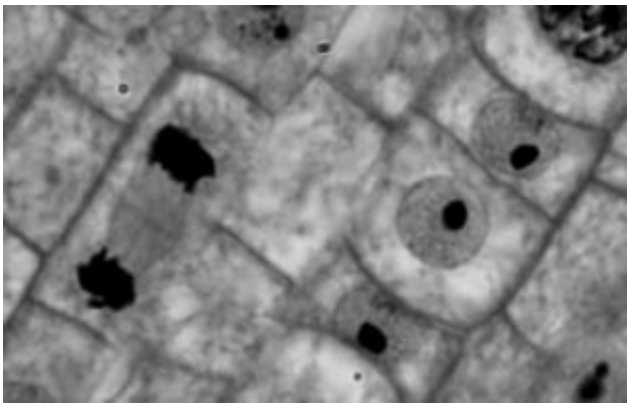


Figure 5.4.7: A cell in telophase

Below is a diagram of mitosis. Label each stage and the relevant structures. Make note of important events.

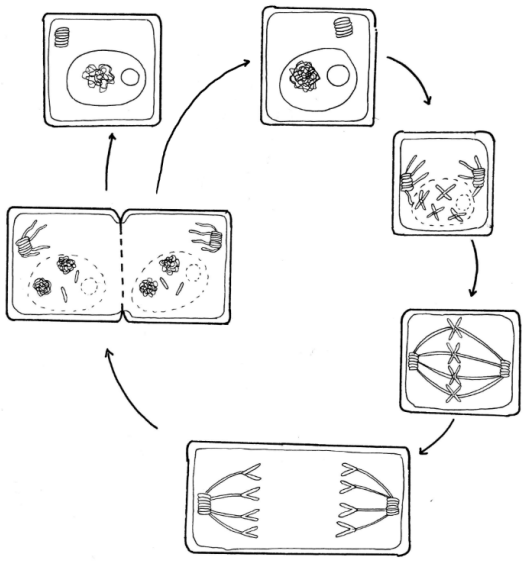


Figure 5.4.8: Diagram of Mitosis

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5.5: The Cell Cycle

As the onion root tip grows deeper into the ground, the cells at the tip continue to divide. One of the resulting cells will remain in place and differentiate into a mature cell, such as a vessel element or a sieve cell. The other cell will remain **meristematic**, continuing to divide as the root grows deeper into the soil. The word meristem, unfortunately, doesn't have a useful root to learn. It is perhaps ironic that the word meristem cannot be divided up into interpretable segments, as the term is derived from a Greek word that means "to divide".

Cells that remain in the meristematic region will remain in the cell cycle, entering a period called **interphase**, which is composed of three distinct phases. **G1** (gap 1), is when cells duplicate the contents of the cytoplasm, including the organelles and cytosol. At the end of G1, they will reach a checkpoint. If duplication of cell contents was successful, they will pass into **S-phase** (synthesis). During S-phase, DNA is replicated and each chromosome becomes a set of sister chromatids. After S-phase, there is another checkpoint to ensure that replication of cell contents, specifically the DNA, was successful. Finally, the cell enters **G2** (gap 2), where it passes a final checkpoint before division. The cell enters cell division again, completing mitosis and cytokinesis to produce two identical daughter cells.

Cells that differentiate exit the cell cycle into **G0** (resting). In this stage, cells can begin to express different genes and specialize for specific tasks. You will see these cells in the upper portion (away from the tip) of the onion root. Note that these cells are much larger than the actively dividing cells in the meristematic region of the root.

> Why are so many checkpoints necessary during this process? What do you think would happen if there weren't checkpoints?

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5.6: Meristems and Tissues in the Root

The Root Apical Meristem (RAM, for short)

When you are viewing the onion root tip, you are viewing the beginning of the formation of tissues of the plant's root system. This formation of tissues begins with the **root apical meristem** (RAM). Just below the tip of the root, there is a region of small, densely packed cells that are actively dividing. These cells make up the RAM. To the outside (below, in your slide) of the root tip, the RAM cells produce an ephemeral tissue called the **root cap**. Cells in the root cap protect the root apical meristem, secrete chemicals to attract beneficial bacteria and fungi, and secrete a mucilage that makes it easier for the root tip to penetrate the soil substrate. As the root tip grows, these cells are sloughed off into the environment and so the root cap must be continually produced by the RAM. To the inside (above, in your slide), the RAM produces cells that begin to form the three **primary meristems**. Remember, a meristem is a region of cells whose function is to produce more cells!

> Based on the root tips you have looked at today, how might you identify meristematic regions in a plant organ under the microscope? What would you look for and why?

Primary Meristems and Their Primary Tissues

Primary meristems divide to form the **primary tissues**. The **protoderm** is the primary meristem that produces the epidermis. The **procambium** is the primary meristem that produces the vascular tissues (xylem, phloem, and any associated tissues). The **ground meristem** is the primary meristem that produces the ground tissue. Depending on the type of plant or the part of the plant, the ground tissue can be divided into distinct regions or not. The *Zea mays* root tip in the image below belongs to a monocot, so the ground tissue in this particular sample is divided into the **pith** (appearing as a column of tissue in the center of the root tip, bordered on either side by vascular tissue) and the **cortex** (located between the epidermis and the vascular tissue on either side of your slide).

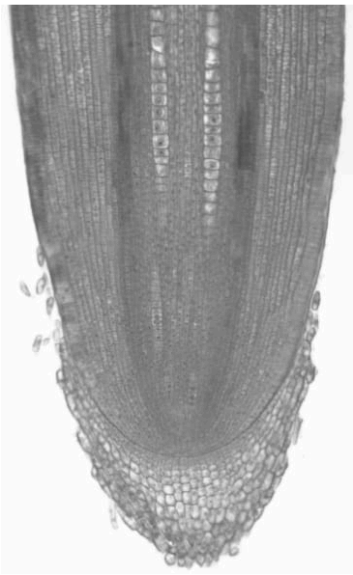


Figure 5.6.1: Root tip, including further up the root

In the image above, label the **RAM, protoderm, procambium, ground meristem, pith, cortex**, and **vascular tissue**.

> Where in the root above would you be likely to find cells in the G0 phase of the cell cycle?
>
> Where would you be likely to find cells in G1, S-phase, or G2?

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5.7: Multicellularity and Clonal Reproduction

Many unicellular eukaryotes undergo mitosis for **asexual reproduction**. This is often called clonal reproduction, because offspring are identical to the parent cell. Because prokaryotes do not have a nucleus, they cannot undergo mitosis, but they can still do asexual reproduction.

How do prokaryotes reproduce asexually?

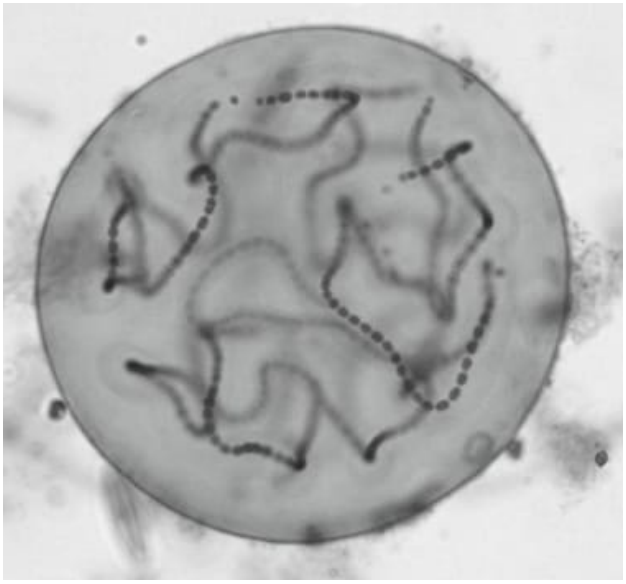


Figure 5.7.1: Nostoc colony

On the right is a colony of the cyanobacterium *Nostoc*. These unicellular organisms reproduce asexually to form colonies of individuals that live together in a secreted mucilaginous sheath (the bubble surrounding them). Much like *Anabaena*, some of these individuals are converted into heterocysts and are unable to feed themselves. How can we distinguish between a collaborative community of individuals and a multicellular organism?

The root tips you have been viewing are a small portion of the larger organism. How did life become multicellular from its unicellular origins? There are many theories about how this happened, but it is well-supported that multicellularity evolved multiple times in the tree of life. One theory for how multicellularity first occurred is through errors in cytokinesis, resulting in two identical cells that were still conjoined. This can be induced in yeasts (unicellular fungi), resulting in branching structures. These yeasts are referred to as snowflake yeasts. Investigate further here: http://www.snowflakeyeastlab.com/experimental%20evolution.htm

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5.8: Summative Questions

1. Mitosis produces identical cells. What can this process be used for?
2. Compare and contrast binary fission and mitosis. Why can't prokaryotes do mitosis?
3. What is the difference between mitosis and cytokinesis?
4. What are the major events that happen in each stage of mitosis?
5. How does the theory of multicellularity described for snowflake yeast relate to the plasmodesmata you have seen forming connections between plant cells?

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6: ROOTS AND THE MOVEMENT OF WATER - HOW IS WATER MOVED THROUGH A PLANT?

Learning Objectives

Content Objectives

- Understand what influences the weird behavior of water, particularly tonicity, adhesion, and cohesion
- Learn how transpiration drives the movement of water through a plant and which environmental factors influence transpiration rates

Skill Objectives

- Predict the movement of water in different situations and explain why it moved the way it did
- Draw and describe the flow of water as it moves through a plant from the soil environment to the atmosphere

6.1: Formative Questions

6.2: Introduction

6.3: The Behavior of Water

6.4: Transpiration and Cohesion -Tension Theory

6.5: Summative Questions

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6.1: Formative Questions

1. What is easier, drinking water through a wide tube or drinking water through a thin tube? Why do you think that is?
2. Why do water drops form a three dimensional, domed structure when dripped onto a surface, rather than spreading out?

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6.2: Introduction

Plants are nature's great water filters. They absorb water from the soil through their roots (if they have roots), use this water to maintain homeostasis, and whatever is left evaporates from open stomata across the epidermis of the plant. Each water molecule that leaves the plant is electrically charged and, due to these charges, tugs on the molecule behind it. The vast majority of water absorbed by most plants will exit via this process, creating a continuous vacuum of water through the plant, from the soil to the atmosphere. This evaporation of water from plant tissues is called **transpiration**. This process is highly dependent on the current environment, but to provide some perspective, an acre of corn transpires about 3,500 gallons of water per day.

Why do plants transpire if they are losing so much water everyday? Why not close their stomata to prevent water from escaping? There are many reasons why plants have evolved to transpire instead of retaining water.

1. Transpiration drives the flow of water and dissolved nutrients through the plant. If plants stop releasing water through the stomata, they will stop pulling in the nutrients dissolved in that water essential for plant function.
2. Transpiration provides evaporative cooling. As water leaves the plant tissues into the atmosphere, it takes energy with it in the form of heat. Much like when we sweat, this allows the plant to cool and maintain homeostasis. This is particularly valuable in hot environments.
3. Leaving stomata open is required for photosynthesis (except in certain plants, more on this in Lab 10: Photosynthesis). Carbon dioxide enters the plant through the stomata and oxygen is released as a waste product. If the stomata are closed, the plant cannot form sugars.

→ **At the beginning of this lab as a class**, set up and number 4 potted plants of similar size and type. On each plant, put a bag over one of the branches (or main stem) and tape it closed around the base. *Note: the bags should be the same type or the mass of each bag should be recorded beforehand.* Water plants 1, 2, and 3 until the soil is saturated. Put plant 1 under a light or next to a sunny window, plant 2 in the dark, and plants 3 and 4 somewhere away from a window but where light is still present. You will check on these later in the lab.

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6.3: The Behavior of Water

Because all atoms are constantly in motion and because this motion is random, atoms tend to disperse relatively evenly across an environment because this arrangement has a higher probability of occurring. This process is called **diffusion**. When you drop food coloring into a glass of water, the molecules in the food coloring bounce off of each other and begin to gradually disperse away from each other. The water molecules do the same until the molecules of food coloring and the molecules of water are relatively evenly dispersed throughout the glass. The molecules don't stop moving, but due to the random motion, the mixture appears to remain evenly mixed.

Osmosis

Osmosis is the diffusion of water across a semipermeable membrane. Because the membrane is semipermeable, water can move through the membrane, but other dissolved compounds may not be able to, for example dissolved ions like Na+ and Cl-. This has some interesting implications.

Tonicity

To think about osmosis, it is important to consider the concentration of water molecules relative to the amount of stuff dissolved in it on either side of the membrane. This concept is called **tonicity** -- how much stuff is dissolved in the solution relative to the other side.

Water will move from areas of high water concentration to areas of low water concentration. Even if you have the same volume of water on both sides of a membrane, the water will move to the side of the membrane with more dissolved solutes, which can also be interpreted as relatively less water.

Hypotonic

How does this influence plant structure and function? Plants use tonicity to provide increased structural support by keeping plant cells in a **turgid** state (swollen with water). Plants sequester dissolved solutes in the central vacuole, making the solution **hypotonic**.

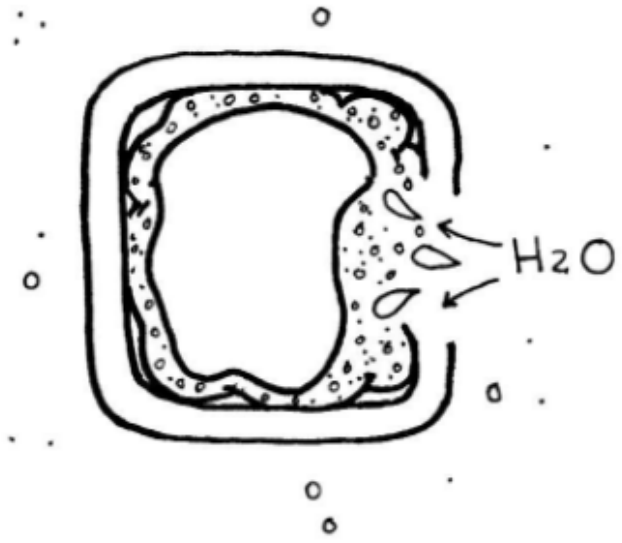


Figure 6.3.1: Hypotonic

Considering your knowledge of root words, what do you think the term hypotonic means?

Because the concentration of water is relatively low inside the central vacuole (due to the high concentration of solutes), this causes water to move from the exterior environment, where it is at a higher concentration, into the central vacuole. The cell wall keeps the plasma membrane from exploding as the central vacuole swells with water and pushes the cytoplasm outward. Think of it like blowing up a balloon inside a cardboard box--the tension of the inflated balloon provides structural support to the box. The cell above is in a hypotonic solution.

Isotonic

For animal cells, which lack a cell wall, being in a hypotonic solution causes cells to swell and burst. Our cells remain in an **isotonic** solution (iso- meaning equal or identical), with the concentration of dissolved solutes (and therefore water) approximately the same in the intracellular and extracellular fluids. The cell in the diagram is in an isotonic solution. Plant cells in this state are slightly wilted.



Figure 6.3.2: Isotonic

Hypertonic

The third possibility is that the concentration of solutes is higher in the solution than inside the cell, a **hypertonic** solution (hyper- meaning over or above). This means that the concentration of water is relatively higher inside the cell than outside, causing the water to move out. This is why salt can dehydrate (pull water out of) things, including organisms. If a plant that is not adapted to saltwater is submerged in a solution of saltwater, or perhaps there is too much salt in the soil, water will exit the plant cells to enter the solution. The cell in the diagram on the right is in a hypertonic solution.



Figure 6.3.3: Hypertonic

To observe the effects of tonicity on plant cells, prepare a wet mount of an Elodea leaf (or similar freshwater plant). For the initial preparation, use pond water or water from the tank the Elodea was growing in. Observe at 400x magnification.

Draw a few cells in the space below, labeling the **cell wall, plasma membrane, chloroplasts** and **tonoplast**. The tonoplast is the membrane of the central vacuole. Though you cannot see it directly, you can infer the location of the tonoplast by where the chloroplasts are--they line the outside of it.

Remove the coverslip, soak up as much of the water as you can, and add a few drops of saltwater (sodium chloride, NaCl, solution) to your slide. Quickly place back under the microscope and view at 400x. Once you see a change in the cells, draw a few of them. Label the **cell wall, plasma membrane, chloroplasts** and **tonoplast**.

> What happened to the cell? Was the solution hypotonic, isotonic, or hypertonic?
>
> In your drawing, use arrows to depict the movement of water either entering or exiting the central vacuole.

Soak up as much of the saltwater as you can, and this time add a few drops of distilled water (water that has had the dissolved solutes removed) to your slide. Quickly place back under the microscope and view at 400x. Once you see a change in the cells, draw a few of them. Again, label the **cell wall, plasma membrane, chloroplasts** and **tonoplast**.

> What happened to the cell? Was the solution hypotonic, isotonic, or hypertonic? Explain the movement of the water molecules in your answer.

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6.4: Transpiration and Cohesion -Tension Theory

When water evaporates from plant tissues, it is called **transpiration**. Ninety percent of water that evaporates from terrestrial surfaces occurs via transpiration--plants are the world's greatest water filters! Water is absorbed by (most) plants through specialized organs called roots. The earliest plants, the bryophytes, don't have roots. Instead, these plants rely on the absorption of water across the entire plant body and dispersal of this water by osmosis. For this lab, we will focus on the later groups of plants--the **tracheophytes**--that have specialized tissues for water absorption and transportation throughout the plant.

In Plant Cell Types and Tissues lab, you learned about cell types and tissues. The image above is a specialized cell called a tracheid. What tissue would you find this cell in? Is that tissue simple or complex?

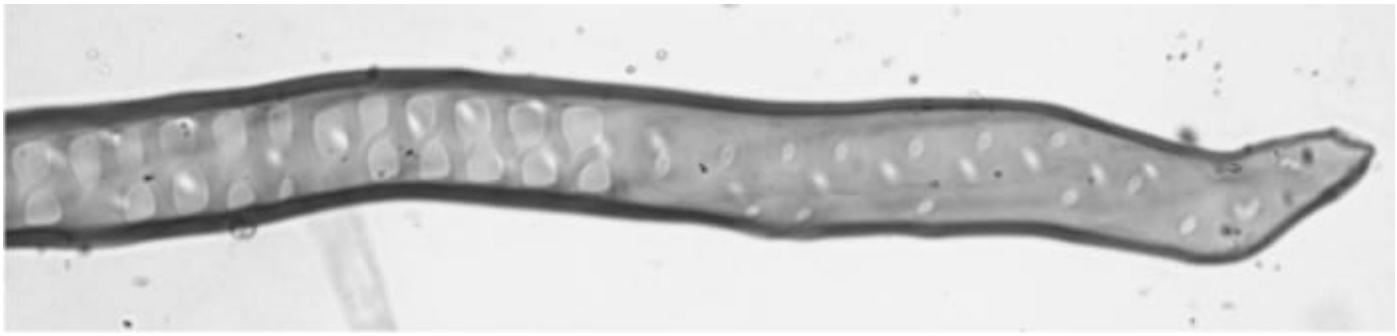


Figure 6.4.1: A tracheid

Based on your knowledge of root words, what does the term tracheophytes mean?

Early plants have tracheids, while later groups of plants have an additional type of water conducting cell: vessel elements.

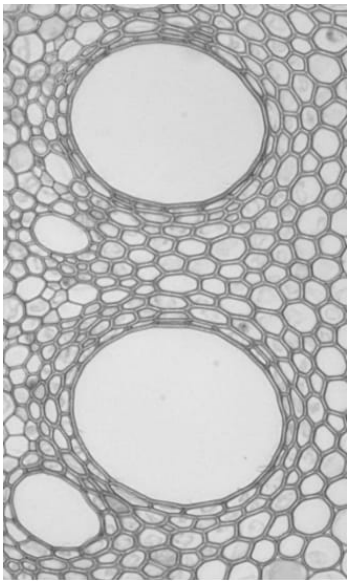


Figure 6.4.2: Vessel elements in corn root

The image above is a cross section through the xylem of a corn root. You can see large open areas (vessel elements) surrounded by smaller, more densely packed cells (tracheids).

How would these two cell types differ in the ability to take up and transport water?

Testing the Relationship Between Tube Diameter and Water Movement

1. Put some water in a shallow dish or petri plate, at least enough to coat the bottom. Add a drop of food coloring and mix thoroughly. You can also mix the dye into the water before adding it to the dish.
2. Obtain glass tubes of different diameters (capillary tubes recommended). Measure and record the diameter of each tube in the table below. Note: The diameter is the longest distance across the opening of the tube.
3. Place the bottom of one of the tubes into the water, leaving space between the bottom of the tube and the bottom of the dish so water can move into the tube.
4. Mark the height of the water on the tube with a pen, remove it from the water, then measure the distance from the bottom of the tube to the line you drew.
5. Repeat steps 3 and 4 for each tube and record your data in the table below.
6. Next to the table, make a graph that shows your results.

Diameter of Tube (mm)	Maximum height of water (mm)

Is there any correlation between tube diameter and the height that the water traveled up the tube? If so, explain the relationship.

Vessel elements are large-diameter conducting cells in the xylem, while tracheids have a much smaller diameter. How would this influence capillary action and adhesion? Use examples from the tube experiment to help explain your answer.

Transpiration in Action

Water moves through the dead water-conducting cells in the xylem much like it moves through a tube. Transpiration acts like suction from the top of the tube, but as you saw in the previous experiment, other forces aid in the movement of the water: cohesion, adhesion, tension, and capillary action. All of these forces work to pull water into the plant through the root hairs, into the xylem, and out through the stomata.

You set up four plants at the start of lab. What were the conditions for each plant?

Plant 1 -

Plant 2 -

Plant 3 -

Plant 4 -

Check on the plants and, before doing anything, simply observe the appearance of the bags. Describe your observations below.

Turn each plant on its side and carefully remove the bags. Try not to let any condensation in the bag escape. Use a scale to obtain the mass of each bag. Note: if you used different types of bags, adjust your end mass measurements by subtracting the initial mass.

Mass of bag (adjusted)	1:	2:	3:	4:

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6.5: Summative Questions

1. Were there any differences in the amount of water in the bags from plants 1 and 3 in your transpiration experiment? If so, what could explain these differences (which variable was changed between these treatment groups)?
2. What about between plants 2 and 3, considering the same questions as above?
3. Plants 3 and 4?
4. What did plant 3 represent in the experiment? Explain your answer.
5. What is the role of water in a plant -- why do plants need it?
6. Open stomata result in water loss through transpiration. Why don't plants just close their stomata to prevent water loss?
7. What environmental factors influence the amount of transpiration in plants?
8. Cohesion, adhesion, tension, and capillary action act on water as it moves through the plant body. Define each of these terms and explain how they participate in the movement water through the plant.
9. How does the diameter of a conducting cell in the xylem influence the ability of the plant to take up water?

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7: ROOTS AND THE MOVEMENT OF WATER - ROOT STRUCTURE AND ANATOMY

Learning Objectives

Content Objectives

- Learn the pathway of water through a plant and the structures involved in this pathway
- Learn the anatomy of a root and different types of root systems

Skill Objectives

- Draw and describe the flow of water as it moves through a plant from the soil environment to the atmosphere
- Identify specialized cells, tissues, and meristems in the root
- Distinguish between different root systems and explain the advantages of each type

7.1: Formative Questions

7.2: Introduction

7.3: Root Structure and Anatomy

7.4: Types of Root Systems

7.5: Summative Questions

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7.1: Formative Questions

1. What is the function of a root?
2. How does its structure contribute to that function?

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7.2: Introduction

An essential part of a plant's survival is obtaining access to water. Early plants did this by having small, creeping forms that grew in areas that would stay moist, never far from any surface. These plants did not have roots or the ability to transport water with xylem tissue. Instead, they absorbed and lost water across their tissues. As you can imagine, this would be a limiting state for plants and, soon after they moved onto land, plants evolved true roots with vascular tissue. Lignified tissues in roots would provide increased strength and stability for burrowing into the substrate (likely not yet a true soil) and access to water stored underground. Vascular tissue throughout the plant would allow water absorbed through the roots to be transported to other areas of the plant, meaning that tissues could elevate out of the water, getting increased access to sunlight.

In this lab, you will learn the general developmental pathway for tissues in the root, as well as the different anatomical organization of two groups of flowering plants: **monocots** and **eudicots**. Monocots, like corn and other grasses, germinate from seed with a single first leaf (called a cotyledon). Eudicots germinate with two leaves. Though this seems like a trivial distinction, these groups differ in many areas of growth and development.

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7.3: Root Structure and Anatomy

The root system of a plant serves two primary functions: water absorption and anchorage. Roots with a higher surface area will be better adapted to absorbing water because they have more area to interact with the soil environment. Increased interaction with the soil environment can also contribute to increased anchorage, but there are always trade-offs. If roots become too fine, they will be easily broken and lose the anchorage function. Additionally, finer roots can also lose more water if the soil environment becomes dry.

Root Development

In plants, both roots and shoots grow from the tip or apex of the plant. New cells are produced in these growing tips by **meristems**, groups of undifferentiated cells whose function is to divide by mitosis to produce new cells. Root growth begins at the **root apical meristem** (RAM). This meristem divides in two directions, producing a **root cap** to the outside of the root to protect the growing tip and the primary meristems to the inside: the **protoderm**, **ground meristem**, and **procambium**.

Primary meristems produce the primary tissues in the root:

- Protoderm → **Epidermis**
- Ground meristem → **Cortex** (and **pith** in monocots)
- Procambium → **Primary xylem** and **primary phloem**

These primary tissues will then either differentiate into specialized cells or, as is the case in many eudicots, become meristematic and produce secondary tissues. More on this in Lab Secondary Growth.

Observe a long section of *Zea mays* (corn) root tip. This root tip can be divided into three regions based on what is occurring in that stage of development:

Locate the root cap, RAM, protoderm, ground meristem, and procambium. These can be found at the very tip of the root, where the cells are small and densely clustered. If you trace the columns of cells back to their origin, they will coalesce at the RAM. This area of meristematic activity is called the **zone of division**.

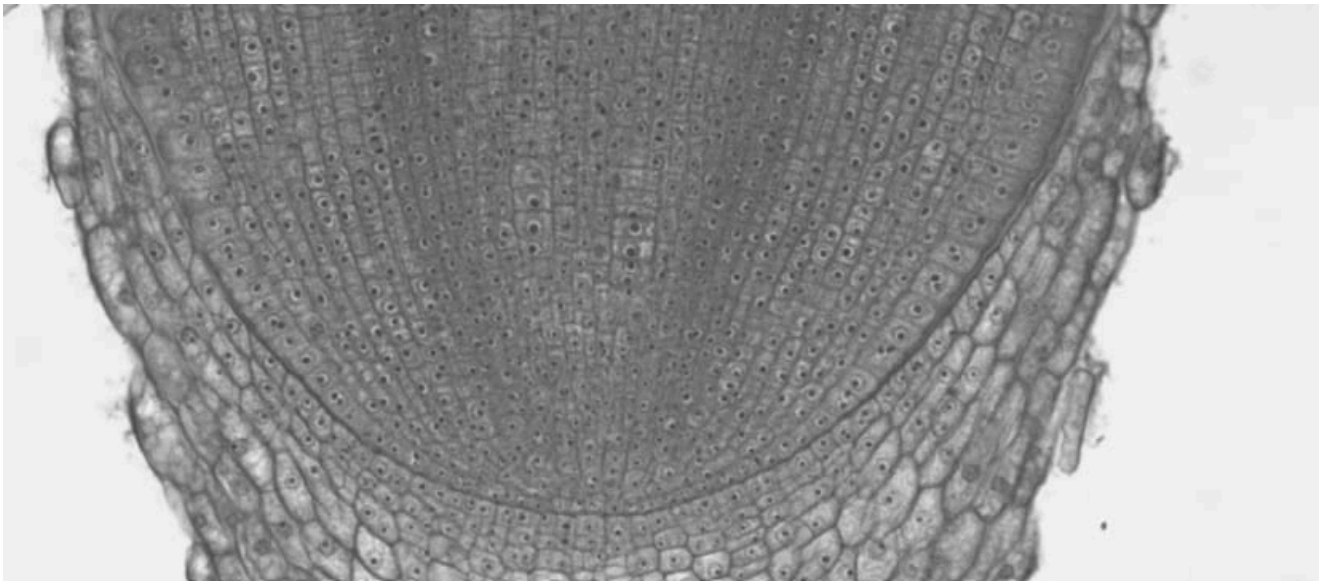


Figure 7.3.1: Zone of division

As you move up in the root, the cells begin to get larger, developing into primary tissues. This region is called the **zone of elongation**.

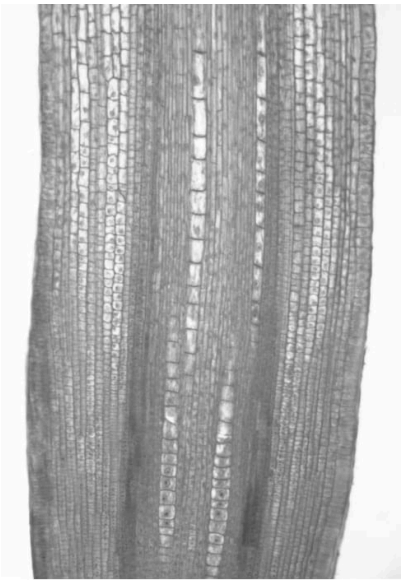


Figure 7.3.2: Zone of elongation

Further up the root, the larger cells begin to differentiate into specialized cells. In the xylem and phloem, you can find sclerenchyma with secondary walls. In the epidermis, you can see elongated cells called **root hairs** projecting outward. This region is called the **zone of maturation**.



Figure 7.3.3: Zone of maturation

Locate each of the zones described above and draw a root tip below. In the zone of division, label the **root cap** and the following meristems: **RAM, protoderm, ground meristem**, **procambium**. In the zone of elongation, label the following primary tissues: **epidermis, cortex, pith, primary phloem, primary xylem**. In the zone of maturation, label the following specialized cells: **root hair, sieve tube element, companion cell, vessel element**.

Root Development Flowchart

Below is a flowchart of eudicot root development in primary growth. There are two lines that will later lead to the secondary meristems. With this information and the filled in boxes, you should be able to determine which meristems and tissues go in the empty boxes.

Fill in the diagram below with the following terms: **cortex, ground meristem, pericycle, primary phloem,** and **protoderm**.

Choose a different color to represent meristems and tissues, then color the boxes accordingly.

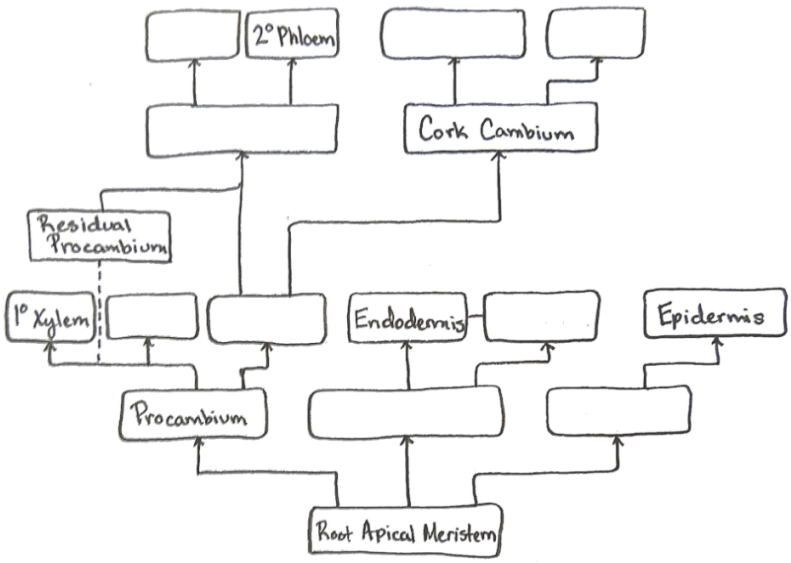


Figure 7.3.4: Flowchart of root development primary growth

How would this flowchart be different in a monocot? Draw a flowchart of monocot root development in the space below.

Root Anatomy

Monocots

Observe a cross section of the zone of maturation in a *Zea mays* root. Locate the primary tissues and specialized cells that you found in the long section and label them in the image below.

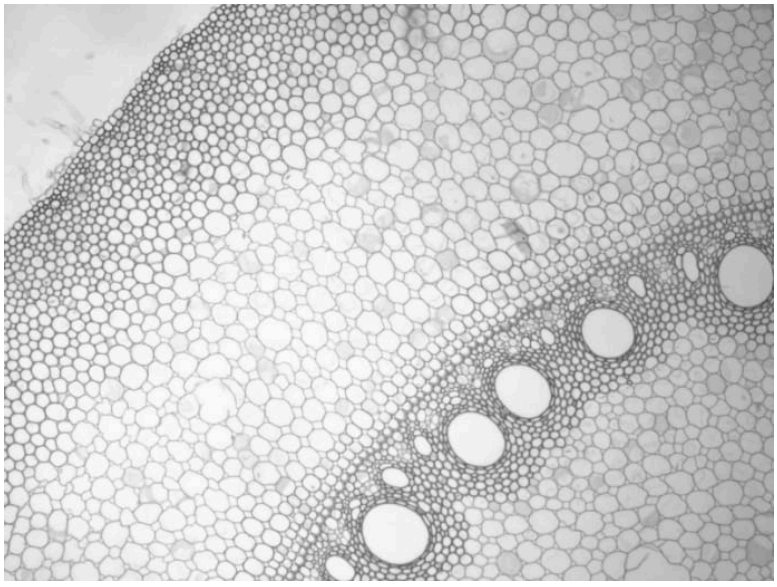


Figure 7.3.5: Cross section of a Zea mays root

Eudicots

The development of roots in eudicots differs slightly from monocots. Monocots develop a ring of vascular tissue with ground tissue (pith) in the center. In eudicots, the vascular cylinder is closed. The primary xylem develops as an X (or sometimes Y) shape

in the center with pockets of primary phloem in the spaces between the arms.

Encircling the conducting tissues is a meristematic layer called the **pericycle**. This single cell layer is responsible for producing lateral roots. Unlike root hairs which emerge on the outside of the root (**exogenous**, exo- meaning outside), lateral roots emerge from the internal tissues (**endogenous**, endo- meaning inside).

> Observe a cross section of a *Salix* (willow) root producing lateral roots. Locate the primary xylem, primary phloem, pericycle, cortex, and epidermis. Label these features in the image below:.

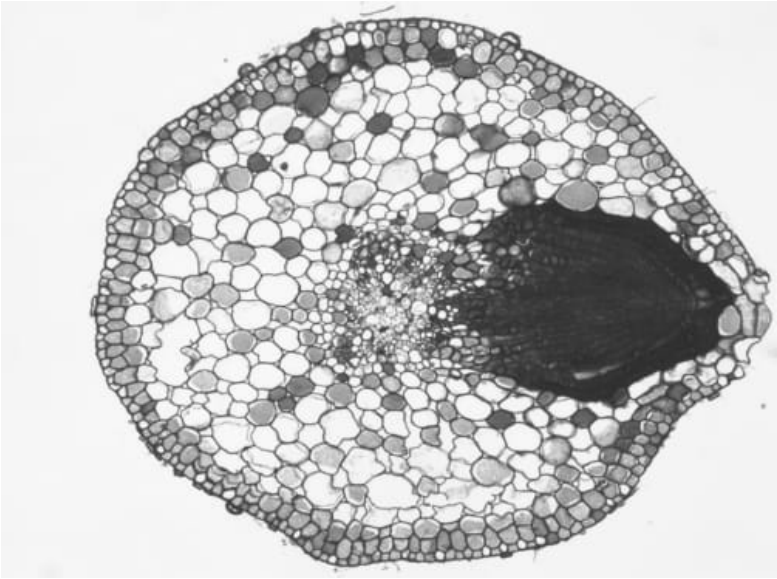


Figure 7.3.6: Salix root with lateral root

Just outside the pericycle is the innermost layer of the cortex called the **endodermis**. The endodermis regulates what enters and exits the vascular cylinder. When the root is young, the epidermis contains many root hairs whose function is to absorb water. This water is transported through the cortex and into the xylem. As the root matures, the root hairs are lost from the epidermis. These areas of the root now function for anchorage and transportation of water. Because these areas are no longer taking up water, the vascular cylinder is sealed off by a waxy layer of **suberin** that covers the endodermis called the **casparian strip**. The casparian strip forms in stages with the areas closest to the arms of the xylem forming last. These are the last areas to allow for the passage of water, giving them the name **passage cells**.

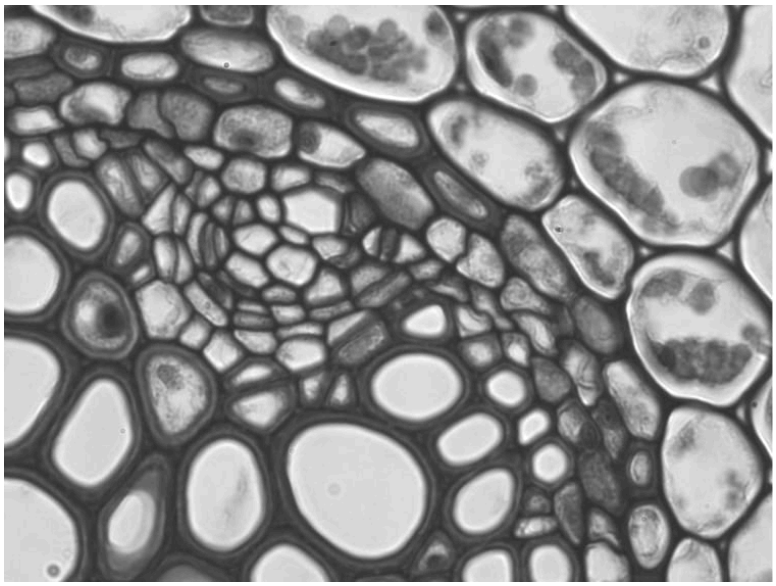


Figure 7.3.7: Casparian strip and passage cells

Observe a cross section of a *Ranunculus* (buttercup) root. Locate the **pericycle, endodermis, casparian strip**, and **passage cells**. The suberin in the casparian strip often stains similarly to the secondary walls in the xylem. Draw and label the cross section in the space below.

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7.4: Types of Root Systems

Plants that have adapted to different environments might develop different root systems in response to the stressors in that environment. Observe the different root systems available in lab and try to classify them as one or more of the following:

Netted or Taproot System

In soils where water is readily available for most of the year, plants might develop a **netted root system** where many similar diameter roots capture as much water and nutrients as possible to outcompete their neighbors. In climates where there are droughts or freezes, plants might develop a **taproot system**, where a larger central root can burrow deeper into the soil profile, accessing water reserves that other plants cannot.

Storage Roots

A larger diameter root can also store water and/or sugars for long periods. This type of root is called a **storage root**. A large central root, such as in the middle left on the following page, could be both a taproot and a storage root.

Adventitious Roots

Adventitious roots emerge from stem tissue. This can happen when there is an underground stem, such as in the system at the top of the diagram on the following page, or to serve as a **prop root**, as in the center of the diagram.

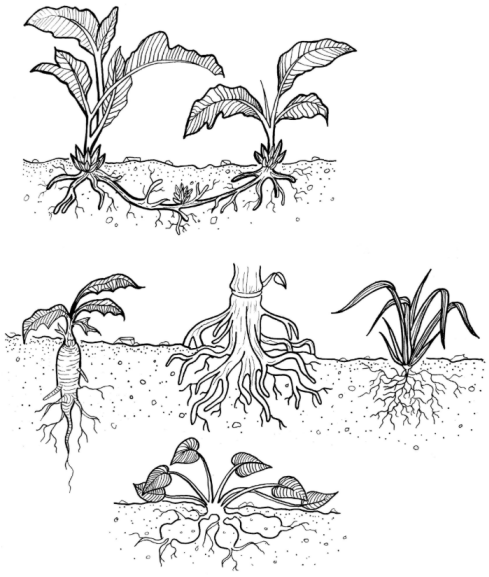


Figure 7.4.1: Types of root systems

In the figure above, label any adventitious roots, prop roots, and storage roots. Label each system as either netted or taproot (except the topmost root system, which is an underground stem).

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7.5: Summative Questions

1. Compare and contrast the arrangement of tissues in monocot and eudicot roots. Use drawings as part of your explanation.
2. What is the function of the pericycle?
3. Why does the Casparian strip form more slowly in some areas? What are these areas called?
4. What is the difference between a root hair and a lateral root?
5. How does the structure of a root hair contribute to its function?
6. What type of environmental conditions might select for a netted root system? Explain your answer.
7. What about a taproot system? Explain your answer.
8. Why would a plant evolve to produce roots from stem tissue? What benefits does this provide the plant?

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8: SHOOT ANATOMY AND MORPHOLOGY

Learning Objectives

Content Objectives

- Learn the anatomy of a shoot and the sequence of development
- Compare shoot anatomy in monocots and eudicots
- Learn the morphology of a woody stem
- Understand that a node has a predictable arrangement of organs

Skill Objectives

- Identify specialized cells, tissues, and meristems in the shoot
- Distinguish between monocot and eudicot stems
- Identify the features of a woody stem and determine the age of the stem

8.1: Formative Questions

8.2: Introduction

8.3: Shoot Development

8.4: Monocots

8.5: Eudicots

8.6: Shoot Morphology

8.7: Summative Questions

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- Thumbnail: Zea mays vascular bundle

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8.1: Formative Questions

1. What is the function of meristematic tissue?
2. What part of a plant do you think the following things you'd get at the grocery store are:
    - Onion
    - Potato
    - Ginger
    - Lettuce
    - Broccoli

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8.2: Introduction

The shoot of a plant is responsible for two major functions: photosynthesis and reproduction. In most plants, the **leaves** carry out photosynthesis, while the **stems** provide stability to elevate those leaves above potential competition. In annual plants, whose entire life cycle from germinate to death is completed in a single year, the epidermis on the stem is often photosynthetic, as well.

Tissues in the shoot are derived from the **shoot apical meristem** (SAM). Just like in the root, the SAM produces three primary meristems, which produce the primary tissues:

- Protoderm → Epidermis
- Ground meristem → Cortex and pith (simply **ground tissue** in monocots)
- Procambium → Primary xylem and primary phloem

These primary tissues will then either differentiate into specialized cells or, as is the case in many eudicots, become meristematic and produce secondary tissues. More on this in Lab Secondary Growth.

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8.3: Shoot Development

Coleus Shoot Tip

Though it looks a bit alien, this is a section through a growing tip of a plant. In the center, where the alien's head might be, is a region of small, densely packed cells. This is the SAM of the apical bud. On either side of the SAM, like two upraised arms, are the **leaf primordia.** These are the early stages of developing leaves. Through the center of these leaf primordia is a darker region of small cells. This is the procambium, which will develop into the vascular tissue. Lining the outer edge of the SAM and the youngest portions of the leaf primordia is the protoderm. As the protoderm matures into the epidermis, it produces hair-like projections called **trichomes**. Between the protoderm and the procambium is the ground meristem.

On either side of the growing tip are two other darkened lumps of densely packed cells. These **bud primordia** will develop into **axillary buds**, producing either branches or flowers. Each bud primordium has its own SAM.

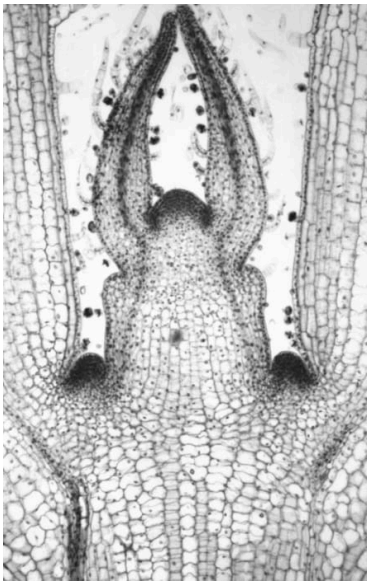


Figure 8.3.1: Coleus shoot tip

Observe a prepared slide of a Coleus shoot tip long section. Locate the meristems, tissues, and specialized cells. Draw what you see in the space below, label any important features.

Flowchart of Shoot Development

Below is a flowchart of eudicot shoot development in primary growth. There are two lines that will later lead to the secondary meristems. With this information and the filled in boxes, you should be able to determine which meristems and tissues go in the empty boxes.

Fill in the diagram below with the following terms: **cortex, epidermis, fascicular cambium, ground meristem, pith rays, procambium** and **primary xylem.**. Choose a different color to represent meristems and tissues, then color the boxes accordingly.

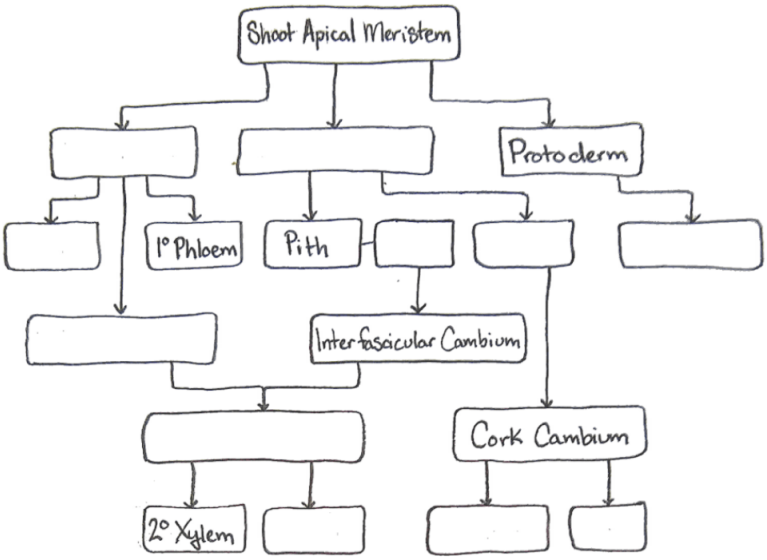


Figure 8.3.2: Flowchart of eudicot shoot development in primary growth

How would this flowchart be different in a monocot? Draw a flowchart of monocot shoot development in the space below.

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8.4: Monocots

Monocots are a group of flowering plants that produce a single first leaf (**cotyledon**) as their seeds germinate. **Eudicots** (frequently referred to simply as dicots) produce two cotyledons. In addition to this feature, monocots and eudicots can be distinguished by several anatomical and morphological features. One of these features is the arrangement of tissues in the stem. In monocots, the vascular tissue is arranged in distinct bundles that are scattered throughout the stem. The xylem is located on the side of the vascular bundles that face the center of the stem and can be identified by the large, hollow **vessel elements** that stain differently due to their secondary walls. In the half of the bundle that faces the exterior is the phloem, which contains **sieve tube elements** and their accompanying **companion cells**. The phloem is capped by a clump of fibers called the **phloem fibers**. The vascular bundles are arranged throughout the **ground tissue** in concentric circles with xylem facing inward.

Vascular bundles in monocots are called **closed vascular bundles**, as they will not go on to form secondary tissues (no residual procambium).

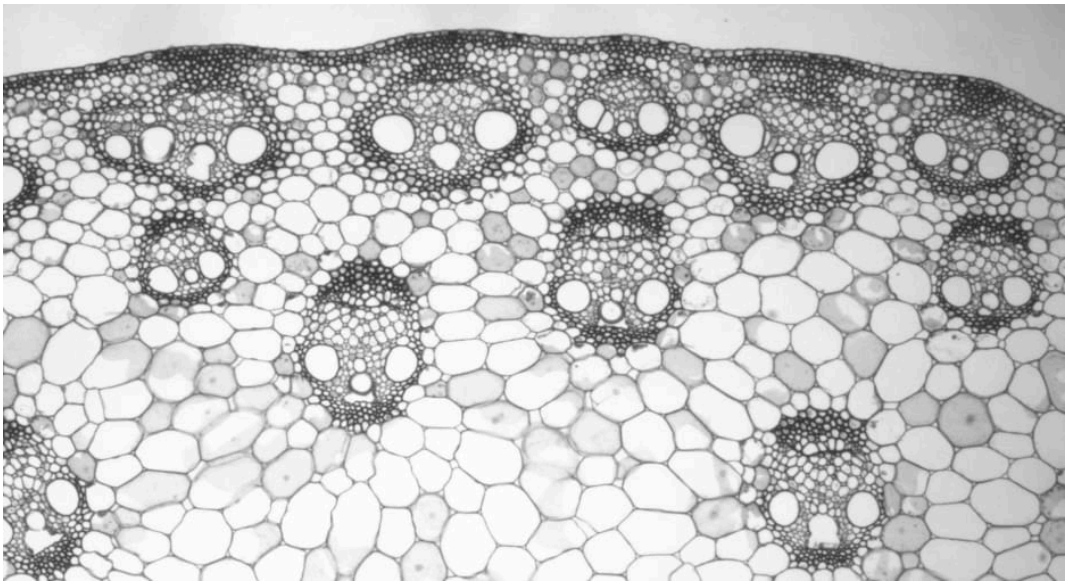


Figure 8.4.1: Monocot stem cross section

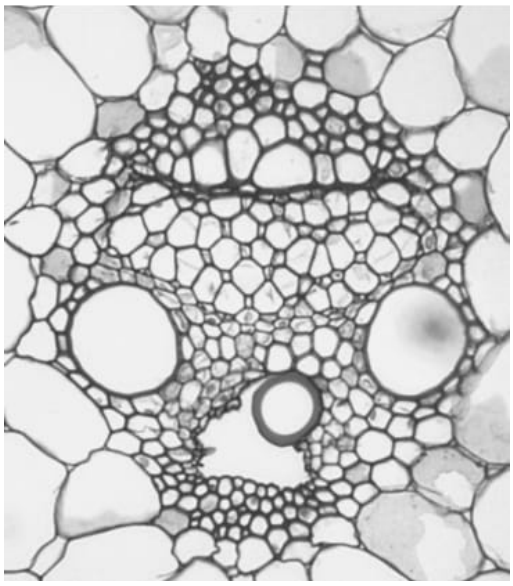


Figure 8.4.2: Zea mays vascular bundle

In the above of the vascular bundle on the left, label the **xylem, phloem,** a **vessel element, sieve tube element,** and

companion cell.

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8.5: Eudicots

In eudicot stems, the vascular tissue is arranged into a ring (the **vascular cylinder**) that separates the ground tissue into two distinct regions. The region of ground tissue contained within the vascular cylinder is called the **pith**. The region of ground tissue that is between the vascular cylinder and the epidermis is called the **cortex**. Similar to the monocots, the primary xylem is located in the region of the vascular tissue facing the center of the stem, while the primary phloem is produced toward the exterior of the stem.

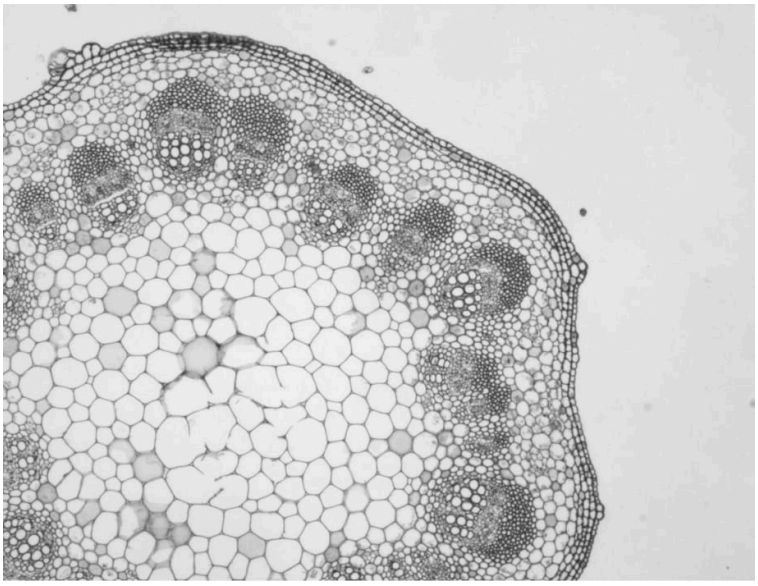


Figure 8.5.1: Helianthus stem cross section

Observe a cross section of a young *Helianthus* (or other eudicot) stem. Locate the **epidermis, cortex, primary phloem, primary xylem**, **pith,** and **pith rays**. Label these tissues in the image above.

What cell types (-enchymas) can you identify in the *Tilia* cross section? Which tissue(s) do you find each cell type in?

This image shows the epidermis and cortex of a young *Tilia* stem in primary growth. The epidermis is the outermost layer of cells and it is covered in a thin layer of wax, the **cuticle**. Just inside the epidermis is the cortex. Because this is from a young, growing stem, the outer cortex is full of collenchyma cells.

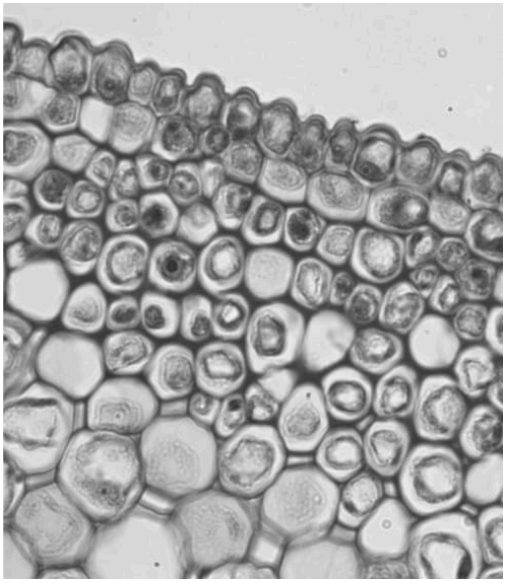


Figure 8.5.2: Close up of Tilia cortex and epidermis

In the image on the right, label the **cuticle, epidermis, cortex,** a **collenchyma** cell, and a **parenchyma** cell.

Why would the stem be covered in wax?

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8.6: Shoot Morphology

Shoots are composed of nodes. Each **node** has a **leaf** and an **axillary bud**, which emerges from the **leaf axil**. The leaf is located just below the bud, which will become either a branch or a flower. The identity of each organ is determined by its location in the node.

In the diagram below, label the bolded features, as well as the photosynthetic part of the leaf (the **blade**) and the stem of the leaf (the **petiole**). Label the bolded features in the diagram below.

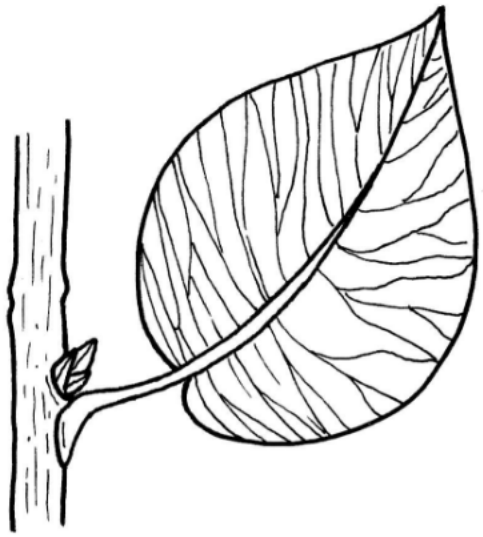


Figure 8.6.1: A node

Scars and Features of a Woody Shoot

When a leaf or bud falls off, it leaves a scar behind. **Leaf scars** are crescent shaped and have small, circular **bundle scars** within them where vascular bundles traversed the plant tissues. A leaf scar will be located below a bud, branch, or **bud scar**.

Plants that grow in temperate regions generally have a growing season. Each year, the newly emerging growth is within the **terminal bud** which is protected by **terminal bud scales**. When these scales fall off as the new growth emerges, they leave a region of **terminal bud scale scars** behind. Regions between terminal bud scale scars represent one year of growth.

On woody shoots, a layer of bark has replaced the epidermis (more on this in lab 8). To continue to exchange gases with the exterior environment, the bark layer develops small tears called **lenticels**. These can be small circular or elongated scars.

Label the bolded features in the diagram below. Draw in leaf scars where they are missing!

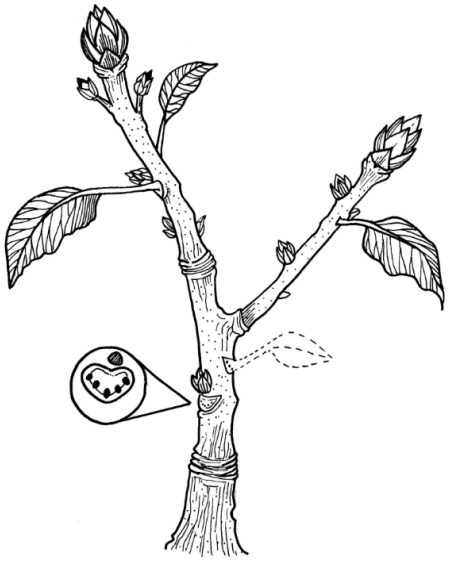


Figure 8.6.2: Woody twig morphology

Leaf Arrangement

As shoots develop, the leaves are arranged in a particular order which can differ from plant to plant. In some plant species, one leaf emerges from the branch at a time (left) so leaves appear to alternate from side to side. This type of leaf arrangement is called **alternate**. In other plants, two leaves are formed on either side of the stem at the same time. This type of leaf arrangement is called **opposite** (middle). If three or more leaves are produced at the same region on the stem, the leaf arrangement is **whorled** (right).



Figure 8.6.3: Leaf arrangement

Observe the shoots available in lab and identify the leaf arrangement and age of each. Record your findings in the table below.

Shoot	Leaf Arrangement	Age (years)

Shoot	Leaf Arrangement	Age (years)

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8.7: Summative Questions

1. Can you identify the leaf arrangement if the leaves have fallen off of a branch? Explain your answer.
2. Compare and contrast the organization of tissues in the shoot of monocots and eudicots. Use drawings as part of your explanation.
3. How does the shoot protect itself from water loss? What type of biomolecule helps in this process?
4. Why are the vascular bundles in monocots considered “closed”? What does this tell you about monocot development?
5. Why were the outer layers of the cortex of the young *Tilia* stem composed of collenchyma cells? What is the function of this cell type?
6. How could you tell that those cells were collenchyma and not sclerenchyma cells, as both of these cell types have thickened walls?

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9: LEAF ANATOMY

Learning Objectives

Content Objectives

- Learn the organization of tissues within the leaf
- Understand how the organization of these tissues changes in adaptation in different environmental conditions
- Explain how the relationship between surface area and volume relates to water retention in plant tissues
- Describe the steps in the process of science

Skill Objectives

- Identify tissues and structures within a variety of leaves
- Identify whether a leaf is mesophytic, xerophytic, or hydrophytic based on leaf anatomy
- Predict the drought tolerance of a leaf using anatomical and morphological features
- Use the process of science to ask and answer scientific questions
- Collect, analyze, and interpret data

9.1: Formative Questions

9.2: Introduction to Leaf Anatomy

9.3: Leaf Anatomy

9.4: Process of Science - Predicting Drought Tolerance in Leaves

9.5: Summative Questions

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- Thumbnail: Mesophytic Leaf

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9.1: Formative Questions

1. What is the primary function of a leaf?
2. How does the structure of a leaf contribute to performing this function?

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9.2: Introduction to Leaf Anatomy

Leaves are specialized organs for performing photosynthesis. A leaf is often a relatively large, flat surface used to optimize sunlight capture. However, surfaces are areas that water can evaporate from, so a large amount of surface area exposed to sunlight results in increased transpiration. The anatomy of a leaf has everything to do with achieving the balance between photosynthesis and transpiration in the environment in which the plant grows. Plants that grow in moist areas can grow large, flat leaves to absorb sunlight like solar panels because sunlight is likely more limiting than water. Plants in dry areas must prevent water loss and adapt a variety of leaf shapes and orientations to accomplish the duel tasks of water retention and sunlight absorption. In general, leaves adapted to dry environments are small and thick with a much lower surface area to volume ratio.

> **Note**
>
> There is an experiment at the end of this lab that you should read through and make plans for as a class at the start of the lab.

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9.3: Leaf Anatomy

Mesophytic Leaf Anatomy

View a prepared slide of a *Ranunculus* leaf. This small, herbaceous flowering plant is more commonly referred to as a buttercup. It grows in many environments, but tends to prefer shaded, cool spots with plenty of moisture. It is a good example of a "standard" leaf, not specially adapted to either wet or dry environments. This type of plant is called a **mesophyte** (meso- meaning middle, -phyte meaning plant), preferring moderate climatic conditions.

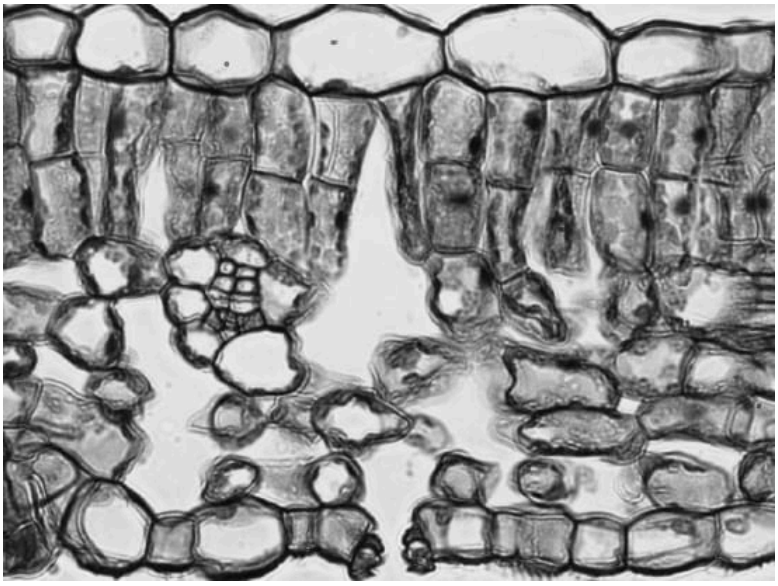


Figure 9.3.1: Mesophytic Leaf

The outer layer of cells on both the upper and lower surface of the leaf is the **epidermis**. Can you find any pores (gaps) in the epidermis? These pores are called **stomata** and allow carbon dioxide (CO_2) to enter the leaf for photosynthesis. Oxygen (O_2), which is produced during photosynthesis as a waste product, is released through the stomata. A third gas, water vapor (H_2O), also escapes through the stomata, though this has both beneficial and detrimental effects for the plant.

Look to either side of a **stoma** (this is the singular version of stomata) to see the flanking **guard cells**. These cells regulate the opening and closing of the stoma by either inflating and opening when there is high water content in the leaf, or collapsing and closing the stoma when water content in the leaf is low. This prevents water vapor from escaping the plant if it has too little water. However, it also prevents CO_2 from entering, stopping the formation of sugars in the plant and cutting of its source of energy. The flow of water vapor out of the leaf helps pull water up from the roots, see lab 5a for a full description of transpiration.

Beneath the upper epidermis is a layer of elongated cells full of chloroplasts. This is the **palisade mesophyll**, which has specialized for capturing incoming sunlight, rotating chloroplasts to the top of the leaf and then allowing them to regenerate by cycling them toward the leaf's center. Just below the palisade mesophyll is the **spongy mesophyll**. The spongy mesophyll is full of air pockets (hence the name spongy) that allow CO_2 to move into the leaf to the palisade mesophyll, as well as allowing oxygen to diffuse from the palisade mesophyll through the spongy mesophyll and out the stomata.

You may see circles of densely packed cells that both stain a different color than the mesophyll cells, as well as have a different organizational structure. These are veins of vascular tissue running through the leaf. The xylem is on the top, staining differently from the rest of the cells due to its lignified secondary walls. The phloem is on the bottom of the bundle, supported by a cluster of fibers (sclerenchyma) that increase structural support for the veins. The xylem is transporting water and dissolved minerals from the roots up to the leaf, while the phloem is transporting sugars made in the leaf to other regions of the plant.

> Draw a cross section of a mesophytic leaf, labeling each structure or tissue with its name and function. Consider simplifying the image to use as an easy reference.

In the leaf you are viewing, are there more stomata on the upper or lower epidermis? Can you think of any reasons why this might be?

How does the structure of the spongy mesophyll contribute to its function?

Hydrophytic Leaf Adaptations

Hydrophytes (hydro- meaning water) are plants adapted to growing in water. The structure of a hydrophytic leaf differs from a mesophytic leaf due to selective pressures in the environment -- water is plentiful, so the plant is more concerned with staying afloat and preventing herbivory.

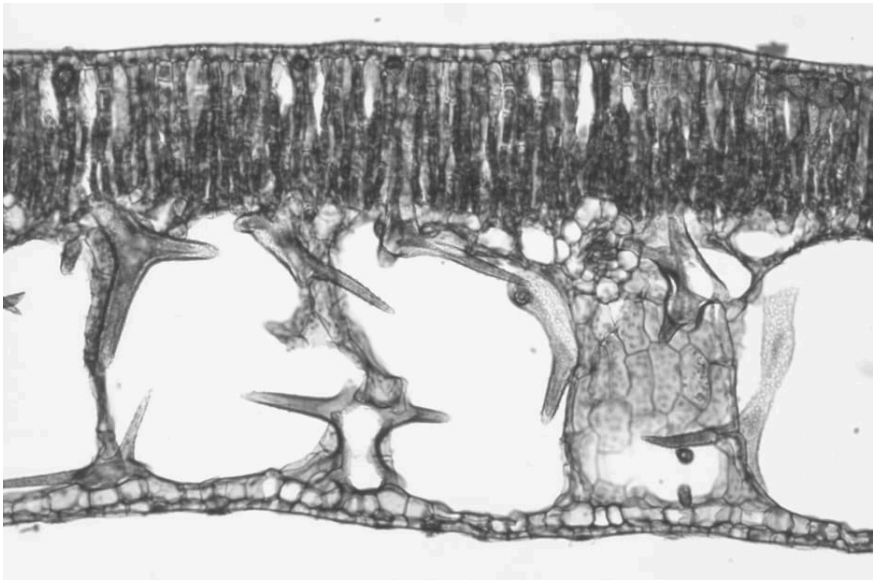


Figure 9.3.2: Cross section of a hydrophytic leaf

Observe a prepared slide of a hydrophyte, such as Nymphaea, commonly called a water lily. Note the thin epidermal layer and the absence of stomata in the lower epidermis. In the spongy mesophyll, there are large pockets where air can be trapped. This type of parenchyma tissue, specialized for trapping gases, is called **aerenchyma**. Look for sharp-looking, branched cells traversing the leaf's mesophyll. These will stain differently from the parenchyma cells because they have a thick secondary wall. These sclerenchyma cells are called **astrosclereids** and provide the leaf structural support, as well as prevention of herbivory.

Why are there no stomata on the lower epidermis of a *Nymphaea* leaf?

Draw a cross section of the Nymphaea leaf, labeling each structure or tissue with its name and function.

Xerophytic Leaf Adaptations

Xerophytic (xero- meaning dry) plants are adapted to dry conditions. California is a great place to view xerophytic plants due to the long dry season that also corresponds to the warmest season. If you are from California, this may seem perfectly normal. However, in most other places, the warm season coincides with the wet season, a much easier climate for plants to navigate. The coincidence of dry and warm seasons occurs in 5 distinct regions of the world, all on the west coast of their continent and all in a narrow latitudinal band between 30-60 degrees on either side of the equator. This type of climate is named after one of these 5 regions -- the Mediterranean.

Warm to hot temperatures cause increased transpiration. Dry conditions have the same effect, doubling the water stress on plants in Mediterranean climates where it is both warm and dry at the same time.

Pines

Pines evolved during a period in Earth's history when conditions were becoming increasingly dry. Pine needles have many

adaptations to deal with these conditions.

1. The epidermis of the leaf seems to be more than one cell layer thick. These subsequent layers of epidermis-like tissue under the single, outer layer of true epidermis are called the **hypodermis** (hypo- meaning under, dermis meaning skin), which offers a thicker barrier and helps prevent water loss.
2. The epidermis itself is coated on the outside by a thick layer of wax called the **cuticle**. Because waxes are hydrophobic, this also helps prevent water loss through the epidermis.
3. The stomata are typically sunken, occurring within the hypodermis instead of the epidermis. **Sunken stomata** create a pocket of air that is protected from the airflow across the leaf and can aid in maintaining a higher moisture content.
4. There are two bundles of vascular tissue embedded within a region of cells called **transfusion tissue**. The transfusion tissue and vascular bundles are surrounded by a distinct layer of cells called the **endodermis** (much like in a root, but not suberized).
5. Finally, the overall shape of the leaf allows for as little water loss as possible by decreasing the relative surface area, taking a rounder shape as opposed to a flatter one. This **low surface area to volume ratio** is characteristic of xerophytes.

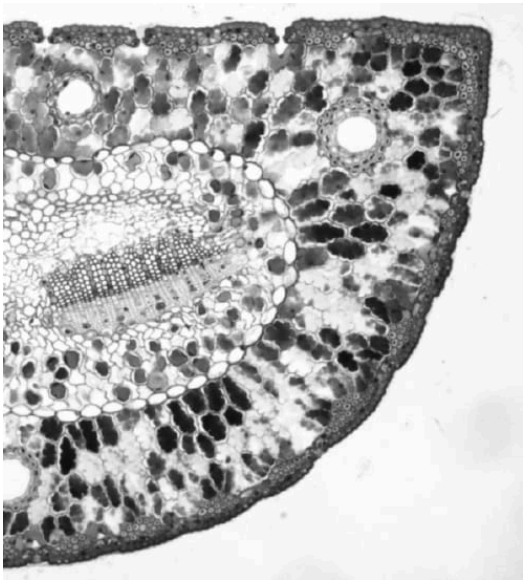


Figure 9.3.2: Pine needle cross section

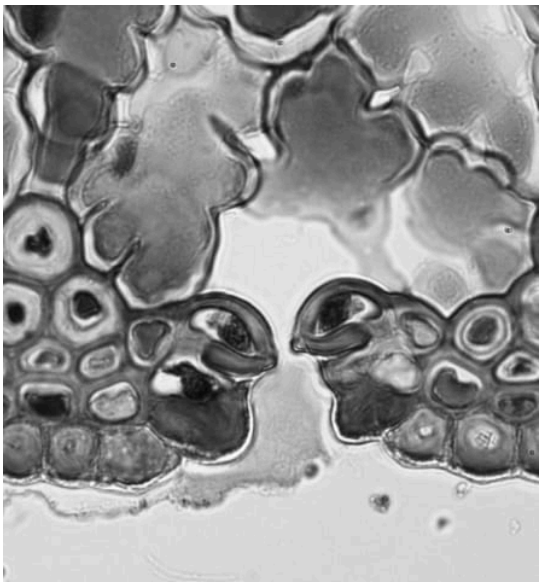


Figure 9.3.3: Close up of sunken stoma

Observe a prepared slide of a pine needle cross section. The strange, invaginated cells between the hypodermis and the endodermis are the mesophyll. Draw in the other half of the pine needle above. Identify and label the structures involved in water retention.

Note

There are several canals that appear as large, open circles in the cross section of the leaf. These are **resin canals**. The cells lining them secrete resin (the sticky stuff that coniferous trees exude, often called pitch), which contains compounds that are toxic to insects and bacteria. When pines evolved, not only was the Earth becoming drier, but insects were evolving and proliferating. These resin canals are not features that help the plant survive dry conditions, but they do help prevent herbivory. In addition to prevention of herbivory, resin can aid in closing wounds and preventing infection at wound sites.

Oleander

Oleander (*Nerium oleander*) is another plant that has specifically adapted to survive drought conditions, possibly native to the Mediterranean though its precise origin is unknown. Oleander also has defenses against herbivory, making the entire plant extremely toxic, even to humans.

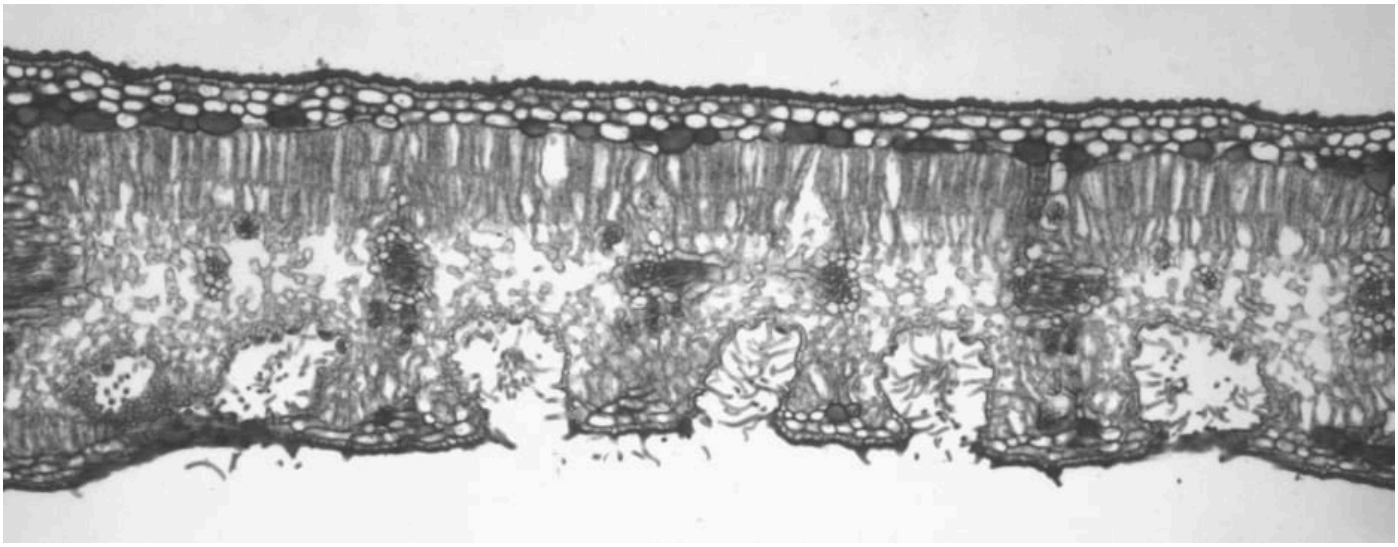


Figure 9.3.4: Nerium leaf cross section

Instead of sunken stomata, the epidermis in oleander recesses and creates a pocket that is lined with trichomes. The stomata are located at the base of these pockets, called **stomatal crypts**. The trichomes help capture evaporating moisture and maintain a relatively humid environment around the stomata. These stomatal crypts are located only on the underside of the leaves, where they experience less sun exposure and therefore less transpiration. The upper epidermis is free from stomata and, instead, is coated by a thick cuticle.

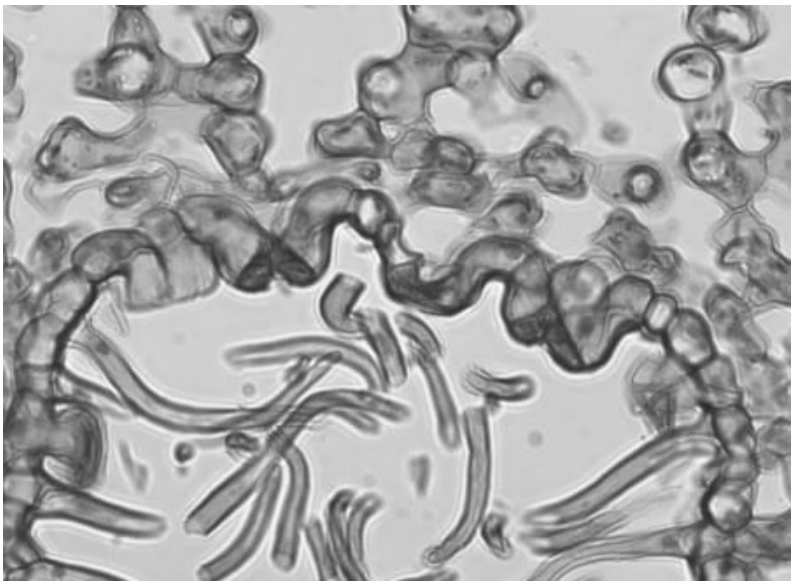


Figure 9.3.5: Stomatal crypt

The image below shows a close-up of the upper epidermis. What is that thick layer on top of the epidermis? How does it compare to the same layer in a mesophytic leaf?

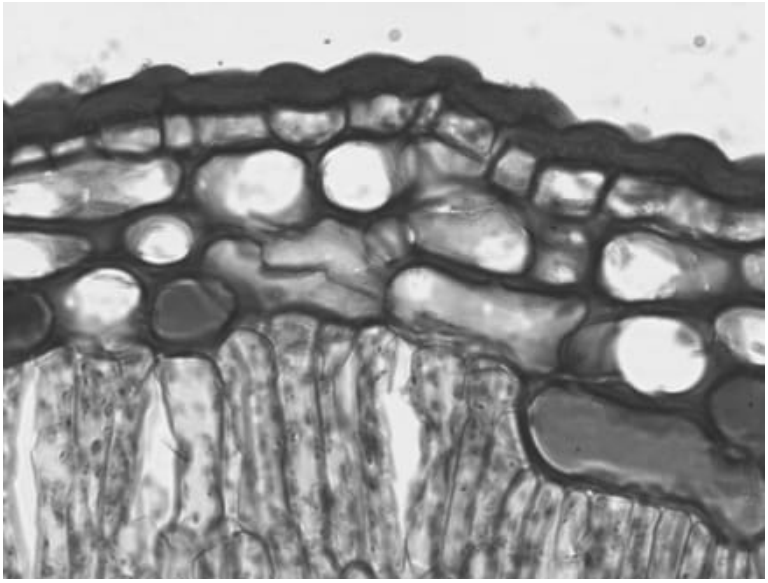


Figure 9.3.6: Nerium upper epidermis

Observe a prepared slide of a cross section of a Nerium leaf. Draw and label the structures mentioned in the paragraph above, as well as any additional features you see from the description of xerophytic adaptations in pines.

Which adaptations do pines and oleander share? Which features found in the pine leaf are absent in the oleander leaf?

Corn

Corn (*Zea mays*) is not necessarily a xerophyte, but it is adapted to deal with high temperatures. One of these adaptations, C4 type photosynthesis, will be covered in the photosynthesis lab. The one you will identify is something that lets the leaf alter the amount of exposed surface area. When moisture is plentiful, the corn leaves are fully expanded and able to maximize photosynthesis. When moisture is limited, the leaves roll inward, limiting both moisture loss and photosynthetic capacity. This is accomplished by the presence of **bulliform cells** in the upper epidermis. These clusters of enlarged cells are swollen with water when there is abundant water available. As the water content in the plant decreases, these cells shrivel, causing the upper epidermis to curl or

fold inward at these points. This adaptation to sun exposure can be found in many other grasses, as well (corn is a member of the Poaceae, the grass family).

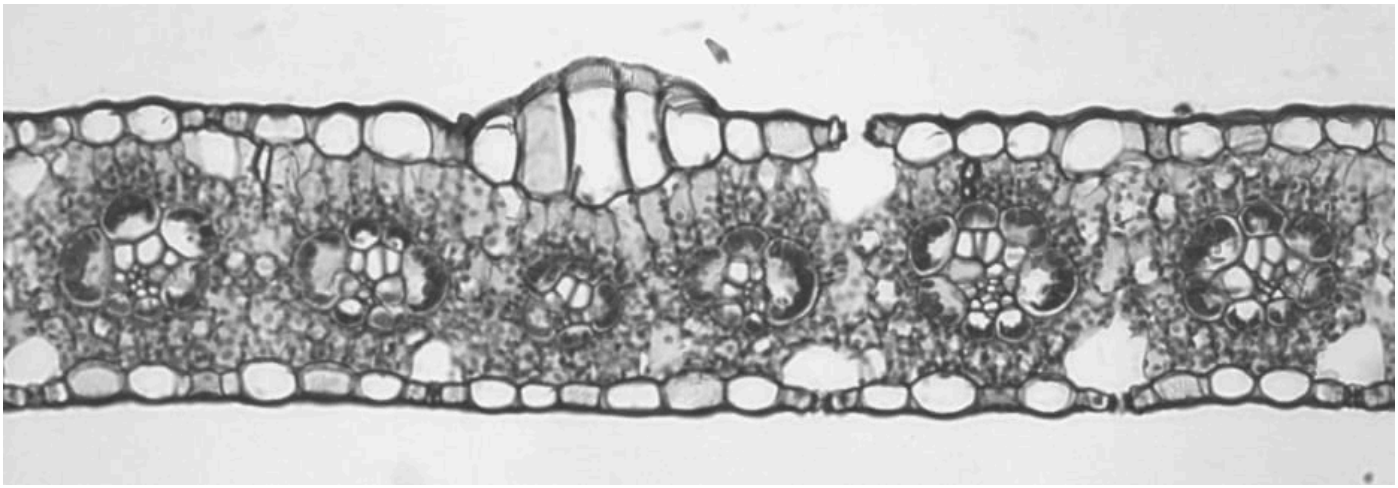


Figure 9.3.7: Zea mays bulliform cells

Observe a prepared slide of a cross section of a Zea mays leaf. Look for clusters of enlarged cells in the upper epidermis. Label the bulliform cells in the image above.

Why aren't there bulliform cells in the lower epidermis as well? What would happen to a leaf with bulliform cells on both sides?

Where are the stomata located on a leaf of *Zea mays*?

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9.4: Process of Science - Predicting Drought Tolerance in Leaves

The object of this activity is to use characteristics of leaf anatomy that you have observed in the previous sections of this lab to predict how drought tolerant a leaf will be. To assess this, you will measure the amount of water lost by individual leaves when exposed to an arid (dry) environment.

Materials needed

- An assortment of leaves of different shapes and sizes preferably collected from different environments. *Note: These leaves should be collected at the same time to account for moisture loss, which will begin once removed from the plant.*
- A ruler
- A digital scale
- A camera
- 1mm^2 graph paper and pencils (optional - a computer with the program ImageJ)
- A calculator
- A contained, arid environment (e.g. an incubator at 30-37C)

Observation: Obtain a set of leaves of different shapes and sizes. Make observations about these leaves, including aspects that the leaves possess or lack, that you think might contribute to drought tolerance. Record your observations below.

Question: The question that has been posed for this experiment is “Which characteristics of leaves are associated with drought tolerance?”

Hypothesis: To narrow the realm of focus, you will be looking specifically at the surface area to volume ratio of these leaves. For your hypothesis, make a statement as to how you think the surface area to volume ratio will influence moisture retention. A null hypothesis (H0), which predicts no relationship between the variables of interest, has been included below.

H0: The ratio of surface area to volume will have no correlation to the moisture retention in leaves when exposed to an arid environment.

H1:

Initial Data Collection

Step 1: Lay the leaves out as flat as possible on a solid background, such as a sheet of white paper, with a ruler aligned to one side of the paper. This will allow you to determine scale in your images. Make a label with your name (or group name), date, time, and "T0". T0 will denote "time zero", the state of the leaves before the start of the experiment.

Step 2: After you have arranged your leaves, ruler, and label, take a picture of them.

Step 3: Use the digital scale to obtain the mass of each leaf and record these values in Table 9.4.1.

> **Note**
>
> The density of water is 1 g/cm^3. Notice that density is a measurement of mass divided by volume (D = m/v). Because leaves are 90% water, we can assume that they have approximately the same density, a 1:1 ratio of mass to volume. With this information, we can use the mass of the leaf as an approximation of the volume of the leaf.

Step 4: Calculate the surface area of each leaf using ONE of the following methods:

1. Upload your picture to the computer and open it with ImageJ. Obtain the surface area and record these values in Table 9.4.1.

or

2. Trace each leaf on 1mm^2 graph paper. Count the number of squares fully contained within the tracing. Try to approximate the number of squares that are partially filled in by matching them to other squares that are also partially filled and counting these as one square. Take the number of completely filled in squares, add the number of approximated squares, then multiply this by 2 to get the total surface area (this accounts for both sides). Record these values in Table 9.4.1.

Note

Because the measurement of volume is using cm, it might be more useful to convert mm2 to cm2. Divide the number of mm^2 by 100 to get cm^2. To do this, place a decimal at the end of the number of mm^2, then move it two places to the left.

Step 5: Use the values in 9.4.1 to calculate the surface area to volume ratio for unit volume of each leaf by dividing the surface area by the volume.

Table 9.4.1: Volume and surface area of different leaves

Leaf ID	Volume (equal to mass, cm^3)	Surface Area (cm^2)	Surface Area : Volume Ratio for Unit Volume
Example:	3.4	120. mm^2 /100 = 1.2 cm^2	1.2 / 3.4 = 0.35

Experiment: To test the drought tolerance, the leaves will be placed into a contained arid environment. After a set time, you will remove the leaves from the arid environment and determine the amount and rate of moisture loss from each leaf.

Step 1: Arrange the leaves on a tray and place in the contained arid environment. Set a timer or note the time. After 1 hour, remove the tray and take it back to your lab table.

Step 2: Use the digital scale to obtain the mass of each leaf in grams and record these values in Table 9.4.2.

Step 3: Calculate the percent of water lost in each leaf by using the formula below:

$$((\text{Initial mass of leaf } - \text{ Mass of leaf after 1 hr in arid environment}) \div \text{ Initial mass of leaf }) \times 100$$

**Order of operations*: Do the subtraction in the innermost parentheses first, then divide the result by the initial mass, then multiply the result of that by 100.

Step 4: Calculate the rate of water loss from each leaf per minute by using the formula below:

$$((\text{Initial mass of leaf } - \text{ Mass of leaf after 1 hr in arid environment}) \div 60 \text{ minutes}$$

Table 9.4.2: Water retention of leaves after 1 hour

Leaf ID	Mass after 1 hour (g)	% Water Loss	Rate of Water Loss (g/min)
Example:	0.9 g	((3.4-0.9) / 3.4) x 100 = (2.5 / 3.4) x 100 = 73.5	(3.4-0.9) / 60 = 2.5 / 60 = 0.04

Analysis:

To interpret data, it helps to visualize it. In the space below, make a graph with Surface Area : Volume Ratio for Unit Volume on the x-axis and Percent Water Loss on the y-axis. Graph these values from tables 1 and 2 for each leaf. Do your data seem to follow any particular pattern?

Add at least 15 more data points from your classmates. Do your data seem to follow any particular pattern? Attempt to draw a line of best fit through your data points.

Interpretation and Conclusions

Did water loss correlate to the surface area : volume ratio? Explain.

Are there any correlations between water loss and any of the other observed characteristics?

Consider any sources of error in this experiment and how you could improve upon the design.

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9.5: Summative Questions

1. Did the results of the experiment support your hypothesis or the null hypothesis? Explain your answer.
2. Design a leaf for a xerophytic plant. Consider the dual and often contrasting objectives of performing photosynthesis while limiting moisture loss. Label important features and briefly explain their function with regard to drought-tolerance.

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10: PLANT ADAPTATIONS

Learning Objectives

Content Objectives

- Understand why environmental pressures select for different plant adaptations
- Recall the identifying features of stems, roots, and leaves

Skill Objectives

- Identify whether a modified organ is a stem, leaf, or root based on location
- Identify the modification type and explain the function of this modification
- Predict modifications you might see in a plant knowing the environmental stressors

10.1: Formative Questions

10.2: Introduction

10.3: Organ Modifications

10.4: Determining Plant Modifications and Function

10.5: Color-coded Organs

10.6: Summative questions

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- Thumbnail: Prop Roots

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10.1: Formative Questions

1. What do you think are the most important selection pressures on plants?
2. Which of these do you think is the most important for determining plant anatomy and morphology? Explain your reasoning.

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10.2: Introduction

In labs Roots and the Movement of Water - How is water moved through a plant? - Leaf Anatomy, you learned the typical anatomy, morphology, and organization of plant tissues and organs. However, over the course of each different plant's evolutionary history, environmental pressures can lead to modifications of these features in predictable ways that we can then classify. For example, plants that frequently encounter drought will experience selection for the ability to access water when there is no water in the environment. The plants that evolve water-storage will have better survival in this environment and are more likely to successfully reproduce. However, animals in this dry environment might then seek out their water-filled tissues. Plants that either hide or protect these water reserves are more likely to survive and experience less herbivory. Over time, as the environment continues to select for these defenses, they improve. And thus, over long periods of evolutionary time, one lineage of plants evolves into cacti, while another related lineage evolves in a different environment to be carnations.

There are many selective pressures on plants. As you saw in lab Leaf Anatomy, climate has a strong selective effect on the anatomy and morphology of plants, particularly water availability and access to sunlight. Herbivory is another strong selective pressure, as plants cannot run away from their predators. Instead, they must evolve other deterrents while balancing the energy costs required for these adaptations with energy devoted to reproduction. A third strong selective pressure is nutrient availability, which is often determined by the soil environment. For example, serpentine soils have low levels of nitrogen and calcium. Plants in serpentine habitats often evolve the ability to trap and digest insects to absorb the missing nutrients. These "carnivorous" plants are not heterotrophic, because they do not use the trapped insects as an energy source.

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10.3: Organ Modifications

Roots

Root tissue is derived from the root apical meristem. In some plants, environmental stressors will select for plants whose root tissues perform functions other than water absorption and anchorage. These organ modifications have specific names, depending on what function they serve.

1. **Storage roots**: In most roots, surface area is maximized for water absorption. In a storage root, the volume becomes more important. Cells in the cortex are enlarged and contain leucoplasts.

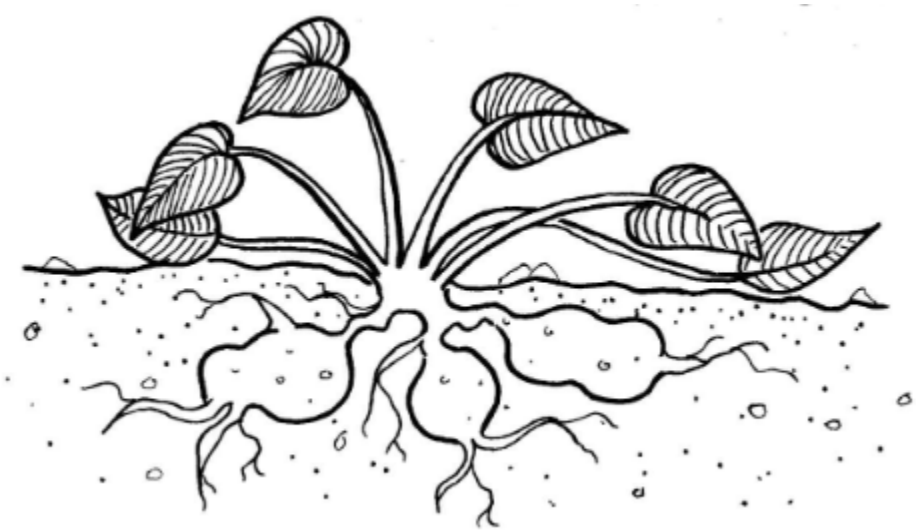


Figure 10.3.1: Storage Root

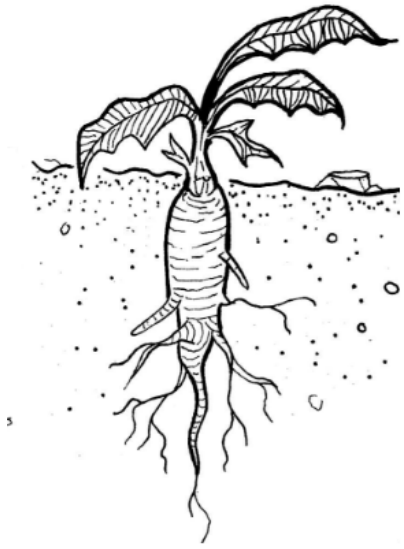


Figure 10.3.2: Taproot

2. **Pneumatophores**: Gases diffuse 10,000x more slowly in water than in air. In plants that grow in saturated soils, such as mangroves, roots cells need to access oxygen to perform cellular respiration at a rate that they cannot accomplish through water. Pneumatophores are roots that emerge above the surface of the saturated zone to “breathe” (pneumo- means lung)

and exchange gases with the environment.

3. **Adventitious roots**: Unlike most roots, adventitious roots emerge from stem tissue. A root apical meristem is derived from tissues in the stem, then root tissues are formed from the RAM, as normal. Adventitious roots can be produced from nodes on horizontal or climbing stems or in response to environmental stressors.



Figure 10.3.3: A rhizome

4. **Prop roots**: Prop roots are adventitious roots with the specific function of providing stability to a plant. This might happen in unstable soils, on climbing plants, or in plants that have a shallow root system.



Figure 10.3.4: Prop Roots

Stems

Stem tissue is derived from the shoot apical meristem. In many plants, there is a central stem that lateral stems emerge from. You can distinguish stems from roots by the presence of nodes. You can distinguish lateral stems from leaves by location within the node: stems emerge above the leaf.

Just like with roots, stems can be adapted to a particular function in response to environmental stressors.

1. **Cladode**: A cladode is a stem that has increased surface area to perform photosynthesis. This is usually because the leaves have been modified to some other purpose and are no longer performing photosynthesis. In essence, the stem is imitating a leaf.
2. **Succulent**: In the case of succulence, it is the volume of the stem that increases. Stem tissues develop large, specialized cells called hydrenchyma to store extra water. The plant can access this water for metabolism in periods of drought.
3. **Tuber**: Some stems are modified for storage of starches instead of water. A tuber is an underground stem that can be identified by its nodes (often referred to as “eyes” on a potato tuber). Each node is capable of producing a new shoot.
4. **Corm**: A corm is also modified for storage of starches. A corm is swollen tissue at the base of the shoot with linear nodes travelling across it. From these nodes, papery leaves emerge.



Figure 10.3.5: A Corm

5. **Rhizome**: Some plants produce horizontal stems that are used for asexual reproduction. A rhizome is a horizontal stem that is underground. Roots emerging from the nodes of rhizomes are adventitious.
6. **Stolon**: Similar to a rhizome, a stolon is a horizontal stem used for asexual reproduction. Unlike a rhizome, stolons are formed above the soil surface.
7. **Thorn**: A thorn is a lateral branch that has been modified to protect the plant, usually from herbivory. Thorns have a subtending leaf or leaf scar.



Figure 10.3.6: Thorns

8. **Stem tendril**: A tendril is a lateral branch that has been modified for climbing. A stem tendril will have a subtending leaf or leaf scar.

Leaves

Leaf tissue is derived from the shoot apical meristem. You can distinguish leaves from stem tissue by location within the node: leaves emerge below the axillary bud, lateral stem, or flower. Under normal conditions, the primary function of a leaf is photosynthesis. However, environmental stressors can select for the following modifications:

1. **Succulent**: Much like in stems, leaves can also be modified for water storage in environments where there is drought. You can distinguish a succulent leaf from a succulent stem because the stem will have nodes (the leaf will not).



Figure 10.3.7: A succulent

2. **Bulb**: Leaves can also be modified to store starch. A bulb, like an onion, is composed of fleshy leaves that surround a short, central stem.



Figure 10.3.8: A bulb

3. **Spine**: A leaf modified to be sharp for protection is called a spine. You can distinguish a spine from a thorn by the location

within the node.

4. **Leaf tendril**: Sometimes leaves will be modified for climbing. You can distinguish a leaf tendril from a stem tendril by the location within the node.

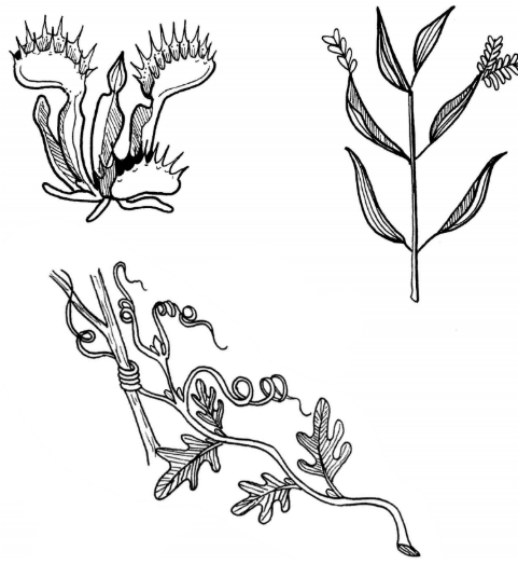


Figure 10.3.9: Leaf Modifications. Clockwise from top left: a trap and phyllode (venus fly trap), phyllode (Acacia), leaf tendril. A combination of all three modifications are shown in the pitcher plant below.

5. **Trap**: In environments where nutrients are low, some plants have evolved to capture insects for access to nitrogen, phosphorus, and calcium. There are a few ways plants can achieve this. One is to modify a leaf into some sort of trap.
6. **Phyllode**: Another instance of leaf imitation is when the petiole of the leaf becomes flat and leaf-like to perform photosynthesis. Similar to a cladode, this is usually in response to a modified leaf. The pitcher plant on the right shows a phyllode, leaf tendril, and trap all in one leaf.



Figure 10.3.10: Copy and Paste Caption here

7. **Stipular spines**: Another sharp armament against herbivory can be a replacement of a stipule with a spine. These can be distinguished from other sharp modifications, as they emerge in pairs at the base of a leaf.

Other Plant Adaptations

In addition to the major organs, plants can have adaptations to specific tissues, cells, or molecules produced by the plant.

1. **Prickles**: Similar to thorns and spines, prickles are a protective adaptation. In this case, it is a modification of the epidermal (and sometimes cortex) tissue. Prickles can emerge anywhere on the shoot, unlike spines and thorns, which are restricted to nodes.



Figure 10.3.11: Prickles

2. **Trichomes**: Trichomes are epidermal cells that have been modified as hairs. While they can still serve a protective function, they tend to be much smaller and less rigid than prickles.

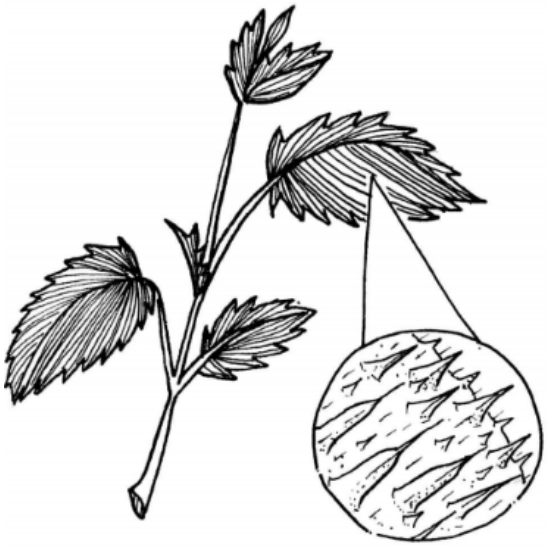


Figure 10.3.12: Trichomes

3. **Raphides**: Some plants have molecular, internal sharp armaments. In plants like Tradescantia, calcium oxalate is crystallized into needle-like structures called raphides.

   Chop up the leaf or stem of a Tradescantia and make a squash mount to see raphides within the plant tissues.

4. **Latex**: About 10% of flowering plants have evolved latex production, a sticky substance exuded when plants are damaged. This latex can prevent infection of wounds. Many groups of plants have independently evolved the production of latex gum up the mouthparts of herbivorous insects. In some plants, the latex also includes toxic compounds to aid in defense. For example, in milkweeds (Asclepias) this latex contains neurotoxins.

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10.4: Determining Plant Modifications and Function

Observe the specimens of different plant adaptations available in the lab. For each specimen, make note of the organ, tissue, or other component of the plant that was modified and the function of that modification. Record your findings in the space below.

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10.5: Color-coded Organs

In the diagram below, identify the organ modification(s). Choose a color for stems, another for roots, and a third for leaves. Make a key to indicate which color represents which type of organ, then color the organs of each plant with the correct color.



Figure 10.5.1: Organ Modifications

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10.6: Summative questions

1. Categorize the plant modifications described above as an adaptation in response to the following stressors. Briefly state how each modification helps the plant deal with the particular stressor.
   a. Water availability:
   b. Access to sunlight:
   c. Nutrient availability:
   d. Defense against herbivory
2. How do you differentiate between a stem and a root? What about a stem and a leaf? Consider both macroscopic and microscopic options.

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11: SECONDARY GROWTH

Learning Objectives

Content Objectives

- Learn the sequence of development of meristems and tissues in secondary growth
- Understand the tradeoffs (costs and benefits) of secondary growth

Skill Objectives

- Identify anatomical features of woody stems
- Determine the age of a tree based on annual growth rings

11.1: Formative Questions

11.2: Introduction

11.3: Secondary Tissues in the Root

11.4: Flowcharts of Development

11.5: Secondary Tissues in the Shoot

11.6: Dendrochronology

11.7: Summative Questions

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- Thumbnail: Tilia stem cross section.

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11.1: Formative Questions

1. What are some factors that limit how tall a plant can grow?
2. What are some factors that limit where a plant can grow?

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11.2: Introduction

The two questions you answered above are essential to understanding the evolution of **secondary growth**. In secondary growth, primary tissues and residual meristematic tissues produce secondary meristems, which then produce secondary tissues. Whereas primary tissues allow for vertical growth, secondary tissues allow for lateral growth: they allow stems and roots to become wider. How might this impact the ability of a plant to grow taller?

In addition to growing wider, secondary growth exchanges the living epidermis for a thick layer of dead, waterproofed cells called cork. The cork and a few other layers of tissue comprise something called the periderm, or perhaps more familiarly called **bark**. Consider the tradeoffs between having a living exterior with guard cells vs. a thick layer of waterproofed dead cells. How might this impact the ability of the plant to interact with the outer environment? How might this impact the ability of the outer environment to interact with the interior of the plant?

Variations on this type of growth appear in a few places, but the evolution of gymnosperms (conifers and their relatives) is when the more typical secondary growth appears in evolutionary history. As you will see in later labs, the gymnosperms evolved during a period in Earth's history when inland seas were drying out and plants were migrating further from the water. This group of plants is specialized for growing tall (think Coast redwoods) or living in harsh, low-water environments. As a general rule, monocots do not undergo secondary growth, so this lab will only address eudicots.

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11.3: Secondary Tissues in the Root

In roots, the formation of both secondary meristems involves the pericycle. The pericycle and some **residual procambium** join together to form the **vascular cambium**, a secondary meristem that produces vascular tissue. The other secondary meristem, the **cork cambium**, is initially formed solely from the pericycle.

Each of these secondary meristems divides in two directions to form a different secondary tissue to the inside and outside of the meristematic layer, respective to the center of the plant.

The vascular cambium produces **secondary xylem** to the inside of the root and **secondary phloem** to the outside.

The cork cambium produces **phelloderm**, a storage tissue, to the inside of the root and **cork**, a protective layer of dead, suberized cells, toward the outside. These three layers -- phelloderm, cork cambium, and cork -- are referred to as a **periderm**. As the first periderm layer is formed, it separates the epidermis, cortex, and endodermis from the conductive tissues of the root. The epidermis and cortex cells die and are shed as secondary growth proceeds.

> The pine root below has one layer of periderm fully formed. Can you label the tissues and meristems described above? What are the large holes in the root?

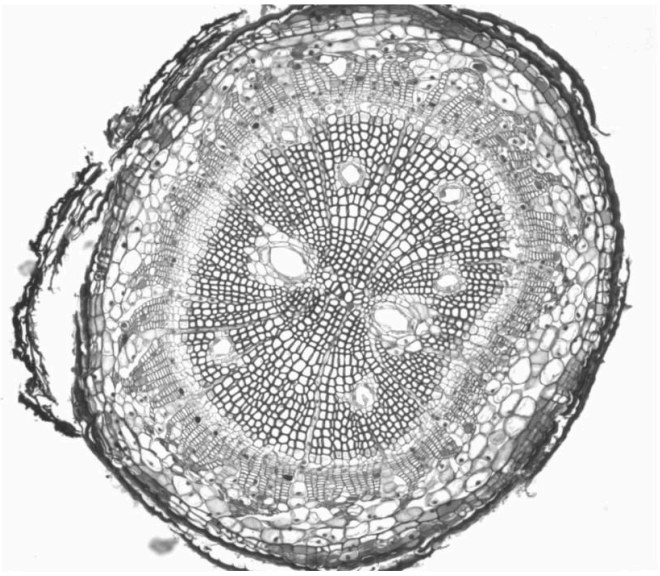


Figure 11.3.1: Pine Root Cross Section

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11.4: Flowcharts of Development

Below are two flowcharts. The upper represents the pathway of development in the shoot, while the lower represents the development of the root. Both of these include secondary growth. Fill in the missing pieces of each flowchart.

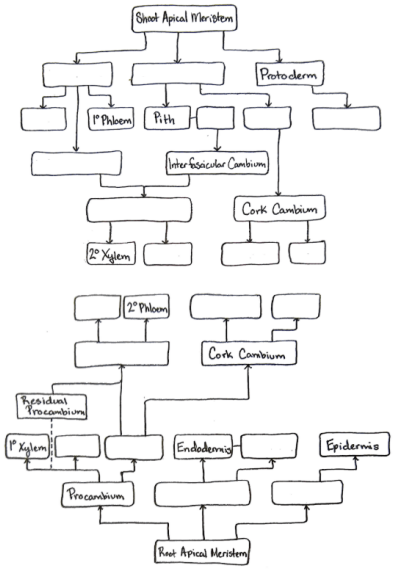


Figure 11.4.1: Flowchart of shoot development

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11.5: Secondary Tissues in the Shoot

Secondary Vascular Tissue

Though the secondary tissues are all the same, the sequence of secondary meristem development in shoots is a bit different than in roots. Shoots have no pericycle, so the secondary meristems must be formed from different tissues. In shoots, the vascular cambium is formed from residual procambium within the vascular bundles (**fascicular cambium**) joined by tissue in the pith rays (**interfascicular cambium**).

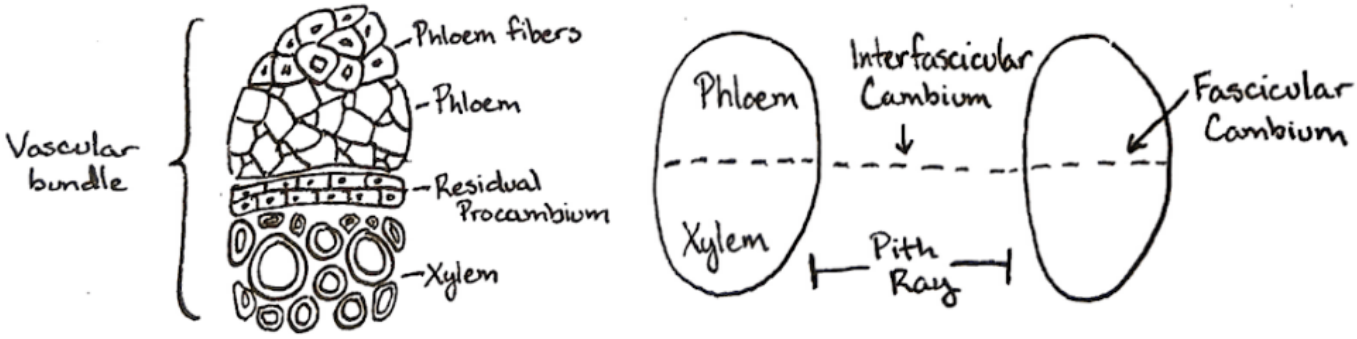


Figure 11.5.1: The vascular bundle of a eudicot stem

This layer of cells will divide to produce secondary xylem toward the inside of the stem and secondary phloem toward the outside. The conducting cells in the secondary xylem are dead at maturity. As the stem matures, these dead cells become separated from the living cells and the plant would be unable to direct the transport of materials into and out of the center of the plant. To solve this, plants have pathways of living cells that traverse the xylem and phloem called rays. **Xylem rays** radiate outward from the center of the stem until they reach the vascular cambium. At this point, they become **phloem rays**. Some of these will balloon out into large deltas of cells in the phloem tissue, while others will remain narrow strips of cells.

The secondary phloem becomes densely packed with layers **secondary phloem fibers** that provide structural support for the stem to grow tall.

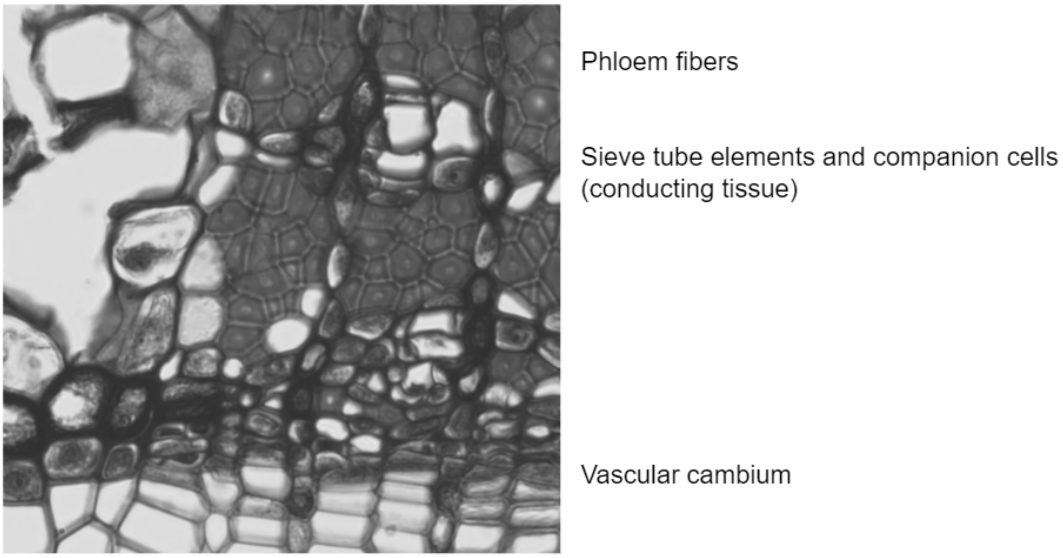


Figure 11.5.2: Close up of vascular cambium

Vessel elements in secondary xylem

In the secondary xylem, different diameter conducting cells form in wet and dry conditions. Larger diameter cells form in the wet season when water is plentiful. As the seasons transition to drier whether or approach freezing conditions, cells are smaller. Because most climates have a wet and dry season each year, you can track years of growth by the formation of these **annual growth rings** in the secondary xylem.

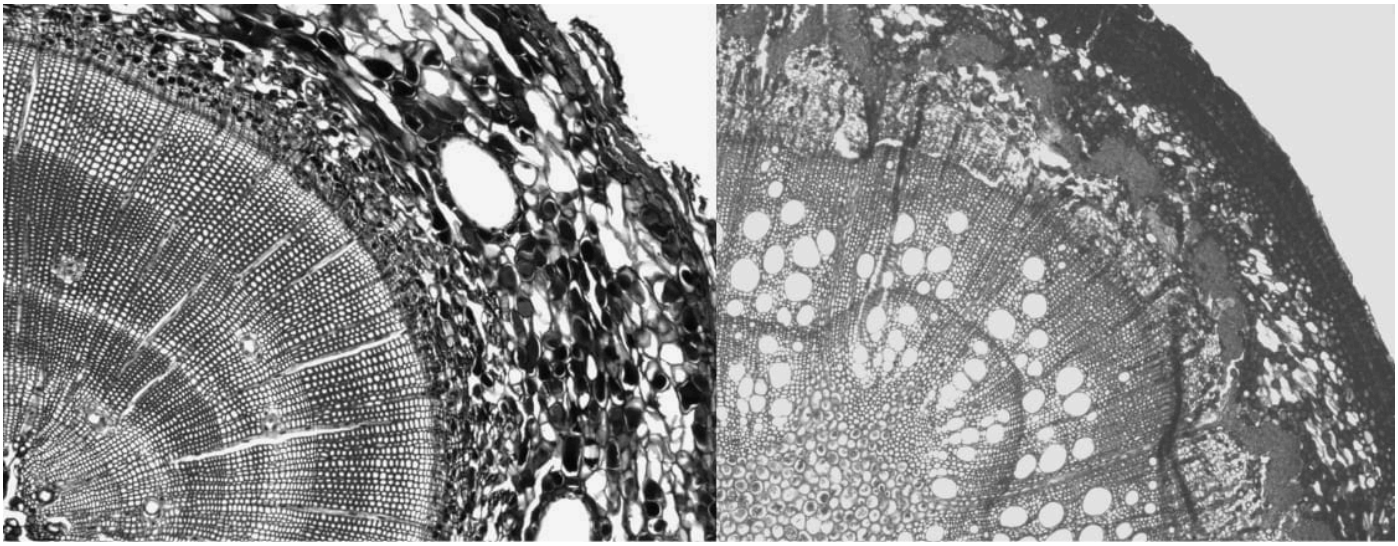


Figure 11.5.3: Tilia stem cross section

> On the left is a pine stem, on the right is an oak. In the pine stem, the cells are a more similar diameter because they are all tracheids. On the right, The largest diameter cells are vessel elements. How old are each of these stems?

Resin canals

In answer to the previous question about the roots, those giant holes in the pine stem (as in the roots) are resin canals. These canals transport a sticky substance called resin. Much like the latex produced in some flowering plants, resin acts as a defense compound and a wound sealant.

> Resin canals are also present in some groups of angiosperms, particularly tropical trees. Why might these structures occur more commonly in tropical plants?

The cork cambium is formed directly from the cortex. Layers of periderm are continually formed and shed until the cortex runs out. At this point, secondary phloem de-differentiates and forms the new layers of cork cambium.

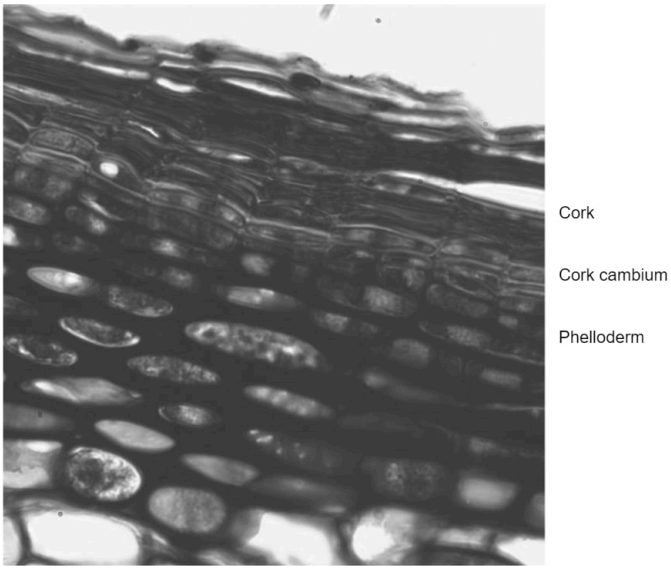


Figure 11.5.4: Periderm

Because the periderm is suberized and dead, it cannot have living guard cells to regulate pores and control gas exchange with the environment. Because the cells on the inside are still alive and respiring, gas exchange is still necessary. This is accomplished through tears in the periderm called **lenticels** (shown below).

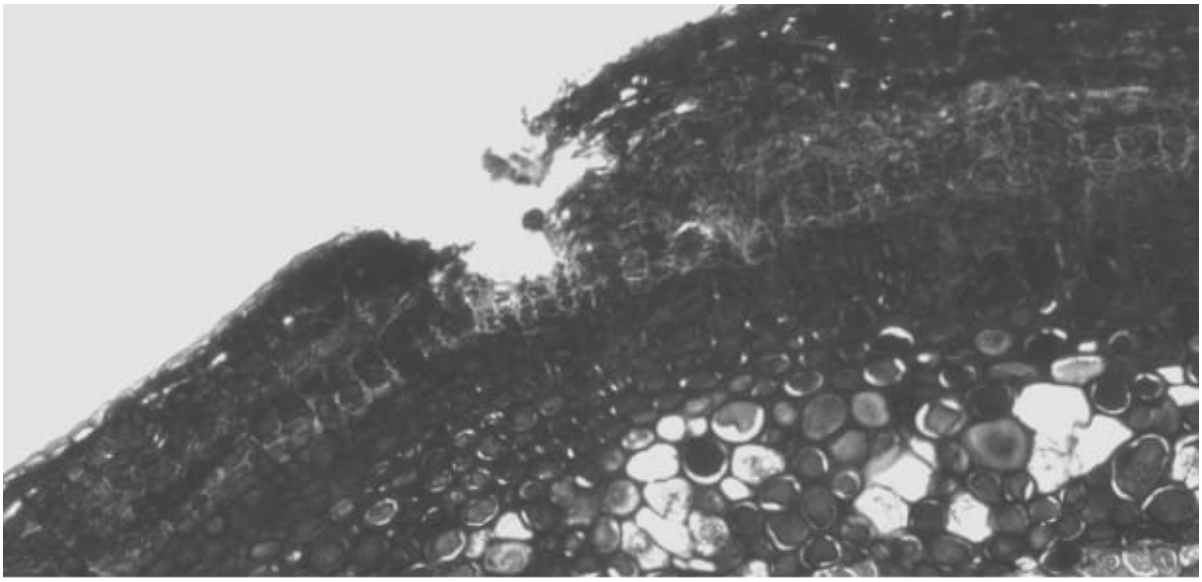


Figure 11.5.5: Lenticel

In a mature woody stem, the layers of periderm are referred to as the **outer bark** and the secondary phloem is the **inner bark**. The secondary xylem is called **wood**. Secondary xylem that is still actively involved in conducting water is called **sapwood**, while inactive xylem is called **heartwood**. The cross section below is too young to have these last two features.

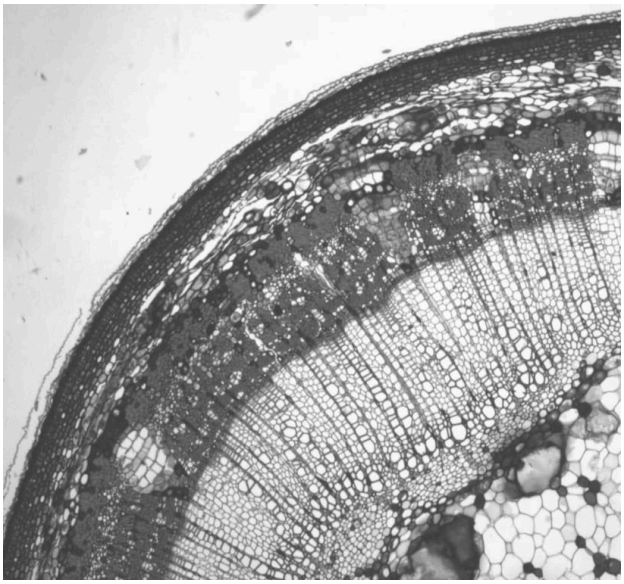


Figure 11.5.6: Cross section of a woody stem

In the stem cross section above, label the following: **pith, secondary xylem, xylem ray, vascular cambium, secondary phloem, phloem ray, cortex, phelloderm, cork cambium, cork,** and **epidermis**. Next, indicate where the oldest and youngest xylem cells are located.

Note: the newest cells will be located closest to the meristem that produced them!

Where is the vascular cambium?

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11.6: Dendrochronology

Dendrochronology is a process used to determine the order and timing (chronology) of events using information in tree rings (dendro- refers to trees). These rings form in response to environmental conditions, storing information on climate and historic occurrence of fires in an area. Essentially, you bore a hole into a living tree and extract a thin section column of the wood. This becomes your reference specimen, as you date each annual ring, tracing back from the present date. Your reference specimen can then be used to determine the timing of events in dead trees, potentially tracing back thousands of years.

Imagine that the sample below is from your reference specimen. The example core shows features you might see in a tree core and how to interpret them.

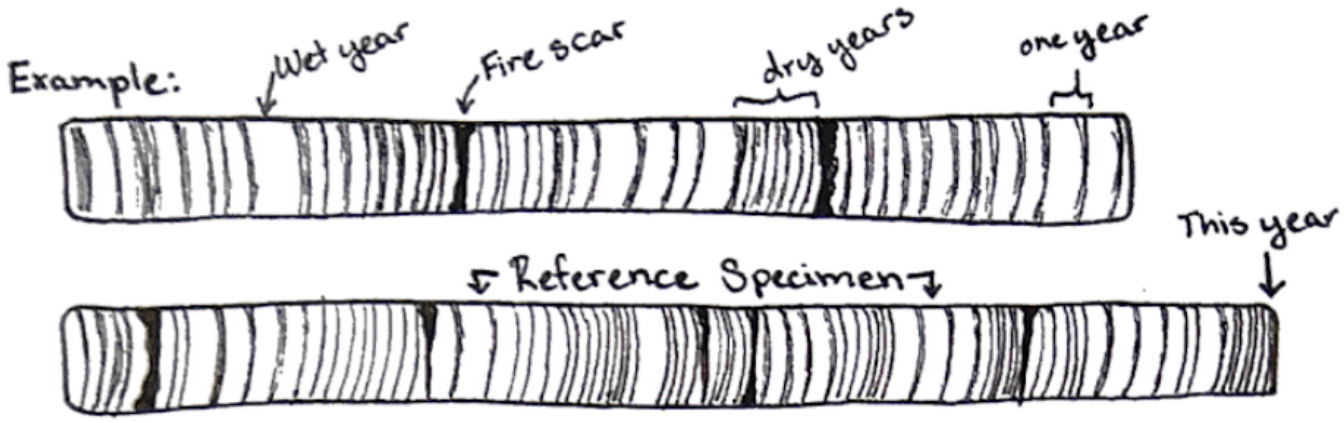


Figure 11.6.1: Tree core example and reference specimen

How old is this tree? At which dates did rainy years occur? Which periods represent droughts? When did fires occur? Make notes on the annual rings with the date and notable events.

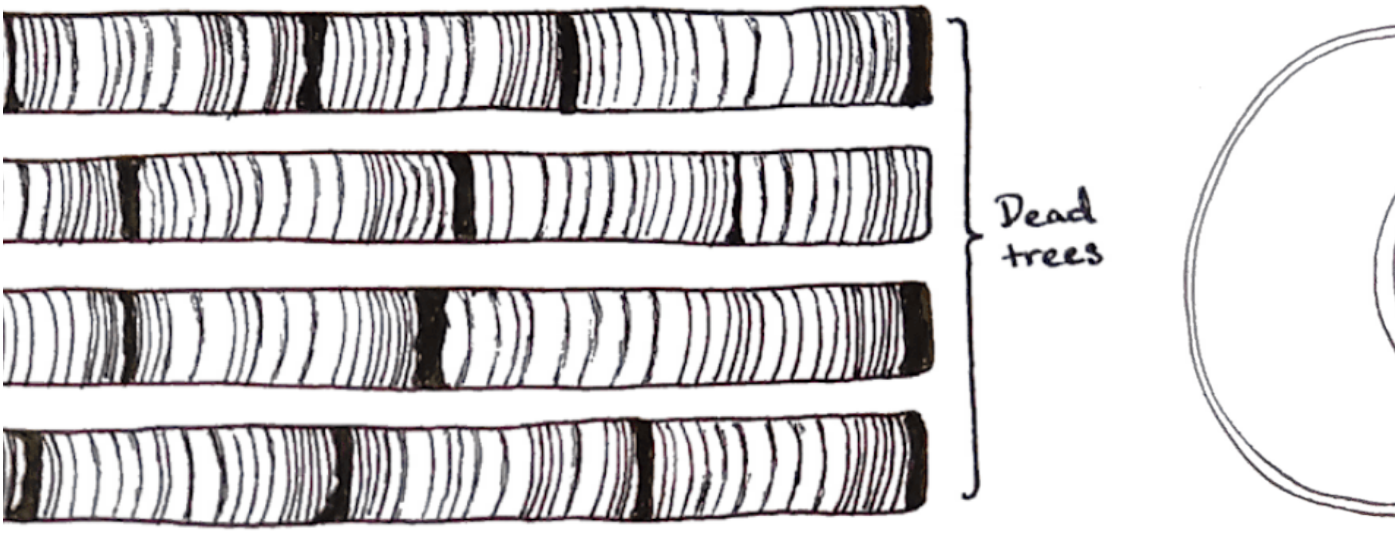


Figure 11.6.2: Dead tree cores

Using your reference specimen, date the events in the following dead trees of unknown age from the same forest. It will be easiest to do this by cutting out each core and aligning it next to the reference. There is no text on the bottom of this page on the opposite side, so cut away!

Based on the dendrochronology you just performed, what did you determine about the history of this forest and climate in this region? Be as specific as possible in your answer.

What is the oldest date that you calculated on the tree core present?

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11.7: Summative Questions

1. How is the production of secondary meristems different in the shoot and the root?
2. What are the tradeoffs (costs and benefits) to secondary growth?
3. What is the function of a lenticel?
4. Would roots in secondary growth need lenticels? Why or why not?
5. What is the function of a xylem ray?
6. How could you distinguish phloem fibers from other phloem cells? What cell type are phloem fibers?
7. What type of questions could you answer with dendrochronology if you didn't have a living reference specimen to connect the cores to the current date?
8. Girdling is a process used to slowly kill a tree and/or to create a standing dead tree (a snag). Both the outer and inner bark of the tree is removed all the way around a section of the trunk. Often, this also removes or damages the vascular cambium.
9. Explain why girdling would kill the tree.

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12: PHOTOSYNTHESIS AND PLANT PIGMENTS

Learning Objectives

Content Objectives

- Understand that colors we see are determined by reflected light and relate this to the absorption spectrum of pigments
- See how photosynthesis converts electromagnetic energy into chemical energy
- Know the stages where products and reactants of photosynthesis are produced or used, respectively
- Relate the process of photosynthesis to the structure of a leaf

Skill Objectives

- Use thin layer chromatography (TLC) to determine which pigments are present in plant tissues
- Determine the Rf values of pigments on a TLC strip
- Determine the relative polarity of a pigment based on the polarity of the TLC solvent
- Identify anatomical structures in leaves involved in photosynthesis and explain their function in this process

12.1: Formative Questions
12.2: Introduction
12.3: Part 1 - Pigments
12.4: Pigments and Evolutionary Adaptations
12.5: Part 2 - Photosynthesis
12.6: C4 and CAM Photosynthesis
12.7: Summative Questions

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- Thumbnail: Diagram of a chloroplast

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12.1: Formative Questions

1. What is the role of photosynthesis in the global cycling of nutrients?
2. Would it be better to wear a white shirt or a black shirt on a particularly hot day? Why is this?

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12.2: Introduction

To understand photosynthesis, we must first understand a bit about light. Light is a form of **electromagnetic energy**, meaning it travels as a wave and does not require a medium to move through. Light, unlike sound, can travel to us from the sun through the vacuum of space. Once it gets to Earth, there are particles for it to either reflect off of, be absorbed by, or pass through. Depending on the length of the light wave--think about stretching or compressing a slinky--and whether it is reflected or not, our eyes will either interpret it as different colors, or we will not be able to see it at all. In fact, our eyes only pick up a tiny fraction of the light spectrum.

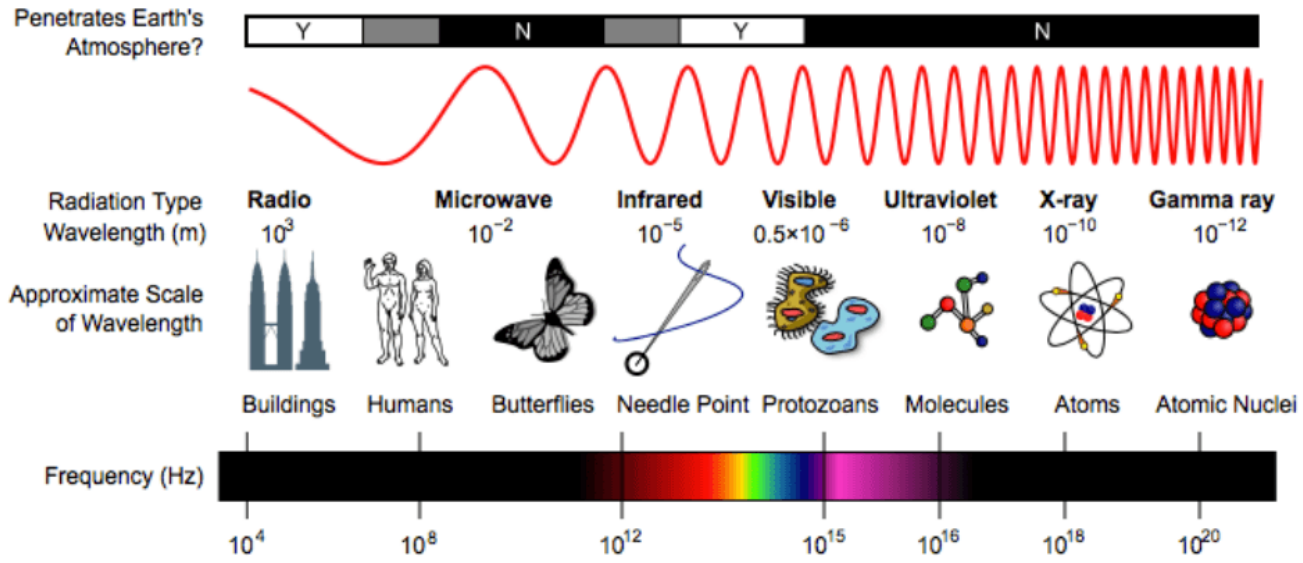


Figure 12.2.1: The Electromagnetic Spectrum, Inductive load by NASA via Wikimedia Commons [CC BY-SA 3.0]

When we look at objects, we may see them as being a certain color. This is because that object reflects that particular wavelength of light back at us. Objects that are white reflect the entire spectrum back at us. Objects that are truly black absorb all of the light, reflecting nothing back. Objects that are a particular color, such as green, absorb all of the other wavelengths of visible light except green, reflecting that green out to our eyes. **Pigments** are molecules that reflect specific colors.

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12.3: Part 1 - Pigments

The molecule **chlorophyll a** has a specific shape. This shape causes wavelengths of light that we see as a dark bluish green to be reflected back. Change the shape of that molecule by adding only two atoms, making it **chlorophyll b**, and the light that is reflected back is now less blue and more yellow.

What does this have to do with photosynthesis? Organisms that perform photosynthesis do so by absorbing light and converting it into usable energy. This absorbed light is not reflected back. This means that the color of the pigment(s) that the organism has will determine the wavelengths of light that the organism can use. For example, plants have two types of chlorophyll molecules, chlorophyll a & b. Each of these reflects green light, meaning that green light cannot be used for photosynthesis. To help capture a bit more of the spectrum, plants have accessory pigments called carotenoids that reflect yellow, orange, and red light, absorbing a portion of the green part of the spectrum.

Chlorophylls tend to mask most other pigments in plants, so to see these other pigments, we need to separate them. You will use a process called **thin layer chromatography** to extract pigments from leaves, then dissolve them in a solvent.

Thin Layer Chromatography (TLC)

> **Note**
>
> Below is a list of suggested materials. Spinach is suggested for the leaves, as it is easy to acquire and rich in pigment. However, consider comparing the pigments in different types of leaves for a more interesting experiment.

Materials needed:

- Mortar and pestle
- Sand or similar material
- Soft leaves (e.g. spinach)
- Extraction solvent: 3 parts propanone to 2 parts ethoxyethane (diethyl ether)
- Capillary tubes
- Test tubes and corks
- TLC paper strips (cut to size of test tube--about 1 cm less in length)
- Chromatography solvent: 5 parts cyclohexane, 3 parts propanone, and 2 parts ethoxyethane
- Pencil
- Forceps

Procedure for Thin Layer Chromatography

1. **Extracting the pigments**.
   a. Prepare your TLC strip by drawing a line across the paper in pencil 2 cm from the bottom of the strip and set aside. **Important note**: Handle the strip as little as possible so oils from your hands do not interfere with the process.
   b. Under a hood or in a well-ventilated room, put some of the leaves into the mortar with a little bit of sand (to help break the tissue apart) and some extraction solvent.
   c. Grind the leaves with the pestle until they have turned to mush. You may need to add more extraction solvent as it soaks into the leaf tissue.
2. **Thin layer chromatography**.
   a. Pull the mush to one side of the mortar. Place the end of a fine capillary tube into the liquid, then transfer the liquid in the tube to a point in the center of your line.
   b. Repeat this process, drawing more liquid from the mortar, until you have a small, concentrated dot of pigment. For best results, keep the dot as concentrated in one place as possible.
   c. Under a hood, add 1 cm of chromatography solvent to your test tube and place this in a test tube rack (label your tube if multiple people are using the same rack).

   d. Add your strip to the tube with the line you drew in pencil sitting about 1 cm above the level of the solvent, then cork the tube.
3. **Calculating Rf values and determining polarity**.
   a. Check on your TLC strip regularly and have a pencil with you. When the solvent has traveled up the TLC strip about 1 cm from the top of the strip, remove the strip from the test tube and draw a line in pencil at the edge of the solvent front.
   b. Allow the strip to dry, then measure the distance from the original line you drew (where the pigment started) to the solvent front.
   c. Next, measure the distance from where the pigment started to the farthest point that each pigment traveled.
   d. Calculate the Rf value of each pigment: divide the distance the pigment traveled by the distance the solvent traveled.

Both the chromatography solvent and the extraction solent you used are **nonpolar** compounds, meaning they lack residual charges. Nonpolar compounds dissolve well in nonpolar solutions, while polar compounds do not. Pigments that are more nonpolar will dissolve better in this solvent, traveling farther up the strip. More **polar** pigments that have residual charges (like water) will not interact much with the solvent, staying closer to the bottom of the strip. High Rf values from TLC using a nonpolar solvent means the pigment is more nonpolar. Lower Rf values mean the pigment is more polar.

Draw or tape your TLC strip and label as many pigments as you can (see the next page for more information on pigments). Record the Rf values of each pigment next to its label.

Which pigment is more polar, chlorophyll a or chlorophyll b? How can you tell?

How many pigments were present in your leaf sample?

Which pigments were the most nonpolar (least polar, highest Rf values)?

If there were polar pigments in the leaves and you used a nonpolar solvent to extract the pigments from the leaf, would they dissolve and be present in the solution you used to run your TLC experiment? How might this impact your results?

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12.4: Pigments and Evolutionary Adaptations

Cyanobacteria were potentially the first organisms to do oxygenic photosynthesis -- the variety of photosynthesis that produces oxygen as a waste product. To do this, cyanobacteria use the pigment chlorophyll a. This is the only pigment directly involved in photosynthesis, but other pigments called accessory pigments can absorb wavelengths of light, then transfer this energy to chlorophyll a. Cyanobacteria have accessory pigments called **phycobilins** that allow them to absorb more of the blue and red portions of the spectrum of light. The pigment **phycocyanin**, a blue phycobilin, resulted in the cyanobacteria's more common name: blue-green algae.

> Which part of the spectrum of light do you think phycocyanin absorbs?

The red algae were the first lineage of organisms to have true chloroplasts, derived from the endosymbiosis of a cyanobacterium, and so they have the same pigments: chlorophyll a and phycobilins. In particular, the red algae derive most of their coloring from a red phycobilin called **phycoerythrin**. This pigment reflects red, meaning it absorbs the blue portion of the spectrum.

Red algae are almost entirely marine and have been found deep in the water column. The record for algal depth was set by a coralline red alga found 268 m (about 880 feet) below the surface. Why is this so impressive? As light travels through water molecules, much of it is reflected back or refracted off course. High-energy blue light is more likely to penetrate deeper into the water column, so it is essential that the algae are able to capture it. Because both chlorophyll a and phycocyanin would reflect much of this blue light instead of absorbing it, red algae make use of phycoerythrin to capture it, making them appear red.

Green algae are more likely to live in shallow marine waters, freshwater, or even terrestrially. This group of organisms has lost the phycobilins present in its red algal ancestors and has adapted chlorophyll b and carotenoids, instead. **Carotenoids** can help mitigate damage caused by solar radiation, as well as absorb some of the green parts of the spectrum. These pigments are reds, oranges, and yellows..

As you saw in your TLC strip, chlorophyll b appears more yellow while chlorophyll a appears more blue. What portion of the spectrum is chlorophyll b absorbing that chlorophyll a is not?

> What color were the carotenoids on your TLC strip?
>
> Where might you see carotenoids in your daily life?
>
> Brown algae have chlorophyll a and chlorophyll c, as well as the carotenoid **fucoxanthin**, which gives them their golden brown color. Compare the available specimens of cyanobacteria, red algae, green algae, and brown algae. What do the colors of these organisms tell you about where they live?
>
> Which pigment do all of these organisms have?

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12.5: Part 2 - Photosynthesis

Photosynthesis is a process used to harness the energy from sunlight to ultimately bond carbon atoms from carbon dioxide into molecules of glucose. This occurs in two major phases--the light dependent phase and the light independent phase--and requires chlorophyll a. Both phases take place inside of the chloroplasts of eukaryotic photosynthesizers or across folded membranes within prokaryotes. For simplicity's sake, we will focus on the eukaryotes and describe these processes in relation to chloroplast anatomy (sorry, bacteria, back seat again).

Anatomy of a Chloroplast

Chloroplasts are surrounded by at least two membranes. The two membranes were derived from the original cyanobacterium that was engulfed but not digested (Keeling, 2004). Inside of the inner membrane, the chloroplast has a jelly-like matrix, much like the cytosol of the cell, called the **stroma**. The stroma surrounds a series of folded membrane-bound structures, **thylakoids**, that resemble pancakes and are stacked (again, much like pancakes) into columns called **grana** (granum, singular). The thylakoids appear dark green, as the **thylakoid membrane** is full of chlorophyll molecules. Enclosed inside each thylakoid is a region called the **thylakoid space**.

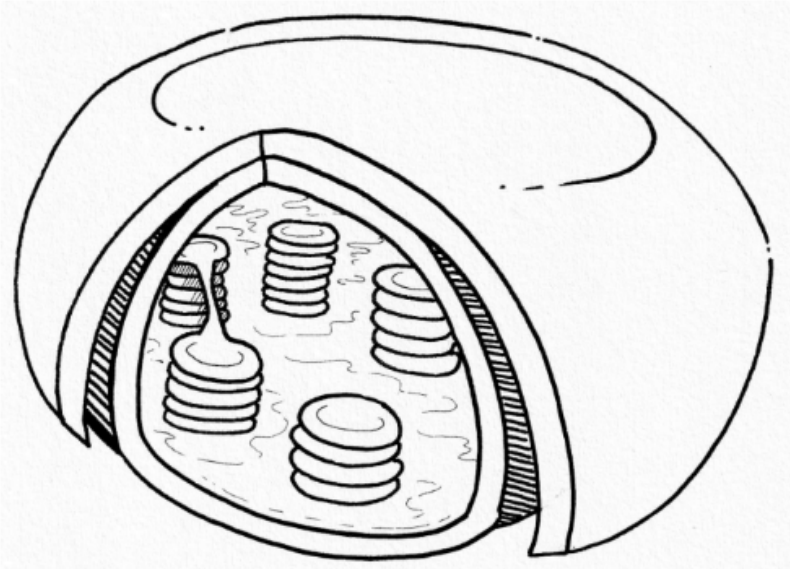


Figure 12.5.1: Diagram of a chloroplast

Label the bolded structures in the diagram of the chloroplast. Indicate the origin of each membrane of the chloroplast.

Light-dependent Phase: The electron Transport Chain

This phase is called the light-dependent phase because to begin this process, a particle of light, called a **photon**, of the correct wavelength must be absorbed by a molecule of chlorophyll a, embedded in a complex called photosystem II (**PSII**).

The energy from the photon causes an electron to be knocked off of the chlorophyll molecule and this electron is shuttled to an adjacent protein complex. More on this in a second.

The chlorophyll molecule needs to replace the electron it lost so that it is ready to respond to the next photon. A water molecule is split at the base of PSII, releasing two electrons and producing oxygen and 2 protons (H^+) into the thylakoid space. Make note of each time H+ is added to the thylakoid space, as this creates a buildup of positive charges, which repel each other.

Back to that first electron. The protein complex it is shuttled to is a proton pump. When the electron enters the protein complex, it effectively switches on the proton pump, causing H^+ to be pumped from the stroma and into the thylakoid space.

The electron then jumps to another proton pump, causing another H+ to be pumped from the stroma into the thylakoid space.

This electron has depleted much of its energy, so it must enter another photosystem (**PSI**) to be reenergized by another photon.

The re-energized electron is then transported to an enzyme called **NADP+ reductase**, which reduces (adds electrons to) a molecule of NADP+ to create high-energy **NADPH**. This requires two electrons, but this process involves a continuous flow of electrons, so another one arrives shortly after the first.

This is the end of the **electron transport chain**. However, there is another component to this phase. Inside the thylakoid membrane, H^+ are building up, creating a storage of energy across the thylakoid membrane as they repel against each other. Even though they are tiny (a single proton), they cannot pass freely through the membrane due to the positive charge.

Instead, an enzyme called ATP synthase allows the H^+ passage to the other side. The flow of H^+ through the enzyme causes it to spin, much like a turbine, converting the stored energy into kinetic energy (movement).

ATP synthase converts this kinetic energy into chemical energy by using it to add phosphate groups onto molecules of ADP. This creates unstable, high energy **ATP** molecules that can be used to power other cellular processes.

Apply it: Work with your labmates to design a model that illustrates the light-dependent phase of photosynthesis. Consider the materials available in lab (including, potentially, other students), as well as whether your model will have moving parts. What is the best way to communicate this process?

> Below is an example of a model of the electron transport chain in photosynthesis. Can you talk your way through what is happening? Try explaining this process to a partner.

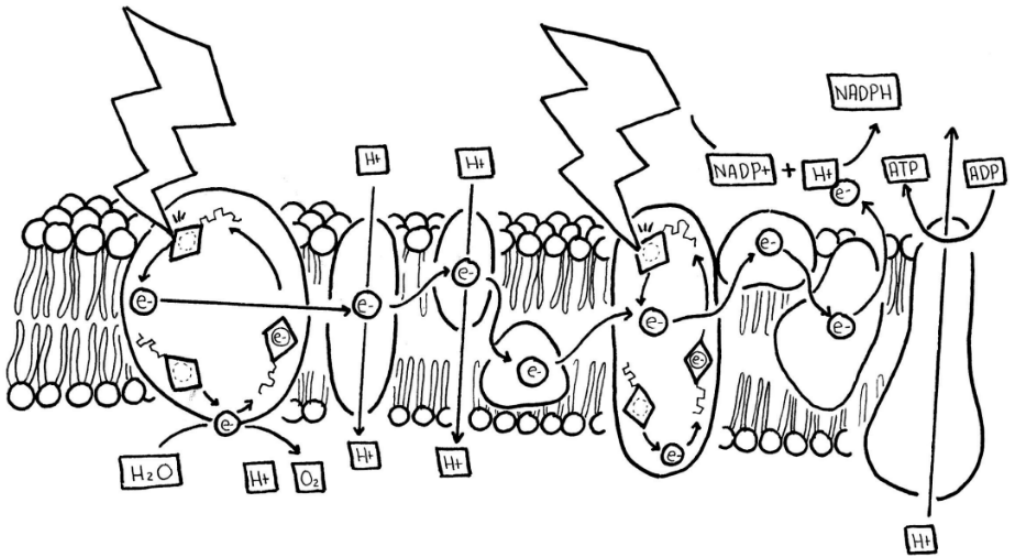


Figure 12.5.1: Diagram of photosynthesis Electron transport chain

Light-independent Phase: The Calvin Cycle

The light-independent phase takes place in the stroma of the chloroplast. During this phase, called the **Calvin Cycle**, the chemical energy stored in the NADPH and ATP produced during the light-dependent phase is used to build molecules of glucose. This happens in three major stages.

1. **Carbon Fixation**: Carbon dioxide (CO_2) enters the plant through the stoma, diffuses into the cells, then into the chloroplast. An enzyme called **RuBisCO** (a much easier way to say Ribulose-1, 5-bisphosphate carboxylase/oxygenase) bonds CO_2 to a 5-carbon molecule called RuBP. This breaks into two 3-carbon molecules of 3-PGA.
2. **Reduction**: NADPH donate electrons and ATP donates a phosphate group to convert each 3-PGA into G3P, two of which are required to make glucose. For every six G3P made, only one goes on to make glucose, the rest must be recycled.
3. **Regeneration**: To keep the cycle going, RuBP must be regenerated. Using energy and phosphate donated by more ATP, five

G3P are recycled to make three more RuBP.

This process can happen during day or night, but it requires a steady input of ATP, NADPH and CO_2.

The reactants above are required to complete this process. What are the products of the light independent phase?

For each of the products and reactants in the chemical reaction for photosynthesis written below, identify where it was either produced or consumed.

Table 12.5.1: Summary Table for Photosynthesis

Phase	Where does it take place?	Reactants	Products
Light dependent			
Light independent			

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12.6: C4 and CAM Photosynthesis

The enzyme RuBisCO needs a high CO_2 environment to function efficiently. If the ratio of oxygen to CO_2 gets too high, RuBisCO will bind oxygen instead and waste energy in the process. This is called **photorespiration** and accounts for a large amount of yield loss for crops in hot areas. Why does photorespiration happen?

If it is too hot or dry, plants often close their stomata to prevent water loss. This prevents CO_2 from entering the leaf, as well as prevents O_2 from exiting. Oxygen builds up inside the leaf and photorespiration happens instead of the Calvin cycle. Though this wastes energy for the plant, preventing water loss is often a larger priority. However, some plants have evolved special ways of performing photosynthesis that prevent or limit photorespiration.

C4 Photosynthesis is for Plants Adapted to Hot Environments

In most photosynthesis, the first product of the Calvin cycle is a 3 carbon compound, so this type of photosynthesis is called C3. For plants adapted to particularly hot environments, the first compound formed has 4 carbon atoms, hence **C4 photosynthesis**. In these plants, RuBisCO is restricted to the bundle sheath cells of the leaf. Carbon dioxide is converted into an acid and transported into the bundle sheath cells where it will be converted back into CO_2. This keeps the concentration high where RuBisCO is active, preventing photorespiration.

CAM Photosynthesis is for Plants Adapted to Dry Environments

CAM plants are often found in desert environments. It is too hot and/or dry to keep stomata open during the day, so they only open them at night. However, there is no light at night to do photosynthesis. To solve this, CAM plants have evolved to take in CO_2 at night and store it in the central vacuole in the form of an acid. This is where CAM gets its name: Crassulacean Acid Metabolism. During the day, the acid is converted back into CO_2, and the Calvin cycle can take place alongside the electron transport chain.

In both of these types of photosynthesis, compounds must be formed, transported, and broken back apart again. Each of these tasks costs energy to perform, but it outweighs the energy lost by photorespiration.

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12.7: Summative Questions

1. What is the energy input for photosynthesis (i.e. what powers the electron transport chain)?
2. At what stage in photosynthesis is water used? What is the function it serves in this process and what is it converted into?
3. At what stage in photosynthesis is CO_2 used? What is the function it serves in this process and what is it converted into?
4. *Zea mays* is a C4 plant. In the cross section of a *Z. mays* leaf below, identify where RuBisCO is and where the Calvin cycle is occuring.

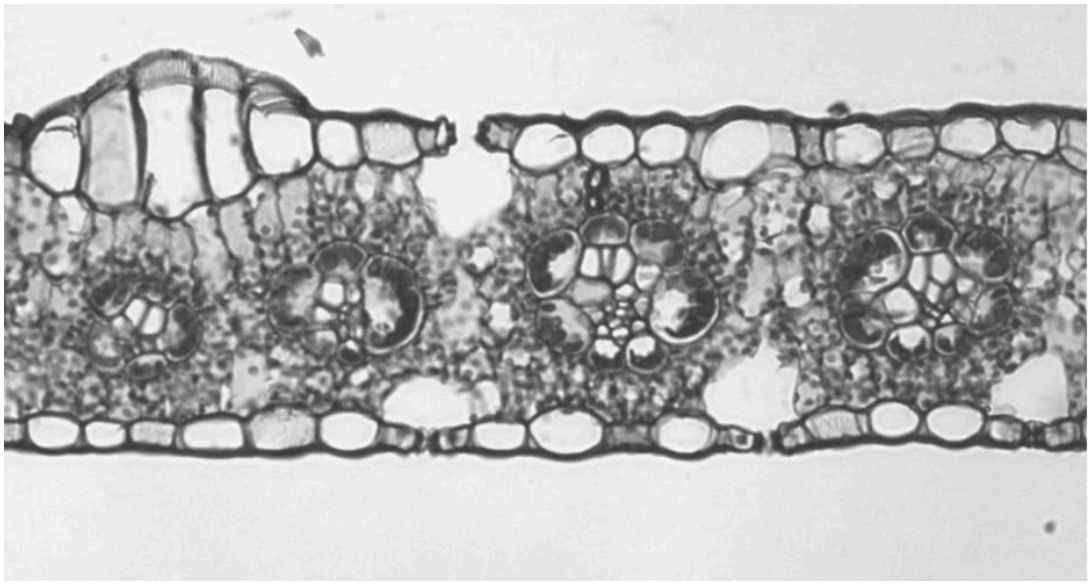


Figure 12.7.1: Zea mays leaf cross section

5. What other features does this leaf have that indicate it might be adapted to an environment where water was limiting?

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13: CELLULAR RESPIRATION AND FERMENTATION

Learning Objectives

Content Objectives

- Understand how the process of cellular respiration converts glucose into usable energy, carbon dioxide, and water.
- Explain why some organisms do fermentation instead of cellular respiration, even though this produces less usable energy

Skill Objectives

- Identify stages in cellular respiration where ATP is used and where it is produced
- Calculate net ATP produced from a single glucose molecule
- Make predictions about the rate of fermentation under different conditions

13.1: Formative Questions

13.2: Introduction

13.3: Cellular Respiration

13.4: Concept Mapping - Connecting Ideas Visually

13.5: Summative Questions

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13.1: Formative Questions

1. If a plant is in the light for 24 hours, what will happen to its mass: will it increase, decrease, or stay the same? Consider the processes occurring within the plant. Explain your answer.

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13.2: Introduction

Part 1: Carbohydrates in Food

When you eat food, you are acquiring nutrients that you need to maintain homeostasis--to keep your internal conditions regulated to the specific parameters required for your survival and function. From these foods, you might get vitamins that your body cannot synthesize itself, amino acids needed to build proteins, and, in anything that is **food** in the scientific sense, carbohydrates that you can break down to use as energy.

Carbohydrates can be simple sugars--monosaccharides like glucose--to complex starches, often made of long chains of those same monosaccharides bonded together to form a much larger molecule called a polysaccharide. Some of these polysaccharides have bonds that our bodies have enzymes to break down, such as Amylose. Amylose is a starch composed of glucose **monomers** attached together by a glycosidic bond, forming a relatively straight line. In your mouth, you produce an enzyme called amylase that breaks the glycosidic bond, eventually turning the long chain of amylose into many molecules of glucose. Amylase functions best at pH 6.7-7.0 [connect to maintenance of homeostasis]. Other polysaccharides are bonded together in ways that we do not have enzymes for, like cellulose, the primary component of plant cell walls. This is why plants contain “dietary fiber,” which passes right through your system and “keeps you regular.”

Part 2: Converting Carbohydrates into Usable Energy

A molecule of glucose stores about 3,000 kJ of **chemical energy**. Chemical energy is the potential energy stored in the bonds that hold atoms within a molecule together. Everytime you break one of these bonds, that energy is released. Molecules of glucose are relatively stable, so this energy is safely stored inside the molecule. Because of this, we can transport glucose, dissolved in our blood, to areas in our body where it is needed or to our liver, where it can be stored for later in the form of glycogen. Plants can do the same through phloem cells, transporting glucose to areas of the plant where it can be stored long term as starch, such as the roots.

Because the glucose molecule is stable, the energy is trapped inside it. To access this energy, the glucose molecule must be broken apart. You can make this happen by applying large amounts of energy, such as heat from a fire--this is what happens when you burn wood or paper. These materials are plant-based, composed primarily of plant cell walls containing large amounts of cellulose. As we saw above, this cellulose is composed of long chains of glucose molecules. The wood itself doesn’t spontaneously catch fire, but when you apply enough energy, such as by igniting a small portion of it with a lighter or a match, you can cause some of those molecules to break apart. This releases energy in the form of light and heat, which can then provide the energy to break more molecules apart. This process is called combustion.

What was required to make this reaction happen? Carbohydrates, oxygen, and an initial energy input. A similar process happens inside most eukaryotic organisms. However, to avoid catching on fire, we break down the glucose molecule piece by piece, releasing small amounts of energy at a time, and using that energy to build molecules of something called **ATP** (adenosine triphosphate).

Unlike glucose, ATP is an unstable molecule. It has three negatively charged phosphate groups, all attached end-to-end. The negative charges on these phosphate groups repel each other, much like the two negative sides of different magnets. As the number of negative charges increases, the repulsion increases exponentially. Because of this, the third phosphate group holds a large amount of energy in its bond to the second. This phosphate group can be “donated” to a reaction (called phosphorylation), breaking the bond and releasing the stored chemical energy to power the reaction. The ATP loses its third phosphate group and becomes ADP (adenosine diphosphate), a relatively low-energy molecule. Our cells use ATP to power most of the work done in our bodies.

Key Point

While heterotrophic organisms like animals and fungi must consume other organisms to obtain carbohydrates, plants and other autotrophs synthesize their own carbohydrates. However, just like heterotrophs, **autotrophic organisms still need to do cellular respiration to access the energy stored in those carbohydrates.**

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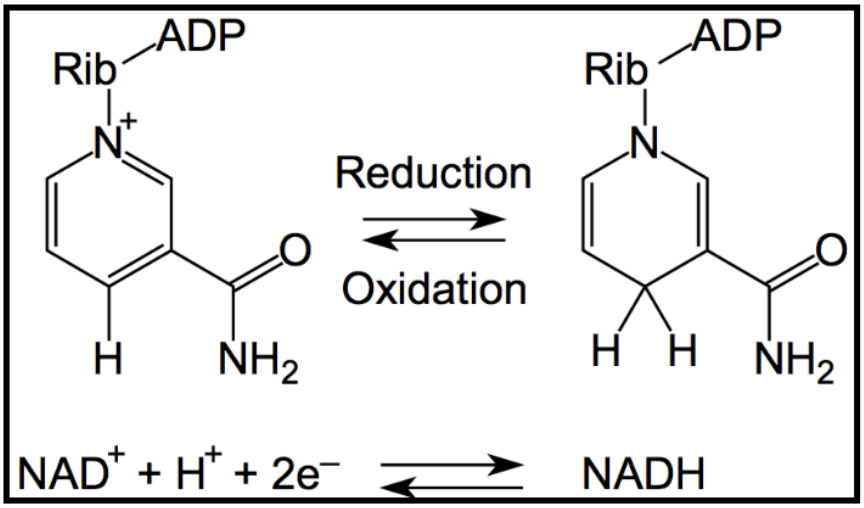
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13.3: Cellular Respiration

Step 1: Glycolysis

When glucose is transported into the cytoplasm of cells, it is broken down into two molecules of **pyruvate**. This process is called **glycolysis** (glyco- for glucose and -lysis, meaning to break apart). Glycolysis involves the coordinated action of many different enzymes. As these enzymes start to break the glucose molecule apart, an initial input of energy is required. This initial energy is donated by molecules of ATP.

Though two molecules of ATP are used to get glycolysis going, four more molecules of ATP are produced during the reaction, resulting in the net production of two ATP per molecule of glucose. In addition to ATP, two molecules of NAD+ are reduced to form NADH. When a molecule is reduced, electrons have been added to it. Electrons have a negative charge, so this is termed "reduction". When NAD+ is reduced to NADH, two high energy electrons derived from breaking the bonds of glucose are added to it. One of those negatively charged electrons is balanced by the positive charge (+) on NAD+. The other is balanced by adding a proton (H^+) to the molecule. Because NADH carries two high energy electrons, it is often referred to as an **electron carrier**.



NAD+ can carry electrons (be reduced) by adding H+ ions

Figure 13.3.1: NAD+ to NADH reaction

Table 13.3.1: Summary Table of Reactants and Products of Glycolysis

Reactants (What went in?)	Products (What came out?)
1 Glucose	
2 NAD+	
2 ADP (net)	

Alternate Pathways: Fermentation

At this point, cells make a check: Is there oxygen present or not? If not, some organisms can go through a process called **fermentation**. In fermentation, glycolysis is the only part of glucose breakdown that a cell can do. Thus, only two net ATP can be gained from each glucose molecule. To continue doing fermentation, the cell must regenerate the NAD+ needed to do glycolysis.

There are two primary pathways to regenerate NAD+. In your body, cells can regenerate NAD+ by producing lactate and H^+. This is called **lactic acid fermentation**, though lactic acid is never actually produced, so it is a bit of a misnomer. Some bacteria, like *Lactobacillus*, are also capable of doing this type of fermentation.

Making Yogurt With Lactic Acid Fermentation

Put some milk into a flask and add a spoonful of yogurt. Mix thoroughly, cover, and place in a warm environment. Over the next 24 hours, the sugars in the milk will be fermented into lactate and H+ ions. This thickens the milk and adds acidity, making yogurt.

> Why did you add the spoonful of yogurt to start it? What did this add to the milk that would allow fermentation to occur?
>
> Why did you need to put it into a warm environment?
>
> Do you think the type of milk you use affects the time it takes to get yogurt? Explain your answer.

Another pathway to regenerate NAD+ is to produce CO_2 and ethanol (alcohol). Certain yeasts, like Saccharomyces cerevisea, perform this type of **alcohol fermentation** when they do not have access to oxygen.

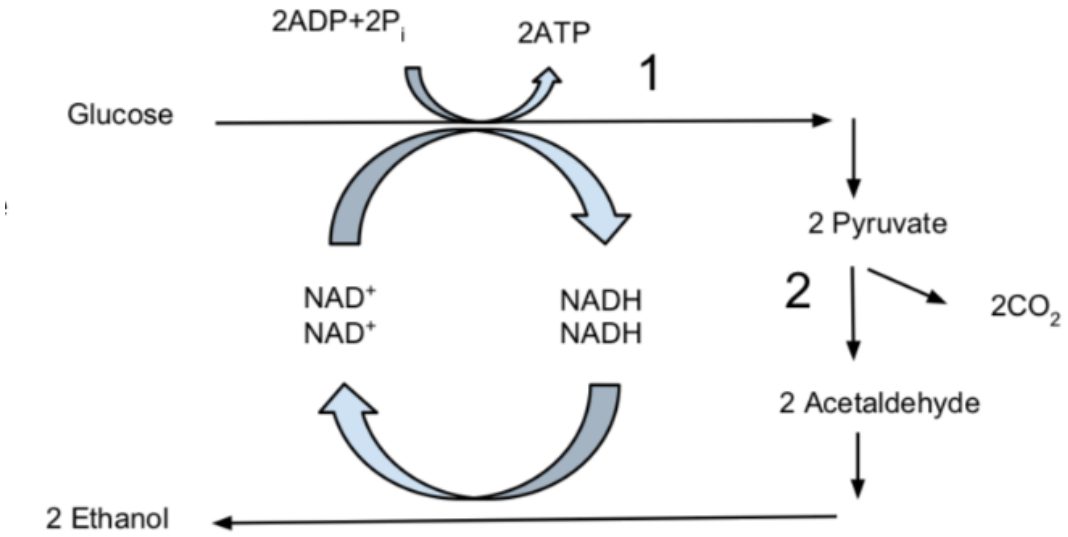


Figure 13.3.2: Alcohol fermentation, David Carmack [CC BY-SA 3.0]

Experimental Design: Rates of Alcoholic Fermentation

For this experiment, you will be attempting to answer the following question:

> "What factors influence the rate of fermentation by yeast?"

You will have the choice between one of two **independent variables**. The independent variable is the variable you are asking questions about. It should be the only thing that you establish as different between your treatment groups:

1. Type of juice used
2. Temperature of fermentation chamber

> Why would it be important to only have one independent variable?

For the **dependent variable**, you will measure the circumference of a balloon that has been placed over your fermentation flask. The dependent variable is the one that you measure to determine the influence of the independent variable on your different treatments.

> Why would the circumference of the balloon be a good indicator for the rate of fermentation? What will the balloon be collecting?

Choose an independent variable and make a prediction on how it will influence the dependent variable. This is called your **hypothesis**.

To measure the effects of the independent variable on the rate of fermentation, you'll need to establish **treatment groups** and controls. Your treatment groups should have some modification to the independent variable (such as different temperatures or different types of juice). Choose three different variations of your independent variable and record them below:

T1:

T2:

T3:

Controls are established to account for any additional variables within the experiment, as well as to give you information on whether your experiment actually worked. A **positive control** should always work (give expected results). In this experiment, fermentation should definitely occur in the positive control for this experiment. If fermentation does not occur in the positive control, you know something about your experiment is off and you could be getting false negatives. Think of a positive control you could use for your experiment and record it below:

Positive control (C+):

A **negative control** is just the opposite. In a negative control, you want to see no change from initial conditions. If there is a change in the dependent variable in the negative control, this gives you a baseline of variability that you can expect in the absence of changes to the independent variable. For example, in this experiment, a negative control should have no fermentation occurring and thus, no inflation of the balloon. However, gases can expand in higher temperatures, so a negative control placed in a warmer environment would have expansion of the balloon. This gives us some baseline data for how temperature will affect the gases in the balloon without the influence of fermentation. Think of a negative control you could use for your experiment and record it below (you may need more than one):

Negative control(s) (C-):

Now that you have designed the experiment, it is time to run it and collect data on the dependent variable. Enter your results into the table below:

Table 13.3.2: Change in Balloon Circumference During Fermentation

Treatment Group	Initial Circumference (cm)	Final Circumference (cm)	Change in Circumference (cm)

Table 13.3.3: Change in Balloon Circumference for Controls During Fermentation

Control	Initial Circumference (cm)	Final Circumference (cm)	Change in Circumference (cm)
C+			
C-			

Once you have collected your data, you need to interpret it and draw conclusions about your hypothesis.

Does the data support your hypothesis or not? Explain your answer.

Were there any variables that could have influenced your experiment that you did not control for? If so, how could you adjust this experiment to account for these on a future trial?

Consult as a class about your findings. Did everyone perform the experiment the same? Did they get the same results?

Compare the results of the class for the two different independent variables. Which had a stronger influence on rate of fermentation: the type of juice or the temperature? Attempt an explanation for these findings.

Connecting back to cellular respiration, how much ATP is produced from one molecule of glucose if a cell only goes through glycolysis?

Why do organisms ferment instead of going through the process of cellular respiration?

We used the balloon to collect gases produced during fermentation. However, the balloon was necessary for another reason (hint: it relates to the previous question). Why else did we cover the flask with the balloon?

Step 2: The Link Reaction

If oxygen is present, cellular respiration can continue (more on this in the next section). The two molecules of pyruvate are transported into the **matrix** of the mitochondrion. During transport, each pyruvate is converted into a 2-carbon molecule called acetyl-CoA. The other carbon atom from each pyruvate molecule exits the cell as $\mathrm{CO_2}$. The electrons from this broken bond are captured by another molecule of NAD+, reducing it to NADH.

Step 3: The Citric Acid (Krebs) Cycle

The acetyl-CoA enters a cycle which, much like glycolysis, involves the action of many different enzymes to release energy and transport it in energy-carrying molecules: ATP, NADH, and another electron carrier, $\mathrm{FADH_2}$. This cycle takes place within the matrix of the mitochondrion.

In the space below, draw a mitochondrion in a cell. Show where **glycolysis**, the **link reaction**, and **citric acid cycle** happen. It may help you to include the compounds involved in each stage, such as glucose, NAD+, $\mathrm{CO_2}$, and others.

Step 4: Oxidative Phosphorylation

This stage of cellular respiration has two steps. During the **electron transport chain**, our electron carriers power a series of proton pumps that move $\mathrm{H^+}$ ions from the mitochondrial matrix to the space between the inner and outer mitochondrial membranes. During **chemiosmosis**, an enzyme called ATP synthase allows the protons to flow back into the mitochondrial matrix, using the physical flow of the protons to turn ADP into ATP.

The Electron Transport Chain

NADH and $\mathrm{FADH_2}$ drop off their electrons at a protein complex within the **inner mitochondrial membrane.** This effectively "turns on" this protein complex, which pumps a $\mathrm{H^+}$ from the mitochondrial matrix to the **intermembrane space**. The electrons are then passed down a line of protein complexes, much like a current of electricity, powering these complexes to each pump a $\mathrm{H^+}$ from the matrix into the intermembrane space. This is appropriately named the electron transport chain.

At the end of the electron transport chain, the low energy electrons need to be picked up to make space for more electrons. An oxygen atom picks up two electrons and, to balance the charge, two $\mathrm{H^+}$ from the matrix, forming a water molecule ($\mathrm{H_2O}$). In cellular respiration, oxygen is the **terminal electron acceptor**, because it picks up the electrons at the end (the terminus) of the electron transport chain. This job is so important that, as you saw above, if oxygen is not present, this part of cellular respiration will not occur.

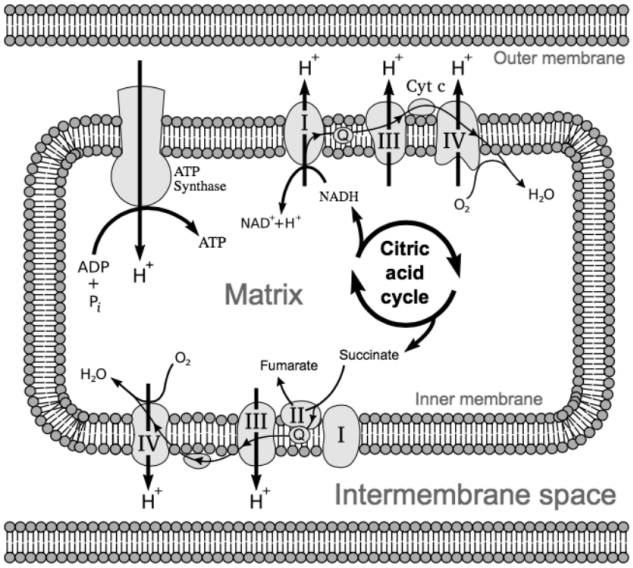


Figure 13.3.3: Mitochondrion and Electron Transport

The diagram above shows the interaction between the citric acid cycle and the electron transport chain inside the mitochondrion. There are two functioning electron transport chains and a single ATP synthase that uses the H^+ gradient established by those H^+ pumps to make ATP.

Chemiosmosis

Why are the protein complexes pumping H^+ into the intermembrane space? The intermembrane space is relatively small. As more H^+ are added to this area, the intermembrane space becomes increasingly positively charged, while the matrix becomes increasingly negatively charged. This is similar to how a battery stores energy--by creating an electrochemical gradient. The positive charges repel each other and would “prefer” to be balanced across both sides of the membrane. However, they cannot directly pass through the membrane. Even though they are small, H^+ ions carry a full charge, making them too polar to pass through the nonpolar tails of the phospholipid bilayer that composes the mitochondrial membranes.

An enzyme called **ATP synthase** allows the H^+ to move back into the matrix. This enzyme is structured much like a waterwheel or turbine -- the flow of protons through the enzyme physically rotates it, converting the potential energy stored in the electrochemical gradient into kinetic energy (movement)! This kinetic energy is used to force another phosphate group onto ADP, converting the kinetic energy back into chemical energy, which is stored in the bonds of ATP

Experiment: Understanding the Relationship Between Cellular Respiration and Photosynthesis

1. Put 50 mL of tap water into a flask (Flask A) and add a pH indicator, such as phenol red. Record the initial color of the solution in the table below.
2. Get out a stopwatch and have a partner ready to time you. When they say go, use a straw to blow into the water + indicator. As soon as it changes color, your partner should stop the stopwatch and you should stop blowing through the straw. Record the time below.
3. Repeat step 1 to set up another flask (Flask B).
4. This time, before you blow into the straw, do 30 seconds of intense exercise, such as running around outside, jumping jacks, burpees, or something else fun. As soon as you are done, have your partner time you as you blow through the straw into the new flask. Stop as soon as the color changes and record the time below.
5. Put a sprig of Elodea (or other aquatic plant) into Flask B, cork both flasks so no gases can get in or out, and set them both under a light source.
6. Observe these flasks over the course of the lab and make note of any color changes.

Table 13.3.4: pH Changes Measured by Indicator Color

	Initial Color	Time to Change	Changes Under Light Source?
Flask A			
Flask B			

Why did the color of the indicator change when you blew into the liquid? What caused the change?

Did the pH of the solution go up or down?

Was there any difference in timing of color change between your two trials? If so, what might explain this difference?

Explain what you observed after you added the plant to Flask B.

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13.4: Concept Mapping - Connecting Ideas Visually

Either individually or as a group, create a concept map on a separate piece of paper or whiteboard that relates the processes of photosynthesis and cellular respiration. The words in the word bank below should go into bubbles. Arrange these bubbles in a way that helps communicate relationships between the words, then connect the bubbles with lines that have a verb or action phrase attached to them. It might help to start by organizing the words into related groups. You can use words more than once.

> For example, you could group CO_2 and **ATP** together, then draw a line connecting them to **RuBisCO** and **Calvin Cycle**. The verb for the connecting line could be “used in”. You could then draw a line from those two that said “produces”. What would that line connect to?
>
> **Word Bank:** Put these terms in bubbles
>
> O_2
>
> H_2O
>
> CO_2
>
> H^+
>
> ATP
>
> Glucose
>
> Photon
>
> Electrons
>
> Chloroplast
>
> Stroma
>
> Thylakoid membrane
>
> Mitochondrion
>
> Matrix
>
> Inner mitochondrial membrane
>
> Cytoplasm
>
> High energy electron carriers
>
> NADH
>
> NADPH
>
> $FADH_2$
>
> Glycolysis
>
> Krebs cycle
>
> Electron transport chain
>
> Chemiosmosis

RuBisCO

Calvin cycle

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13.5: Summative Questions

1. Why do plants need to use cellular respiration if they can do photosynthesis?
2. If a plant is in the **dark** for 24 hours, what will happen to its mass: will it increase, decrease, or stay the same? Explain your answer.
3. Explain how the action of your respiratory system relates to the process of cellular respiration.
4. Which stage of cellular respiration produces the most energy?
5. How much energy is produced during fermentation? Why do some organisms undergo fermentation instead of respiration?
6. What factors influenced fermentation the most in your class experiment? Develop a hypothesis for why this might be.
7. Both glucose and ATP store chemical energy. Why can't glucose be used to directly power cells instead of ATP?
8. All experiments should have controls, if possible. Explain what a positive control and a negative control can tell you about your experiment.

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14: MEIOSIS, FERTILIZATION, AND LIFE CYCLES

Learning Objectives

Content Objectives

- Learn the process of meiosis and how it leads to genetic diversity
- Understand the difference between gametes and spores
- See the three different life cycles of multicellular organisms
- Learn the terms sporophyte and gametophyte and the processes occurring within and between these life stages

Skill Objectives

- Identify stages of meiosis and differentiate them from mitosis
- Distinguish between different life cycles based on the ploidy of the multicellular stage(s)
- Identify key stages and features within life cycles and know their general functions

14.1: Formative Questions

14.2: Introduction

14.3: The Production of Genetic Diversity

14.4: Fertilization

14.5: Life Cycles

14.6: Life Cycle Diagram Fold Out

14.7: Summative Questions

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- Thumbnail: Lillium anthers

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14.1: Formative Questions

1. What do you consider to be the stages of a human life cycle?
2. At which point does your life as a human start? When does it end? What makes it a cycle?

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14.2: Introduction

If the only type of cell division eukaryotes underwent was mitosis, the only source of genetic variation we would have would be through mutations. Mutations still provide the foundation for differences, but another type of cell division allows organisms to mix and match their own DNA. In **meiosis**, the sets of chromosomes that an organism inherited from each parent interact and recombine to form novel combinations. The haploid cells or organisms produced through this process can then fuse with another haploid cell or organism that has gone through the same process of recombination.

The result is that these **sexually reproducing** populations are composed of genetically distinct individuals. As environmental conditions change, genetically diverse populations have more options within the gene pool to adapt to those conditions. This increases the overall likelihood of survival of that species. As always, there are trade-offs to each type of reproduction.

Asexually reproducing organisms can mass-clone themselves and often reproduce quickly, investing very little in the survival of individual clones and instead relying on the probability that some might survive. Often, these organisms are found in high-resource environments (like mold on a sugary fruit) or colonizing a new area because they do not need a partner to reproduce.

Sexually reproducing organisms generally require a compatible partner to reproduce with, though some species can “self”, combining their own products of meiosis with each other. This process still results in an increase in diversity, as the offspring can still differ from the parent due to the novel recombinations that occur during meiosis. Finding a partner might be a passive process, such as release into the ocean, or a more active one, such as courtship rituals performed by birds of paradise.

Organisms that undergo sexual reproduction have a defined life cycle that describes the events from fertilization to meiosis and back again. The type of life cycle an organism has can offer insight into its evolutionary history, as well as its ecology. In this lab, you will learn the process of meiosis and the three generalized life cycles of multicellular eukaryotes.

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14.3: The Production of Genetic Diversity

Mitosis is a type of cell division in which the original cell makes a duplicate copy. If this were the only form of cell division, the production of genetic diversity would be limited to mutations. Most lineages of organisms might not be able to adapt to the rapidly changing conditions of Earth's many environments. This is not to say that asexually reproducing organisms cannot be successful. The most proliferate, widespread organisms on the planet, the Bacteria, are asexual and cannot undergo meiosis because they lack a nucleus. Most multicellular eukaryotic organisms (and some unicellular eukaryotes) have evolved to use sexual reproduction to create diversity through **meiosis** and **random fertilization**.

Meiosis = PMAT x 2

If a diploid cell undergoes meiosis, the product will be four genetically distinct haploid cells. In humans, this process is used to make eggs and sperm. Meiosis is almost like doing mitosis twice. This description will focus on the differences between the phases of meiosis and mitosis, rather than describing everything that occurs in each stage. For a refresher of the other events, see lab 4 (Multicellularity & Asexual Reproduction).

Meiosis I

- **Prophase I:** During prophase I, **homologous chromosomes** pair together. These chromosomes have the same genes in the same order but are derived from different parents. Due to their similarity, when they pair, they can overlap and trade segments of the chromosomal arms. The result is a mixture of genes from each parent on each chromosome. This process is called **crossing over** and it will happen differently in each cell that undergoes meiosis.
- **Metaphase I**: In metaphase I, homologous chromosomes line up across from each other on the metaphase plate. This is another source of variation, as they may align differently in each cell with a different combination of genes on either side of the metaphase plate. This is called **independent assortment**.
- **Anaphase I**: During anaphase in mitosis, sister chromatids are separated from each other. In meiosis, pairs of homologous chromosomes that are separated.
- **Telophase I**: Telophase I is similar to telophase in mitosis. The only difference is that the two daughter cells that emerge are genetically distinct from each other.

Meiosis II

Meiosis II is nearly identical to mitosis. It consists of **prophase II**, **metaphase II**, **anaphase II**, and **telophase II**. It is in anaphase II that sister chromatids are pulled apart. At the end of telophase II, four haploid cells have been produced, each genetically distinct.

Meiosis in Lilium Pollen

Anthers are one of the sexually reproducing structures in flowers, producing haploid pollen that will fertilize haploid eggs.

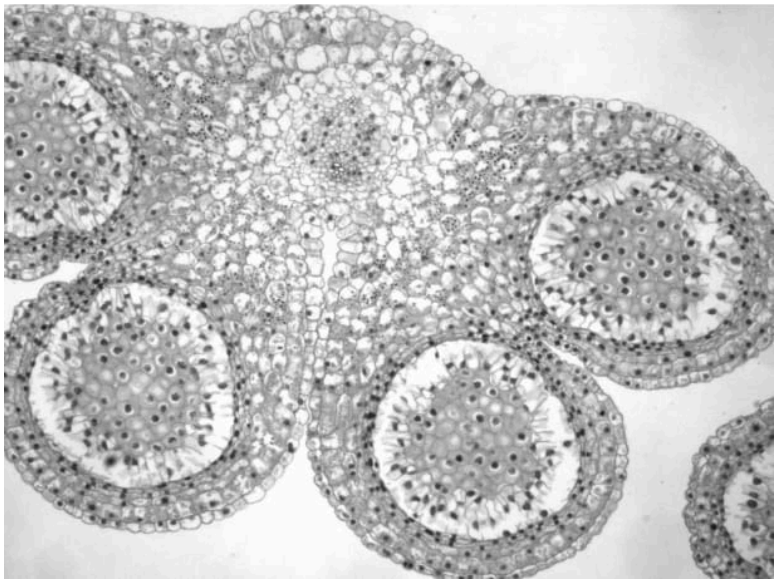


Figure 14.3.1: Lillium anthers

The above image shows a cross section through *Lillium* anthers. There are four circular areas, one of which is circled in the picture. These are the pollen sacs. It is inside these pollen sacs that meiosis occurs, so look within these areas for cells in different stages of meiosis.

Pollen divides synchronously, so most cells should be in approximately the same stage. However, meiosis is a continuous process, so some cells may be in anaphase while most are in metaphase. Additionally, dividing pollen cells remain attached, so you will be able to tell if you are in meiosis I or meiosis II by how many cell walls have formed within the dividing cell. In meiosis I, there should be one cell until cytokinesis occurs during telophase I, producing two joined cells. In meiosis II, there will be two cells stuck together until cytokinesis during telophase II, producing four cells.

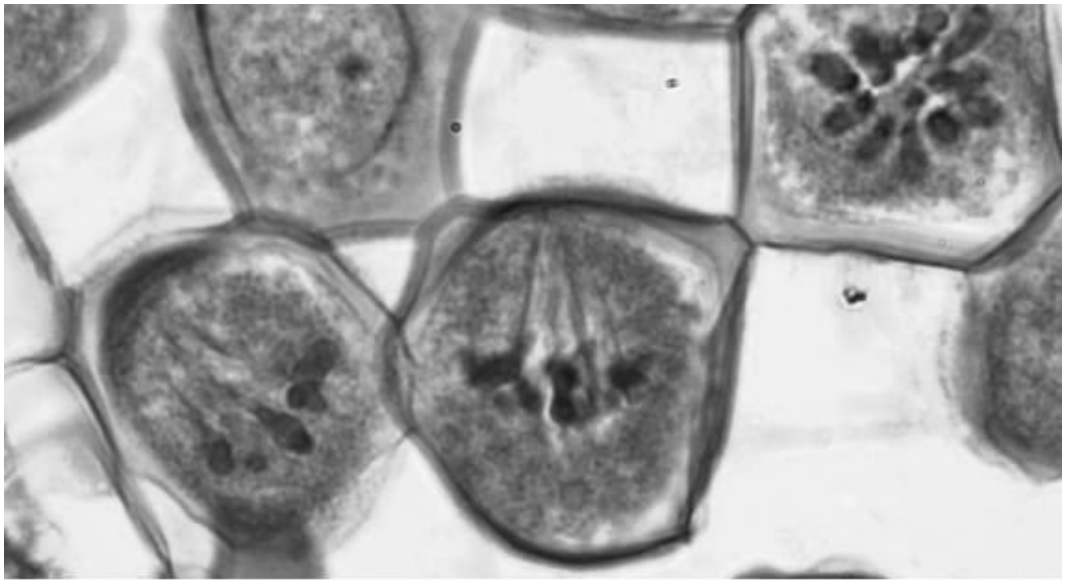


Figure 14.3.2: Cells in meiosis 1

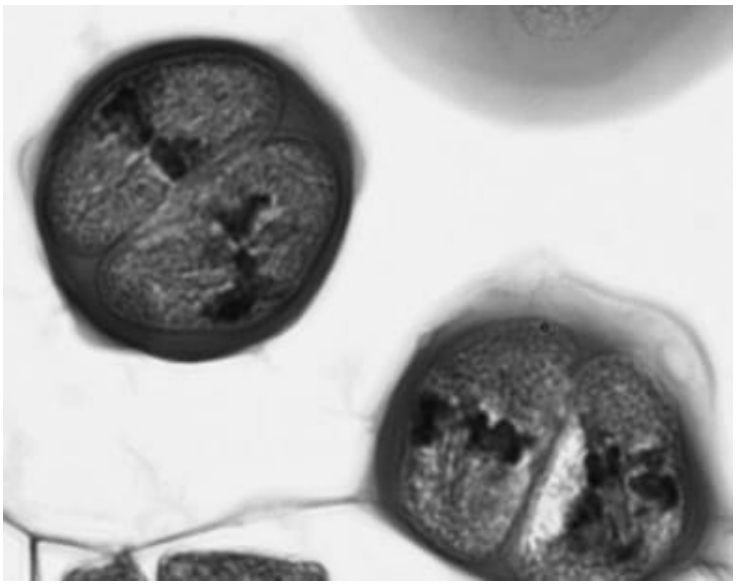


Figure 14.3.2: Cells in meiosis 2

The image on the left shows two cells in metaphase I (left and middle) and one cell in prophase I (upper right corner). The image on the right shows two “cells”, both in metaphase II and showing that each “cell” is now actually two cells stuck together.

Note the wall that travels down the center of each of the cells in the photo on the right. During which phase of meiosis would this wall have been formed?

Observe slides of *Lilium* anthers at different stages of cell division and find each phase of meiosis. Draw and label each phase below. Make sure to note where crossing over and independent assortment are happening.

Meiosis I:

Meiosis II:

At what point did the number of sets of chromosomes in each cell go from 2 sets to 1 set? Said another way, at what point did the ploidy change from diploid to haploid?

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14.4: Fertilization

Haploid cells that must fuse together are called **gametes**. Gametes do not grow by mitosis, they must fuse to another haploid cell to produce a **zygote,** the first diploid cell in an organism. This process is called **fertilization** and it is composed of two distinct stages: plasmogamy and karyogamy. During **plasmogamy**, the cytoplasm of the two gametes combines together (plasm- referring to cytoplasm, -gamy meaning marriage). In most organisms, **karyogamy** is simultaneous with plasmogamy and the nuclei of each gamete fuse together into a single diploid nucleus. When you learn about fungi, you'll see that plasmogamy and karyogamy can be separated by long periods, resulting in a strange condition called being **dikaryotic** (having two nuclei).

Each gamete produced during meiosis is genetically distinct, resulting in a pool of genetic options. During sex, organisms don't choose which gametes are combined, so any combination of genes from the two parents is possible. This is called **random fertilization** and exponentially increases the potential for diversity within a population.

How many different zygotes could you make by combining the following two sets of gametes produced by meiosis?

Parent 1 eggs	Parent 2 sperm
1	1
2	2
3	3
4	4

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14.5: Life Cycles

A **life cycle** describes the events from the start of life to the reproduction of new life. For humans, we each begin as a zygote and grow by mitosis to become a multicellular. At some point, reproductive cells in our bodies undergo meiosis to make either eggs or sperm. If we fuse our eggs or sperm with another human, this forms a new zygote and the cycle continues. We can classify the type of life cycle that multicellular organisms have based on the **ploidy** of the multicellular stage, whether it is haploid or diploid.

Diplontic: The multicellular stage is diploid

Humans have a **diplontic life cycle** because the multicellular stage is diploid. The zygote grows by mitosis into a diploid, multicellular organism. Part of this multicellular organism undergoes meiosis to produce haploid cells called gametes within structures called **gametangia** (gametangium, singular). These gametes fuse to create a diploid zygote. Because gametes are produced by meiosis in this life cycle, each gamete is unique.

This is also sometimes called gametic meiosis because meiosis results in the production of gametes. In the life cycle diagram, the gametes are alone on the haploid portion.

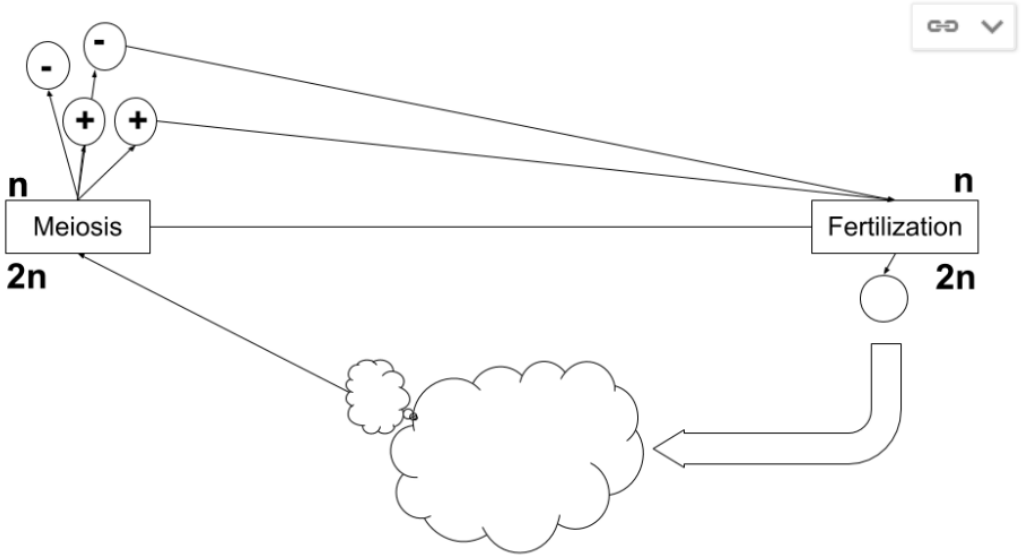


Figure 14.5.1: Generalized diplontic life cycle

Haplontic: The multicellular stage is haploid

For organisms with a **haplontic life cycle**, such as fungi and some of the green algae, the multicellular stage is haploid. In this case, as soon as the diploid zygote is formed, it undergoes meiosis to produce haploid **spores** inside structures called **sporangia** (sporangium, singular). Spores can be distinguished from gametes, not by how they are produced, but based on what they do afterward: spores grow, gametes fuse.

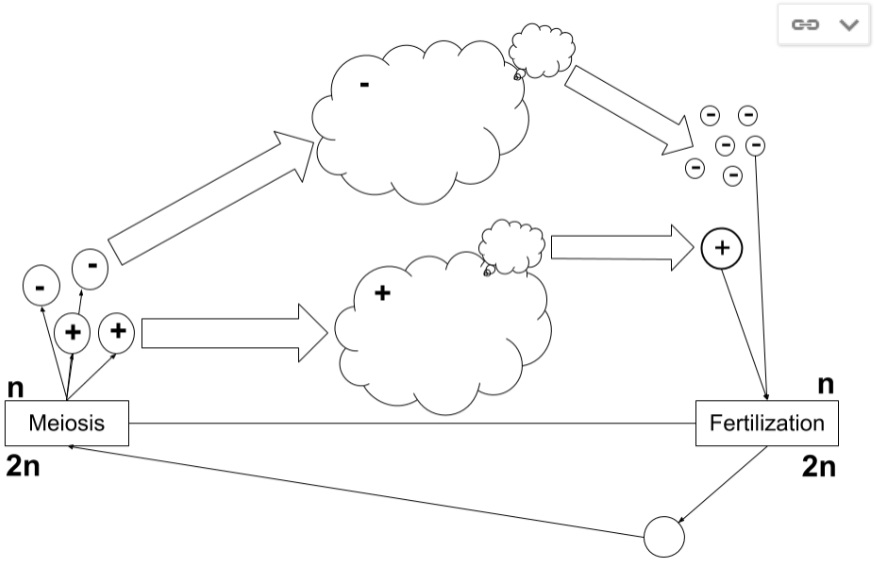


Figure 14.5.2: Generalized Haplontic Life Cycle

These spores then grow by mitosis to produce multicellular haploid organisms. These haploid organisms produce haploid gametes by mitosis. In this life cycle, all of the gametes produced by an organism are identical to each other and to the parent organism. These haploid gametes can then fuse to form a zygote.

This is also called zygotic meiosis because the zygote undergoes meiosis. In the life cycle diagram, the zygote is alone on the diploid portion.

Haplodiplontic: There are two multicellular stages, one haploid and one diploid

For a few marine algae and all plants, the **haplodiplontic life cycle** becomes more complex. To complete one life cycle, there are at least two multicellular individuals. The diploid zygote grows by mitosis to become a multicellular diploid organism, the **sporophyte**. A sporophyte produces haploid spores through meiosis in sporangia. These spores then grow by mitosis into multicellular haploid organisms, the **gametophyte**. A gametophyte produces haploid gametes by mitosis in gametangia. Gametes fuse to produce a diploid zygote.

This complex life cycle is also referred to as **alternation of generations** and, occasionally, sporic meiosis because meiosis produces spores. However, I avoid using this term because meiosis also produces spores in a haplontic life cycle.

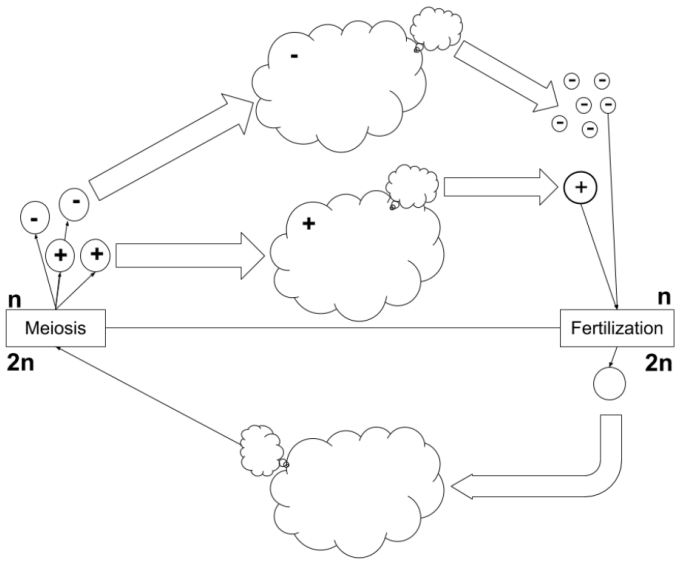


Figure 14.5.3: Generalized Haplodiplontic Life Cycle

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14.6: Life Cycle Diagram Fold Out

To help you remember the different life cycles, you are going to make a fold out. When the page is completely unfolded, you'll see the haplodiplontic life cycle. When you fold down only the top ¼ of the page, you will be looking at the diplontic life cycle. When you fold up only the bottom ¼ of the page, you will be looking at the haplontic life cycle. Make notes on this fold out to help you remember which organisms have these different life cycles and other important aspects highlighted by your instructor.

1. Remove the last page of the lab and position it so the haplodiplontic life cycle is facing you, right side up. You can find a copy of the folding diagram to print here.
2. Fold the paper in half by bringing the top of the page down to line up with the bottom of the page: "hamburger style". Then unfold it again.
3. Now fold it again so that the top of the page lines up with the fold you made in the middle. If done correctly, you should be looking at a diplontic life cycle. If what you are looking at matches this description, write "Diplontic Life Cycle" at the top of the folded page.
4. Unfold the paper again, then fold the bottom half up so that the bottom of the page lines up with the middle fold. If you are looking at the haplontic life cycle, write "Haplontic Life Cycle" on the bottom of the folded paper.
5. Label the important structures and stages in the diagram, including **gamete**, **spore**, and **zygote**.
6. On thick arrows, label that **mitosis** is occuring.
7. Choose a color to represent haploid and another to represent diploid. Make a key and color in the structures in the diagram to match the appropriate ploidy.

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14.7: Summative Questions

1. Label the following diagram of meiosis. Note important events that are happening at each stage and whether the cells are currently haploid or diploid.

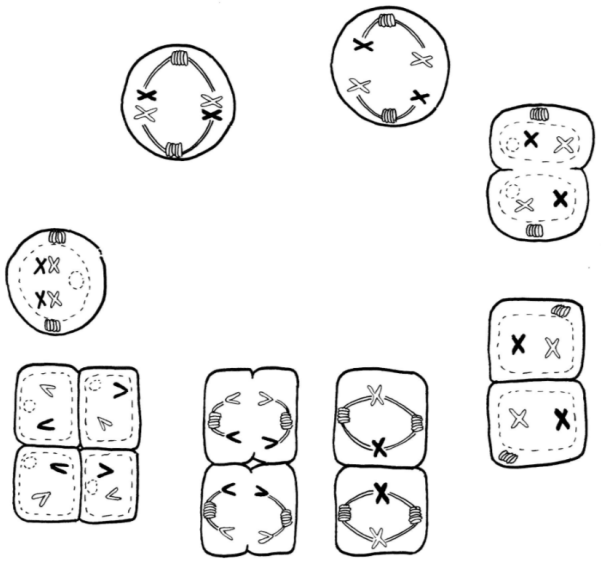


Figure 14.7.1: Meiosis Diagram

2. At which stage(s) in meiosis is genetic variation introduced? Explain how this occurs.
3. Can genetic variation be introduced after meiosis? Explain.
4. What is the difference between plasmogamy and karyogamy? What do the words plasmogamy and karyogamy mean?

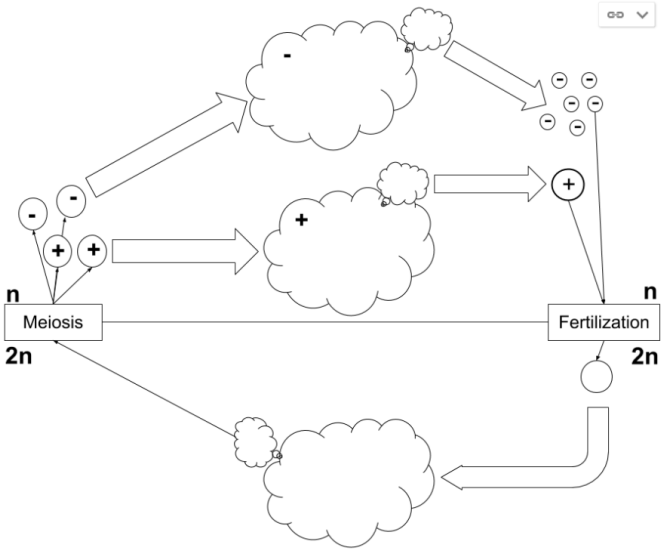


Figure 14.7.2: Haplodiplontic Life Cycle

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15: MICROFUNGI - SLIMES, MOLDS, AND MICROSCOPIC TRUE FUNGI

Learning Objectives

Content Objectives

- Learn the traits used to distinguish between true fungi and fungus-like organisms
- Understand how filamentous morphology relates to feeding by external absorption
- Compare feeding strategies and ecology of different fungal groups

Skill Objectives

- Use life history traits to differentiate between true fungi and fungus-like organisms
- Identify important structures in the haplontic *Rhizopus* life cycle. Know the function and ploidy of these structures.
- Interpret a phylogeny to draw conclusions about the relatedness of organismal groups
- Use stains to view microscopic features more effectively

15.1: Formative Questions
15.2: Introduction
15.3: Fungus-Like Organisms
15.4: Kingdom Fungi - The True Fungi
15.5: General Morphology
15.6: The Fungal Phylogeny
15.7: Summative Questions

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15.1: Formative Questions

> **Note**
>
> This lab is one of a two-part series (Microfungi - Slimes, Molds, and Microscopic True Fungi and Macrofungi and Lichens) that can be modified or combined based on available specimens.

1. What is a fungus? What traits do you associate with being fungal?
2. Which group of organisms do you think fungi are most closely related to? Explain your reasoning.

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15.2: Introduction

There are many groups of unrelated organisms that are referred to as ‘fungus’ or ‘mold’. Formerly, these groups were all believed to have been related, sharing the characteristics of being heterotrophic eukaryotes, generally with cell walls, usually decomposers or parasites, and often with the storage carbohydrate glycogen. These organisms were placed into groups ending with “-mycota”, meaning fungus. On closer inspection, we find that these groups differ on many important life history traits and very few of them actually belong to the true Fungi. However, if you take a mycology course, you will most likely study these unrelated organisms, as well. Similarly, fungi are still studied under the umbrella of botany as a relic of past classification, but they are more closely related to animals than they are to plants.

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15.3: Fungus-Like Organisms

Myxogastria (formerly Myxomycota): Plasmodial Slime Molds

Myxomycetes (members of the Myxogastria) are fungus-like organisms called slime molds, but they are not members of Kingdom Fungi. In their feeding stage, myxomycetes form one large amoeba with many nuclei and no cell wall. This amoeba moves over damp, decaying material looking for bacteria to engulf and digest. When it dries out or runs out of food, it begins to make fruiting structures called **sporangia** (sporangium, singular). Inside these sporangia, the myxomycete will undergo meiosis, wall off individual nuclei and make **haploid spores** for aerial dispersal. Dispersal by spores, heterotrophism, and glycogen as a storage carbohydrate originally classified this group within Kingdom Fungi, but this is the end of the similarities. The spores have **cell walls made of cellulose**, like plants. When these spores land, they will germinate into haploid cells (called swarm cells) that will fuse together to form a diploid amoeba. This means that, unlike true Fungi, they have a diplontic life cycle.

> Observe the slime molds on display. If possible, make a wet mount of a small sample. If there are motile cells (cells that are actively moving around), look for the presence of 2 flagella. This also distinguishes myxomycetes from Kingdom Fungi, where only one flagellum is present. If a mature amoeba is present, can you see **cytoplasmic streaming** occurring?
>
> Draw what you see and make observations below. Label the name, function, and ploidy of any identifying structures.

Other Slime Molds: Dictyostelia and Protostelia

Quite on theme for fungal classification, there are several different groups of unrelated organisms that are called slime molds. The two mentioned above, Dictyostelia and Protostelia, represent cellular slime molds and are relatively closely related to the plasmodial slime molds. Unlike the plasmodial slime molds, these groups exist as individual amoebae until it is time to leave the area. In the Dictyostelia, the amoebae assemble together to form elaborate fruiting structures where only some of the individuals will become spores and the rest will die. They are studied for this altruistic behavior.

Oomycota -- The Water Molds

Oomycetes are also fungus-like organisms with **cell walls made of cellulose**. Similar to myxomycetes, they have motile spores with 2 flagella. However, one of these flagella is "normal"-looking (called a whiplash flagellum) and the other is ornamented. This strange characteristic puts organisms into a group called the heterokonts (meaning "different flagella"). Like us, true Fungi are part of the opisthokonts (opisth- meaning rear, -kont meaning flagellum).

> Also similar to myxomycetes, oomycetes have a **diplontic life cycle**. What does this mean?

If supplies are available, place a dead bug into a petri dish with some pond water. Observe the insect under a dissecting scope, then add a cover to your petri dish. Label “Saprolegnia Culture”, your initials, and the date. Set the covered dish aside to incubate until Lab Heterokonts, where you will be learning about heterokonts in more detail.

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15.4: Kingdom Fungi - The True Fungi

Though many heterotrophic decomposers and parasites are fungus-like, an organism must be in Kingdom Fungi to be considered a true fungus. In addition to genetic relationships, organisms are classified into Kingdom Fungi based on the following traits:

- Eukaryotic
- Heterotrophic by absorption
- Morphology: Unicellular or a thallus composed of **hyphae**. If present, motile cells have only a single, whiplash flagellum (like us).
- Cell walls: **Chitin**
- Storage carbohydrate: **Glycogen**
- Life cycle: Haplontic (though this one gets a bit weird)
- Ecology: Many fungi are decomposers, primarily in terrestrial ecosystems. Other groups of fungi live in symbiosis with other organisms as parasites, mutualists, or commensalists.

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15.5: General Morphology

Unicellular fungi are called **yeasts**. Yeasts reproduce asexually by **budding**, where the cell produces an outgrowth that enlarges and is eventually pinched off, creating an identical copy of the parent cell. The parent cell is left with a small circular scar (called a **bud scar**) that, at the right angle, refracts the light of the microscope and appears to glow a brighter white.

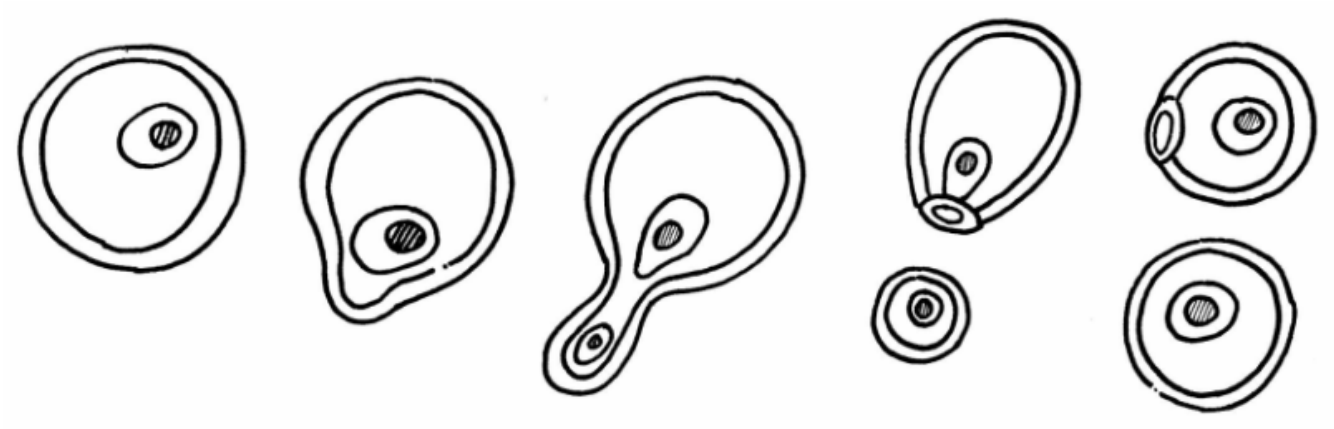


Figure 15.5.1: Yeast budding

Place a small drop of the yeast culture on a slide, dilute it with a drop or two of water, and add a cover slip. Observe your slide under the microscope at 400x (or 1000x, if possible) and look for yeast reproducing asexually. Can you see bud scars?

Draw what you see in the space below and label any important structures.

When fungi produce a larger vegetative body, it is called a **thallus** (a body plan that is not differentiated into tissues). The thallus is composed of microscopic strands called **hyphae** (pronounced high-fay). As a collective, these hyphae are called a **mycelium** (pronounced my-seal-ee-um).

Safety Note

Congo Red is carcinogenic, do not contact with skin. Do not wash slides with Phloxine B in the sink, as this compound is harmful to aquatic life. See your institution's MSDS for safety information on these compounds before use.

Obtain a sample of mycelium, make a wet mount with 5% KOH and stain it with Phloxine B and/or Congo Red. The stains are optional, but usually the fungal mycelium lacks pigment. The stains are picked up by the hyphae and allow them to stand out from the background. Phloxine B stains only the contents of the hyphae, while Congo Red stains the contents and walls. You can combine these two stains together or use separately.

In your prepared slide, can you see divisions of the hyphae into compartments? These dividing walls are called **septa** (septum singular) and are only present in certain groups of fungi.

Draw a strand of the hyphae (also sometimes called a hyphal thread or filament), label the **cell wall**, **septum** (if present), **plasma membrane**, and any other features you see.

Molds

Molds are the asexual form of a fungus. Before the advent of DNA sequencing, we thought molds were fungi that only reproduced asexually and they were placed in their own group, the Fungi Imperfecti (also sometimes called the Deuteromycota). As we are sequencing different mold species, we are discovering that they are identical to sexually reproducing fungi that we have already identified. This is causing a lot of trouble for taxonomy, as now we have one species with two names.



Figure 15.5.2: Mold Conidiophore

Asexually reproducing fungi produce spores called **conidia.** Much like the yeasts, many conidia are formed from budding off of another cell. Make a wet mount of a mold by adding a drop of 5% KOH to your slide, scraping a small amount of mold onto a razor blade or other tool, and gently depositing it onto the droplet. GENTLY lay down a cover slip. You may also consider trying to view molds as a dry mount, as they tend to be extremely hydrophobic.

> Look for **conidia** and **conidiophores**, structures where the conidia are produced. Draw what you find below and label any identifiable structures:

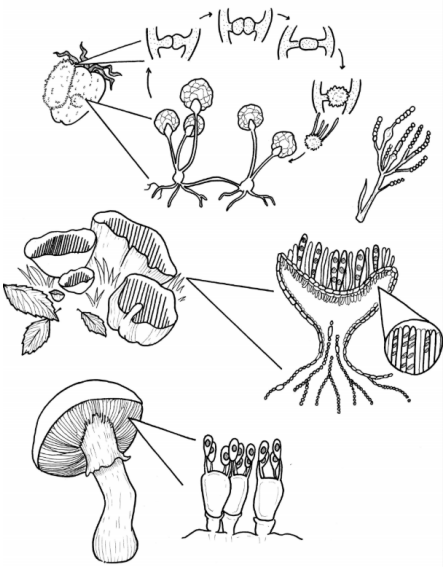


Figure 15.5.3

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15.6: The Fungal Phylogeny

Determining the ancestry and relatedness of groups of fungi is surprisingly difficult. DNA sequencing has led to continual rearrangements of the fungal tree of life and, at the time of writing, there is no one agreed upon picture of the history of fungi that the author is aware of. However, there are a few major groups that Kingdom Fungi is commonly broken into, and these will be discussed in the following section.

The image below is from an open-access publication (doi.org/10.1128/ mBio.01739-16) and presents one possible hypothesis for the relationships between groups of fungi. This hypothesis is called a phylogeny and is based on genetics, as well as physiological and morphological features. No single phylogeny is currently accepted by all mycologists.

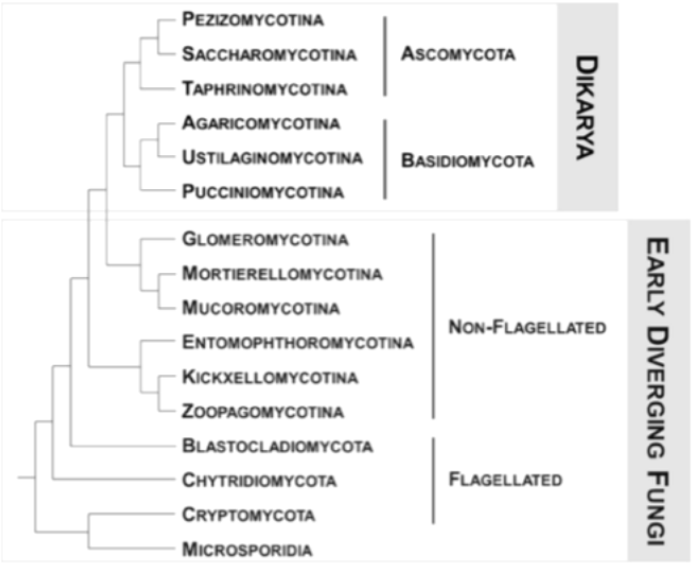


Figure 15.6.1: Fungal Phylogeny

Chytrids: includes Chytridiomycota and Blastocladiomycota from the above phylogeny

Chytrids comprise the oldest lineages of fungi. Unlike any other group within this kingdom, they are **aquatic** and have **swimming spores** (zoospores) with a single flagellum. Though many in this group are harmless decomposers, the most famous of the chytrids is *Batrachochytrium dendrobatidis*, a fungus that infects the skin of amphibians. This chytrid is contributing to a worldwide decline in many amphibian species (though there are numerous other contributing factors), particularly frogs.

If available view specimens of chytrids under the dissecting and compound microscopes. What features can you find?

Zygomycetes: includes all of the non-flagellated, early diverging fungi above, except Glomeromycotina

The zygomycetes are composed of at least two distinct lineages of fungi that all share a common structure during sexual reproduction, the **zygosporangium**. This is a large, ornamented, orange-to-brown structure where both fertilization and meiosis occur. Zygomycetes have no septations in their hyphae, which is referred to as being **coenocytic**. These fungi are commonly found on high-sugar substrates, such as rotting fruits or molding bread, or as insect parasites. Zygomycetes can reproduce asexually by producing **mitosporangia** (shown below), making haploid spores by mitosis.

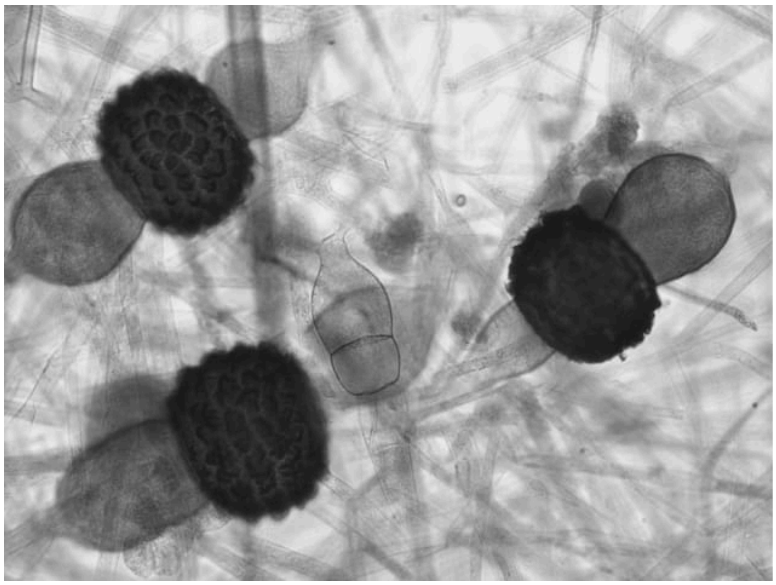


Figure 15.6.2: Zygosporangia

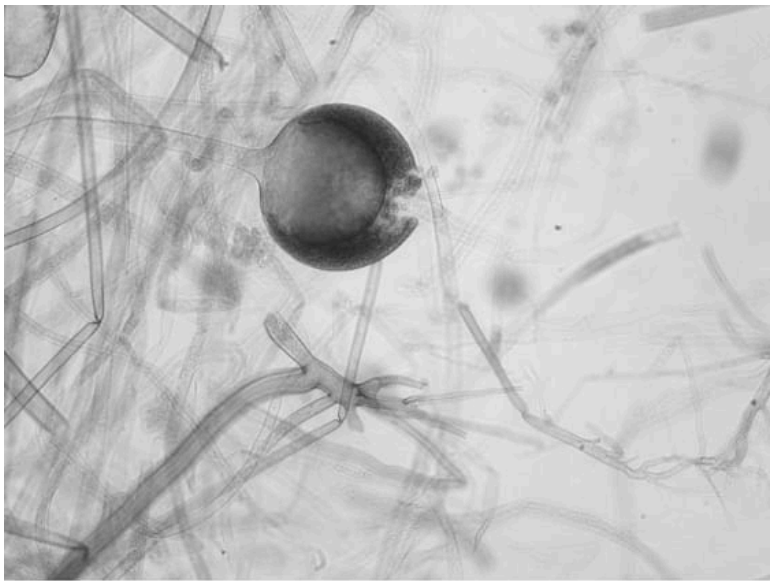


Figure 15.6.3: Mitosporangium

Above are three mature zygosporangia produced during sexual reproduction of *Rhizopus stolonifer*. In the center of the image, two compatible mycelia (+ and -) have connected together and are currently forming gametangia. They will flood these gametangia with haploid nuclei, which will fuse within the zygosporangium to create diploid zygotes. Each of these will immediately undergo meiosis to produce haploid spores.

> View specimens of zygomycetes available in lab and record your observations below. Which features would help you identify this group?

Glomeromycota: listed as Glomeromycotina in the fungal phylogeny

This single lineage within Kingdom Fungi forms relationships with the roots of almost all land plant species and thalli of the earliest plant lineages, who evolved before roots. This **mycorrhizal** (myco- meaning fungus, rhiza meaning root) relationship has existed for 400 million years and was likely involved in the movement of plants onto land. Glomeromycetes are called **endomycorrhizal** because the fungal hyphae enter inside of plant cells. The fungus enters the plant tissue, usually through the roots, and penetrates the cell walls of the cortex cells in the root. However, they hyphae do not go through the plasma membrane.

Instead, they form highly branched, tree-like structures called **arbuscles**. This provides a large amount of surface area for the plant and fungus to interact with each other. How are they interacting?

These images are from an open access paper (doi: 10.1038/srep29733) studying fungal colonization of plant cells. In the image on the right, the fungal tissue was stained with a fluorescent dye. In the lower two (B and C), fungal hyphae were stained dark and are forming arbuscules within the plant cell walls.

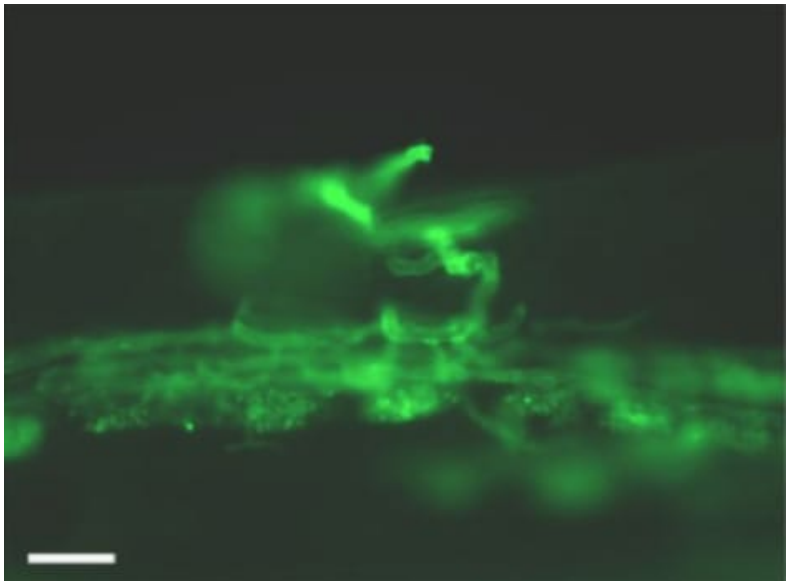


Figure 15.6.4: Endomycorrhizae

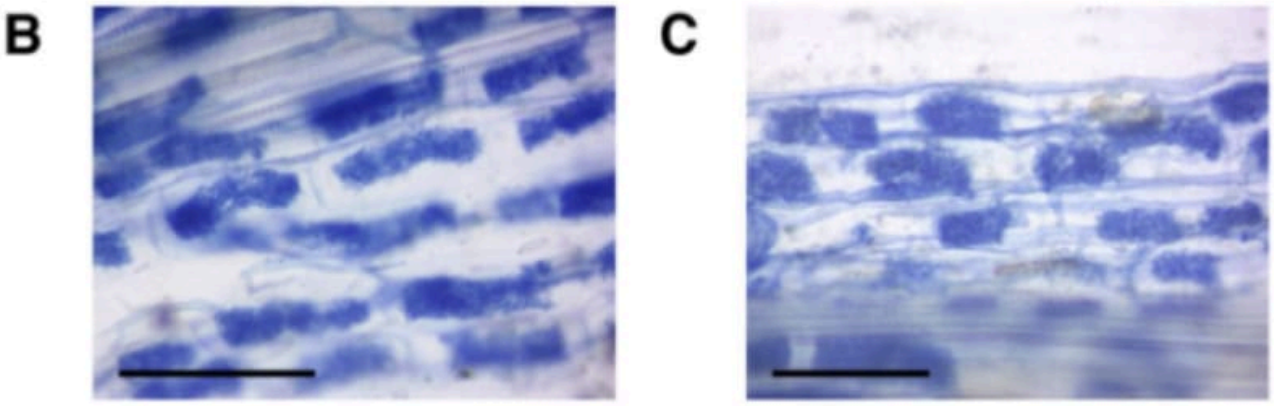


Figure 15.6.5: Endomycorrhizae B and C

Because it is a heterotroph, the fungus takes sugars from the plant. The fungal hyphae extend beyond the plant roots into the soil, where it can absorb water and nutrients that are transferred to the plant. Each partner gains a benefit from this relationship, so this is called a mutualistic symbiosis, or **mutualism**.

> A symbiotic relationship refers to a shared relationship between at least two organisms of different species. This relationship can benefit both parties, as above, only benefit one, potentially causing harm to the other. What would you call this last type of symbiosis?
>
> View a mycorrhizal root tip under the compound microscope, either as a prepared slide or from a fresh sample. If from a fresh sample, use 5% KOH + Phloxine B or Cotton Blue to stain the fungal tissue. Draw what you see below and label any distinguishing features of both the plant and fungus.

The Dikarya: Ascomycota and Basidiomycota

These two groups of fungi are referred to as the dikarya because some portion of their life cycle is **dikaryotic**. When two compatible mating types meet, they fuse together and begin the process of fertilization with plasmogamy (fusion of the cytoplasm). However, the nuclei do not fuse. Instead, a new mycelium is formed with two different haploid nuclei in each cell, making the ploidy n + n (as opposed to diploid, 2n). This state is called dikaryotic. Karyogamy (fusion of the nuclei) does not occur until the fungus is about to make spores. The two nuclei fuse and the zygote immediately undergoes meiosis, forming haploid spores.

> Which type of life cycle would you classify this as and why?

Though there are microscopic species and life stages in each group (including the yeast you saw earlier), members of the Ascomycota and Basidiomycota both form macroscopic fruiting bodies. Because of this, they will be covered in more detail in Lab Macrofungi and Lichens.

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15.7: Summative Questions

1. How would you classify a heterotrophic eukaryote with a filamentous thallus? What traits would you need to make your determination?
2. Fungal hyphae are much smaller in diameter than plant roots. How would this influence the ability of a mycorrhizal fungus to acquire water and nutrients from the soil, in comparison to the plant?
3. Compare and contrast yeast and conidia.
4. What classifies something as a mold?
5. Where do you most often see molds and how might this relate to the reproductive strategy of these organisms?
6. Describe what is happening in the *Rhizopus* life cycle diagram below. Label important structures and note where fertilization and meiosis are occuring. Choose a different color to represent haploid and diploid tissues.

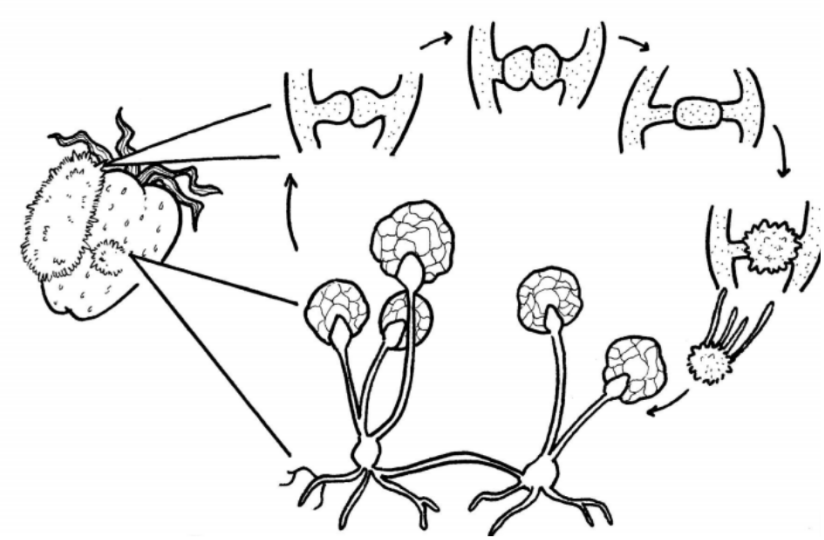


Figure 15.7.1: Rhizopus life cycle diagram

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16: MACROFUNGI AND LICHENS - TRUE FUNGI AND FUNGAL MUTUALISMS

Learning Objectives

Content Objectives

- Learn the differences between groups of macrofungi
- Understand the relationships between fungi and other organisms

Skill Objectives

- Identify features of fungi both microscopically and macroscopically
- Differentiate between endomycorrhizal and ectomycorrhizal fungi
- Locate the photobiont in a lichen cross section

16.1: Formative Questions

16.2: Introduction

16.3: Macrofungi

16.4: Fungal Ecology

16.5: Summative Questions

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- Thumbnail: *Amanita muscaria* mushroom

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16.1: Formative Questions

Note

This lab is one of a two-part series (Microfungi - Slimes, Molds, and Microscopic True Fungi and Macrofungi and Lichens - True Fungi and Fungal Mutualisms) that can be adjusted and combined based on available specimens.

1. What does the term symbiosis mean to you? How do you think this is different from the term mutualism?
2. What is the function of a mushroom? Do all fungi make mushrooms?

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16.2: Introduction

Though both of the groups of fungi we will learn about today contain microscopic subgroups and/or life stages, we still refer to them as the macrofungi because they account for nearly all of the fruiting bodies that we can easily see with the naked eye.

Fungi make a diversity of fruiting structures, structures in which meiosis occurs to form spores. In the microfungi, you saw zygomycetes making their fruiting structures: zygosporangia. In the macrofungi, you will learn three different types of ascocarps and the anatomy of a basidiocarp, otherwise known as a mushroom. These structures are analogous to fruits produced on a tree. The rest of the fungal body (or, the rest of the tree, in this analogy) is the mycelium, buried within the substrate and busily acquiring food. Note: The mycelium is not the equivalent of the roots of the tree, but of the entire tree, including the roots, stems, and branches. Mushrooms are the ephemeral fruits of this structure, emerging for sexual reproduction.

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16.3: Macrofungi

Ascomycota -- The Sac Fungi

This group of fungi is when the life cycle starts to get particularly strange and the fungus forms something called a **dikaryon** (di- meaning two, karyo- meaning nucleus). When two different hyphal bodies fuse, they do not fuse their nuclei, only the cytoplasm. The result is a single fungal body with two separate types of nuclei floating around inside it. Because it is neither haploid (n), nor truly diploid (2n), this condition is called being dikaryotic (n+n).

Ascomycota are distinguished from other groups of fungi by the following characteristics:

- Production of **ascospores** (usually 8) within an **ascus**, a normally elongate, sac-like structure
- Hyphae with **simple septations**
- The mycelium is primarily haploid. When two haploid (n) mycelia of the correct mating types meet, they can form a dikaryotic (n+n) fruiting body called an **ascocarp**.

There are three different types of ascocarps:

1. **Apothecium** - a (usually) cup-shaped fruiting body with asci lining the interior of the cup. Two exceptions are Helvella and Morchella (morels), where the cup has been inverted, no longer looking like a cup, and the asci cover the now-exterior surface.
2. **Perithecium** - a round fruiting body with a long neck, much like a bottle, with the asci inside the bottom of the bottle. Microscopic and quite similar to a *Fucus* conceptacle.
3. **Cleistothecium** - a spherical, enclosed fruiting body packed with rounded asci. These are also microscopic and can be beautifully ornamented.

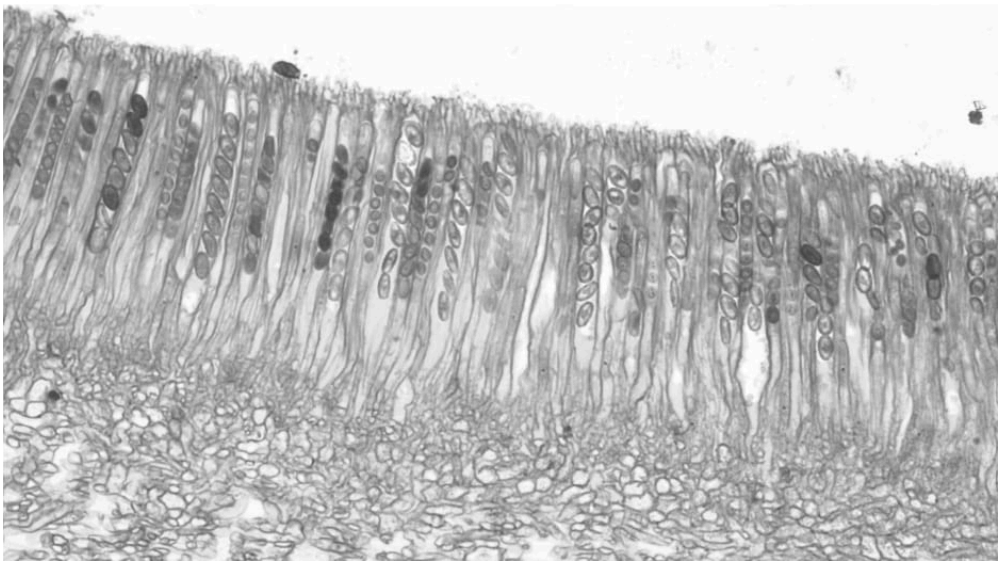


Figure 16.3.1: Peziza Asci

Above is the spore producing surface of an apothecium. The long asci each contain 8 ascospores.

> Observe the ascomycetes on display. What type of ascocarps do you see? Draw and label them below, indicating where the asci would be found.
>
> Make a thin section slide of Xylaria using KOH for the wet mount. Draw a perithecium below. Label an **ascus** and **ascospores**.
>
> Make a thin section slide of an apothecium. Draw it below, labelling an ascus and ascospores. Can you find septations in

the hyphae?

If available, view a cleistothecium from the Erysiphales (powdery mildews) under both the dissecting and compound microscope. Draw it below, labelling an ascus and ascospores.

Basidiomycota -- The Club Fungi

Basidiomycota are the other group of dikaryotic fungi. This group includes the mushroom-forming species of fungi, as well as two groups of (mostly) plant **parasites**, delightfully referred to as the rusts and the smuts.

Basidiomycota are distinguished from other groups of fungi by the following characteristics:

- **Basidiospores** (usually 4) produced from a **basidium**--a normally squat, roundish structure with prongs called **sterigmata** that spores are produced on.
- Hyphae with **complex septations.** These specialized septations look like they are surrounded by parentheses and help the mycelium maintain its dikaryotic state.
- **Clamp connections** can sometimes be seen, though are only obvious in certain genera.
- The mycelium is primarily dikaryotic. The haploid spores germinate and must find another germinating spore of the correct mating type to form a dikaryotic mycelium. This can then produce fruiting bodies called **basidiocarps**, or as we commonly call them, mushrooms.

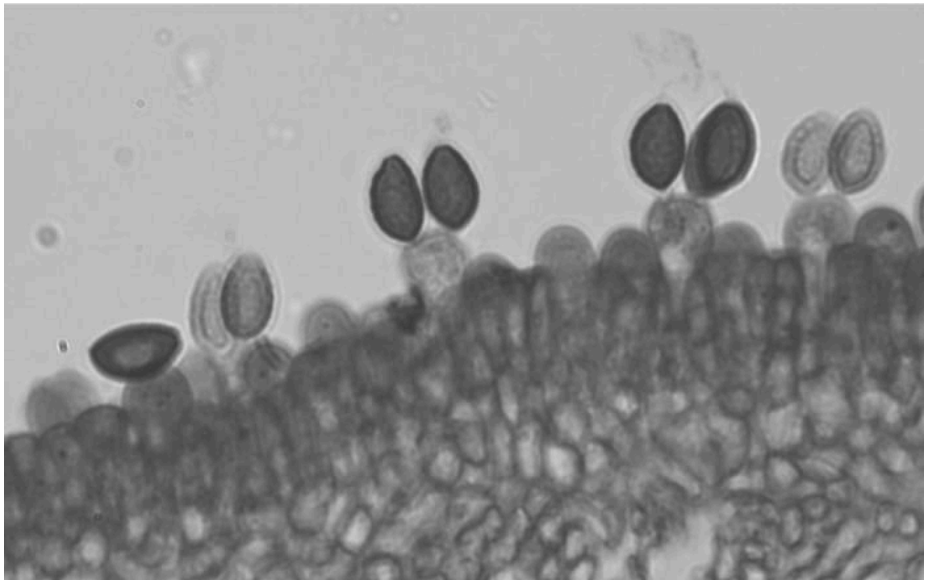


Figure 16.3.2: Coprinus Basidia

The image above shows the spore producing surface of a basidiomycete, *Coprinus*. The dark football-shaped structures are the haploid **basidiospores**. They sit atop small projections called sterigmata (**sterigma**, singular) that emerge from the top of the **basidium**. In most mushrooms, each basidium produces four basidiospores.

Based on the presence of four haploid spores, which type of cell division do you think formed these spores and why?

How could you explain the presence of 8 spores in ascomycetes?

Label the anatomy of an *Amanita muscaria* basidiocarp below, including the **cap** (pileus), **universal veil scales**, **gills** (lamellae), **annulus**, **stipe**, **volva**, and **mycelium**.

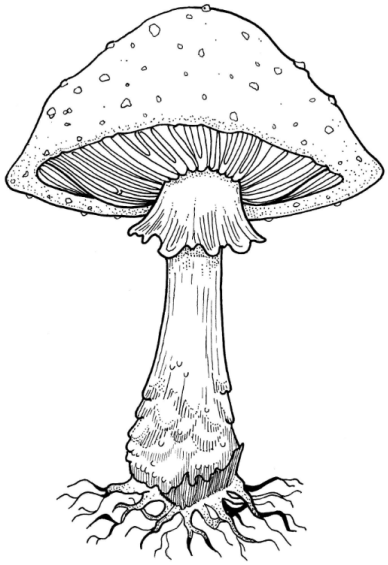


Figure 16.3.3: Amanita muscaria mushroom

Not all basidiocarps look like *Amanita muscaria*. Observe the diversity of basidiomycetes on display. In the space below, draw and label a jelly mushroom, a coral mushroom, a bracket, and a puffball.

Make a thin section of a gilled mushroom, using 5% KOH for the wet mount. Try to find basidia and basidiospores. Can you see clamp connections? It may help to stain with Phloxine B. Draw and label what you see below.

The phylum Basidiomycota is composed of three major groups. All of the fungi above are from the subphylum Agaricomycotina. The two other groups are composed of primarily parasitic fungi, rusts (Pucciniomycotina) and smuts (Ustilaginomycotina). View the available prepared slides of these fungi and draw what you see below. Can you find basidia and basidiospores? Compare and contrast what you see with the Agaricomycetes.

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16.4: Fungal Ecology

The Mycelium

Like us, fungi are heterotrophic and digest other organisms to survive. Unlike us, they do this digestion outside of their bodies, then absorb the nutrients. Consider the structure of a hyphal filament and what you know about surface area to volume ratio. How does the structure of the mycelium allow for more efficient uptake of water and nutrients?

Because fungi must absorb their food, they tend to live on or in whatever it is they are eating. If a mushroom is growing out of a log, it is likely that it is eating that log or something contained within it. This structure and diversity is what makes them such important decomposers. However, fungi play many other important ecological roles.

Mutualisms

Mycorrhizae

As you saw in Lab Microfungi - Slimes, Molds, and Microscopic True Fungi, not all fungi are decomposers and parasites. Members of the Glomeromycota form a mutualistic relationship with plant roots called endomycorrhizae, penetrating inside the cell wall.

Some members of both the Ascomycota and Basidiomycota (as well as at least one zygomycete, *Endogone*) also form mycorrhizal relationships with plants, but the interface between the plant and the mycelium is a bit different. Instead of penetrating inside the cell wall, the fungal hyphae surround the plant cells and make a sheath on the exterior of the root. This type of relationship is called being **ectomycorrhizal** (ecto- meaning outer), because the hyphae are outside of the cells.

> View specimens of fruiting bodies of ectomycorrhizal fungi (such as chanterelles, boletes, Russula, etc...). Compare and contrast these fungi with the glomeromycetes you saw in Lab Microfungi - Slimes, Molds, and Microscopic True Fungi.

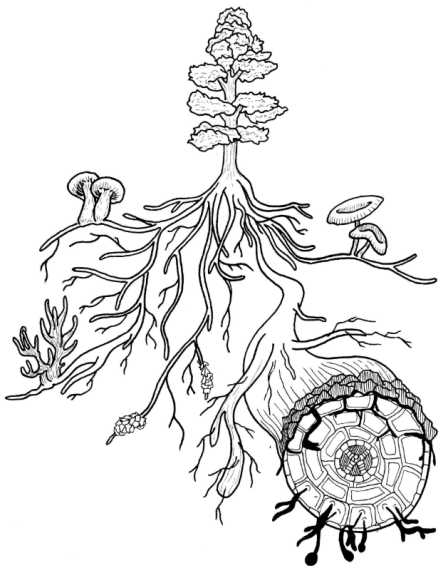


Figure 16.4.1: Mycorrhizal fungi

> In the diagram above, both ectomycorrhizal and endomycorrhizal fungi are shown interacting with the roots of a tree. In the root cross section, label which structures represent each type of mycorrhizal relationship. Next, show the direction of the flow of sugars with arrows. Do the same for the flow of water and nutrients.

Lichens

A lichen is a mutualistic relationship between several organisms. There is always a fungal partner, the **mycobiont,** and this is usually an ascomycete. There are a few basidiolichens, but they look very different from ascolichens.

The mycobiont is heterotrophic and so must eat sugars produced by other organisms. The sugars it consumes are harvested from the photosynthetic partner, the **photobiont**, which is either green algae, cyanobacteria, or less commonly, both (these lichens are called tripartite lichens)!

The photobiont produces glucose through photosynthesis, which the mycobiont harvests and converts into **mannitol**, a form of sugar that only the fungus can use. The photobiont only really gets to eat when the mycobiont is focused on maintaining the lichen thallus from desiccation (drying out) and sun damage. Though this relationship is technically a mutualism, it has some very parasitic components.

> What does the photobiont get out of this relationship?

Lichens are incredibly diverse, but we can begin by classifying them into three different growth forms:

- **Crustose** lichens are firmly attached to the substrate and usually have to be chipped off. These lie flat, like a crust.
- **Foliose** lichens have a distinct upper and lower surface, like a leaf (think 'foliar').
- **Fruticose** lichens are shrub-like and usually attach to the substrate at a single point, like a plant with roots.

> Observe the diversity of lichens on display. Draw a lichen from each of the three forms below. Label any ascocarps (or basidiocarps) that you find.

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16.5: Summative Questions

1. What determines whether a fungus is considered microfungi or macrofungi?
2. How would you differentiate between an ascomycete and basidiomycete? Which features would be most helpful in making this determination?
3. Fungi can form many different types of symbiotic relationships with plants. Compare and contrast parasitic and mutualistic symbioses.
4. What is a lichen? How would you classify this in the tree of life and why?
5. How do lichens obtain food? Are they autotrophic or heterotrophic? Explain your reasoning.
6. Label the structures present in the diagram on the next page and identify the group of fungi that each of these is from. Choose a different color to represent haploid, diploid, and dikaryotic tissues.

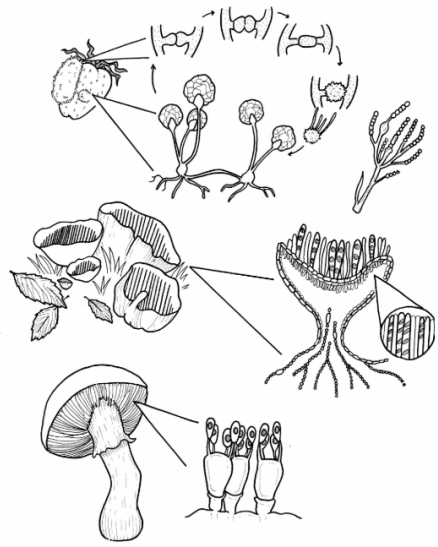


Figure 16.5.1: Fruiting structures of Kingdom Fungi

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17: HETEROKONTS

Learning Objectives

Content Objectives

- Learn the characteristics used to classify an organism as a heterokont.
- Explain the process of secondary endosymbiosis and how it lead to photosynthetic heterokonts.
- Understand the important ecological roles of heterokonts

Skill Objectives

- Identify important features in the life cycles of *Saprolegnia* and *Fucus*. Know the functions of these features.
- Use life history traits to distinguish between different groups of heterokonts, fungi, and other algal groups.

17.1: Formative Questions

17.2: Introduction

17.3: Oomycota -- The Water Molds

17.4: Photosynthetic Heterokonts - Descendents of Secondary Endosymbiosis

17.5: Phaeophyta - The Brown Algae

17.6: Fucus Life Cycle

17.7: Bacillariophyta - The Diatoms

17.8: Summative Questions

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- Thumbnail: Unfertilized oogonium

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17.1: Formative Questions

1. How do autotrophs and heterotrophs differ in how they obtain energy?
2. How do autotrophs and heterotrophs differ in how they use energy?

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17.2: Introduction

Heterokont means “different flagella”. Organisms in this group are eukaryotes that have a life stage with two different flagella, one whiplash and one ornamented. In addition to this shared feature, heterokonts have a diplontic life cycle. The earliest heterokonts were heterotrophic. These often function as decomposers or parasites in aquatic ecosystems, and primarily as plant pathogens in terrestrial ecosystems. The Irish potato famine was caused by one of these.

At some point in history, a heterotrophic heterokont tried to eat an ancestor of the red algae. This photosynthetic, red alga-like organism was not digested and, instead, evolved slowly over time into a four-membraned chloroplast. This process is called **secondary endosymbiosis** and is described in more detail later in the lab.

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17.3: Oomycota -- The Water Molds

Oomycetes (a term used to refer to organisms in the phylum Oomycota) are a group of fungus-like organisms that rely on water for completion of their life cycle, hence the common name “water molds”. Members of this group share the following characteristics:

- Heterotrophic by absorption
- Morphology: Filamentous
- Cell wall composition: Cellulose
- Storage carbohydrate: Glycogen
- Life cycle: Diplontic
- Ecology: Many oomycetes are important decomposers in aquatic ecosystems, while others -- namely those in the genus *Phytophthora* -- are some of the most destructive plant pathogens. You can culture some of the more common decomposers (genus *Saprolegnia*) by putting pond water into a petri dish, adding a dead insect, covering it, and waiting for a few days.

  Considering what you have learned about root words, how does the name *Saprolegnia* help you understand this organism’s ecology?

Saprolegnia Life Cycle

View prepared slides of *Saprolegnia*. This organism reproduces asexually by producing **zoospores** (zoospores are spores that swim, zoo- meaning ‘to live’) inside of an elongated sac called a **zoosporangium** (-angium meaning vessel, so a zoosporangium is what zoospores are produced inside of). These zoospores grow by mitosis into a diploid **thallus**, an undifferentiated body.

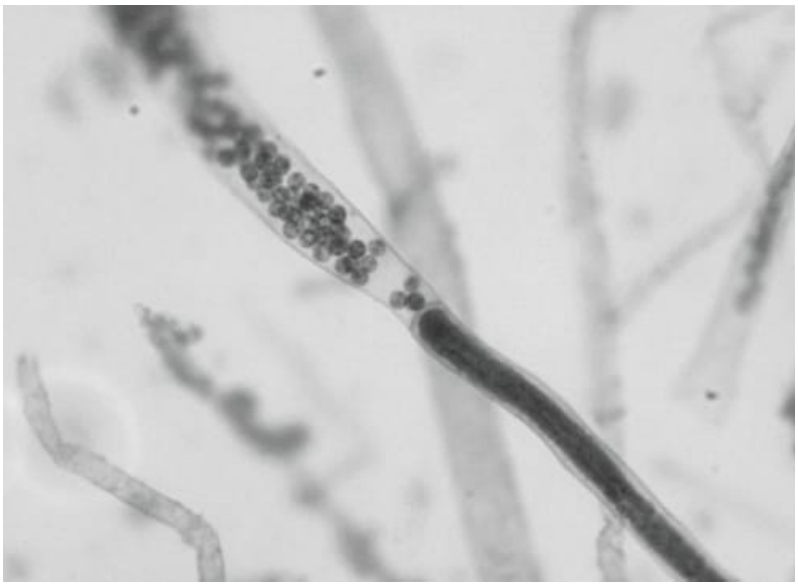


Figure 17.3.1: Zoosporangium

Look for asexual reproduction in the form of elongate zoosporangia releasing zoospores. The life cycle of *Saprolegnia* is diplontic. Are the zoosporangia and zoospores haploid or diploid?

The image above shows a mature zoosporangium releasing diploid zoospores. Each of these spores has two flagella, one ornamented and one whiplash.

Look for *Saprolegnia*'s sexual reproducing structures, the globose **oogonium** and smaller, pad-like **antheridia** (singular, antheridium) that attach to the oogonium. Because these structures produce gametes--much like spores are produced in sporangia--the oogonia and antheridia are also referred to as **gametangia** (gametangium singular). The oogonium produces haploid **eggs** via meiosis. These eggs are fertilized by the haploid **male nuclei** produced by meiosis within the antheridium, creating a diploid, thick-walled zygote called an **oospore**.

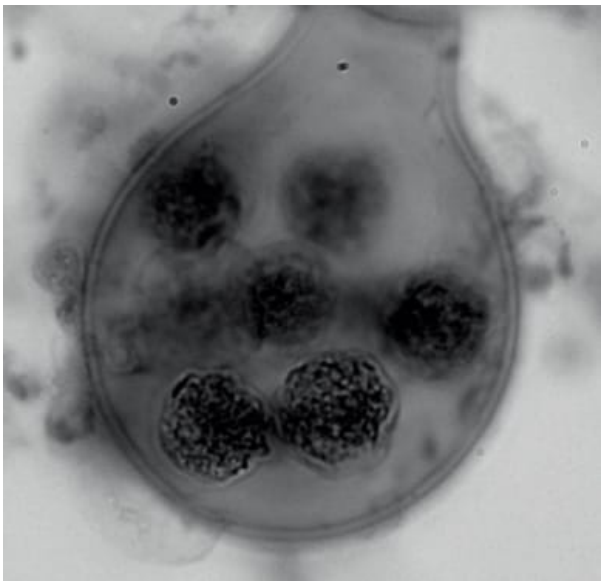


Figure 17.3.2: Unfertilized oogonium

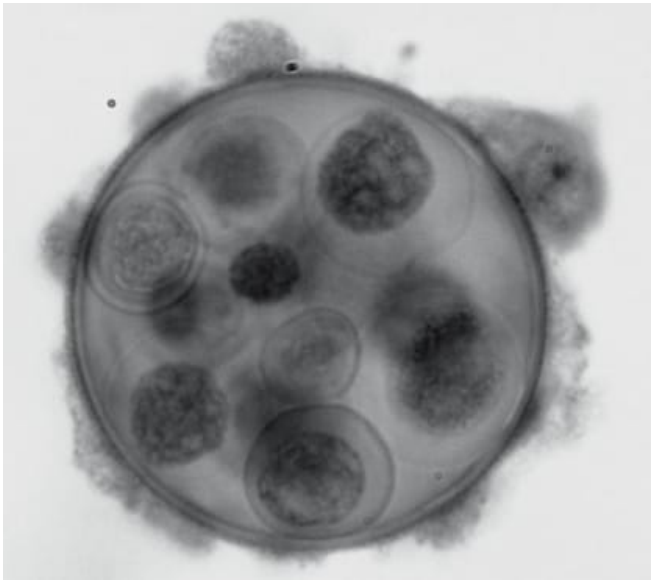


Figure 17.3.3: Fertilized oogonium

The oospore will be released and grow by mitosis to create a new multicellular **thallus**, completing the life cycle.

Check your *Saprolegnia* cultures for presence of mycelium (fuzz around the dead insect). Make a wet mount of some of the mycelium and look at it under the compound microscope. It may help to stain the tissue, as you did in the fungal labs.

Do you see any features that belong to Saprolegnia? Do you see any that belong to a member of the true fungi?

Draw what you see in the space below and attempt to identify which group(s) of organisms you have in your culture.

Below is the life cycle diagram of Saprolegnia. Label an **oogonium, antheridium, male nuclei, egg, oospore (zygote), zoosporangium, zoospore**, and **thallus**. Indicate where **meiosis** and **fertilization** occur. Use a different color to indicate which tissue is haploid or diploid.

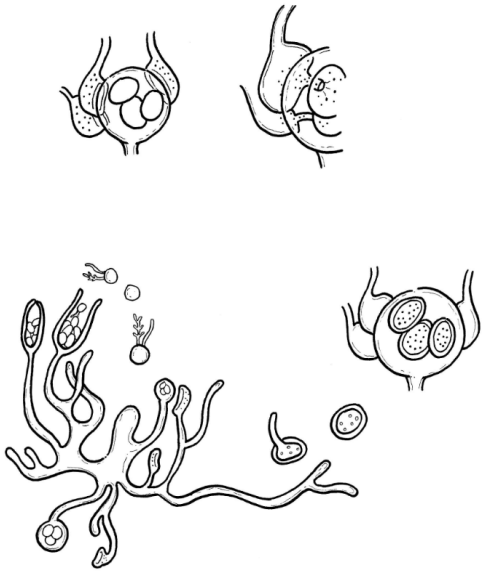


Figure 17.3.4: Saprolegnia life cycle diagram

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17.4: Photosynthetic Heterokonts - Descendents of Secondary Endosymbiosis

The photosynthetic lineages of the heterokonts derived their golden brown chloroplasts from **secondary endosymbiosis**. In this event, an ancestral oomycete engulfed a red alga. As in primary endosymbiosis, instead of being digested, overtime the red alga degenerated into a chloroplast, this time with 4 membranes -- the engulfing membrane from the oomycete, the red alga's plasma membrane, and the two membranes of the original chloroplast within the red alga. *Note: In many groups derived from secondary endosymbiosis, the chloroplast has lost one of these membranes.*

The process of secondary endosymbiosis is shown on the following page. Add arrows to show the sequence of events. Label the heterotrophic **oomycete**, the photosynthetic **red alga**, and the origin of each membrane of the 4-membrane chloroplasts.

> Note
>
> The red algal cell would also have mitochondria. Feel free to add one in!

Secondary Endosymbiosis in Heterokonts:

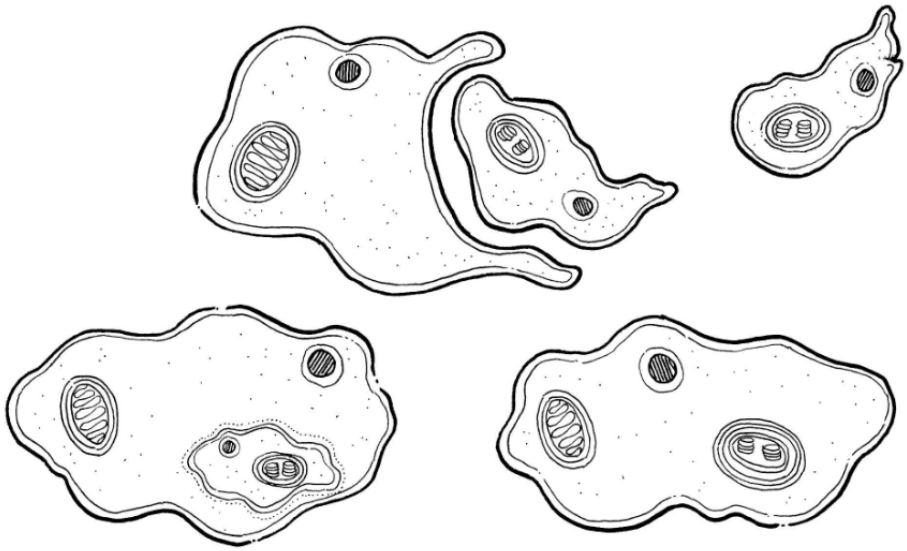


Figure 17.4.1: Secondary Endosymbiosis

Brown algae and diatoms are the result of this endosymbiotic event. Their chloroplasts have chlorophyll a, chlorophyll c, and fucoxanthin. Which pigment(s) are ancestral from secondary endosymbiosis (present in the red alga)?

Which pigment(s) were derived after this event (not present in the red alga)?

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17.5: Phaeophyta - The Brown Algae

Brown algae are brown due to the large amounts of carotenoids they produce, primarily one called **fucoxanthin**. These organisms are exclusively **multicellular** and can get so large that they require special conductive cells to transport photosynthates from their blades down to the rest of their tissues. These conductive cells are called **trumpet hyphae** and have sieve plates and resemble sieve tubes found in flowering plants. You may not see these, but be on the lookout for them!

- Morphology: Multicellular thallus
- Cell wall composition: Cellulose
- Chloroplasts: 4 membranes, pigments are chlorophyll a, chlorophyll c, and fucoxanthin
- Storage carbohydrate: Laminarin
- Life cycle: Diplontic
- Ecology: Marine

View the variety of brown algae on display. In the space below, label the morphology of a brown algal **thallus**. Much like *Saprolegnia*, the body of an alga is termed a thallus because it is not differentiated into specialized tissues. Label the **holdfast, stipe, gas bladder**(s) [also called a **float**], and **blade**(s).



Figure 17.5.1: Kelp Thalli

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17.6: Fucus Life Cycle

Our model organism for the Phaeophyta life cycle is *Fucus* (rockweed), which, like its relative *Saprolegnia,* has a diplontic life cycle.

Observe the displayed *Fucus* **thallus**. Note the dichotomous branching (forking into two equal branches) and the swollen, heart-shaped reproductive tips of the branches. These swollen branch tips are called **receptacles**. The receptacles are covered in small bumps, each with a pore at the center of the bump called an **ostiole**. The bumps are **conceptacles**, chambers that house the male and female gametangia.

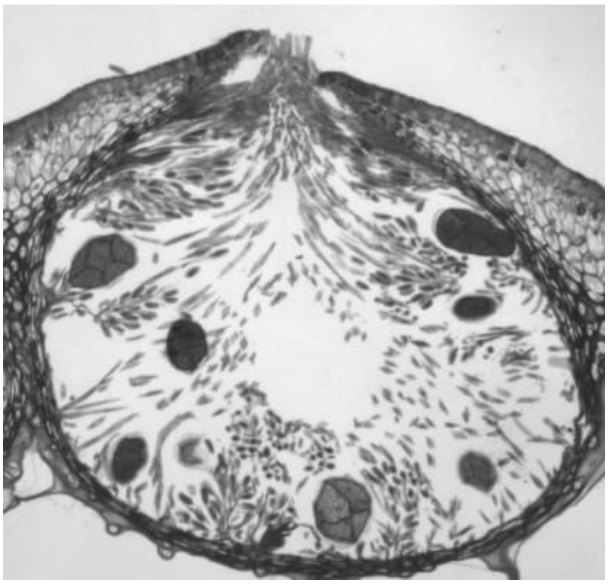


Figure 17.6.1: Fucus conceptacle

View prepared slides of a cross section through a *Fucus* receptacle to view inside the conceptacles. The male and female gametangia are housed within the conceptacle chamber. The **antheridia** are branched structures that look like small trees. These produce **sperm** with heterokont flagella.

The oogonia are globose structures divided into sections as **eggs** are produced. The eggs will be fertilized by sperm that swim in through the ostiole, forming a diploid **zygote** that will be released in the marine water. This zygote will grow by mitosis into a multicellular, diploid thallus. Label the bolded structures in the life cycle diagram on the following page.

In the *Fucus* life cycle below, label any important structures, indicate where meiosis and fertilization occur, and color the haploid and diploid tissues differently. Draw arrows that show where mitosis is occuring.

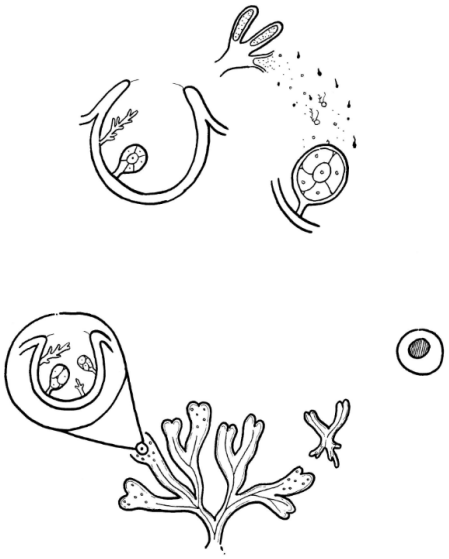


Figure 17.6.1: Fucus Life Cycle Diagram

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17.7: Bacillariophyta - The Diatoms

Diatoms are an incredibly diverse group of unicellular organisms containing anywhere from 20,000 to 2 million species.

- Morphology: Unicellular
- Cell wall composition: Silica frustule
- Chloroplasts: 4 membranes, pigments are chlorophyll a, chlorophyll c, and fucoxanthin
- Storage carbohydrate: Chrysolaminarin
- Life cycle: Diplontic
- Ecology: Everywhere! Marine, freshwater, and terrestrial.

    We are still trying to figure out how to determine what a diatom "species" is and, so far, they have been classified based on the morphology of their **frustules**, a silica shell made from two distinct valves that enclose the plasma membrane. Using this classification, there are two major groups of diatoms: **centric** (have radial symmetry) and **pennate** (have bilateral symmetry). Draw and label an example of each type below.

    Diatoms are a major component of the **phytoplankton** (phyto- meaning plant, plankton meaning 'to wander'). These are photosynthesizing, microscopic organisms in aquatic environments and include members from many of the other groups covered in general botany, including cyanobacteria, Rhodophyta, and the green algae.

    Would any members of Phaeophyta be considered phytoplankton? Why or why not?

    Considering that phytoplankton are primary producers, what important roles might they have in aquatic and/or terrestrial environments?

In addition to morphology, diatoms can also be classified by where they occur. Free-floating diatoms are **planktonic**. Diatoms attached to other organisms (like giant kelp) are **epiphytic**. **Benthic** diatoms tend to dwell toward the bottom of a body of water. Try to find some planktonic diatoms by preparing slides from fresh samples of pond or seawater. Look for epiphytic diatoms by mounting a piece of algae and searching along its edges. *Note: I have the best luck with epiphytic diatoms on intertidal red algae. In fact, you can usually find diatoms on prepared slides of Polysiphonia, our model organism from the Rhodophyta.*

Draw what you find below. Label **frustules** and **chloroplasts** and identify whether the diatom is **centric** or **pennate**.

Diatoms primarily reproduce asexually by **binary fission**, similar to prokaryotes. During binary fission, the two valves of the frustule are separated and each new cell forms a new valve inside the old one. However, the new valve is always smaller. If diatoms only reproduce in this way, it results in a continual decrease in average size. When some minimal size is reached, this can trigger sexual reproduction. When diatoms sexually reproduce, they have a diplontic life cycle and produce a very large **auxospore**. Stay on the lookout for these strange, enlarged diatoms!

> **Note**
>
> Apparently, diatoms can produce auxospores through asexual or sexual reproduction.

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17.8: Summative Questions

1. What traits could you use to differentiate between Oomycota and Kingdom Fungi? Specify which traits belong to which group in your answer.
2. Which traits could you use to differentiate between Phaeophyta and Bacillariophyta?
3. Water molds, brown algae, and diatoms do not initially appear to have anything in common. What traits could you use to classify these organisms into an evolutionary related group?
4. Why do the heterotrophic heterokonts have chloroplasts with extra membranes? Where did these membranes come from?
5. Could brown algae be considered phytoplankton? Why or why not?

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18: RED AND GREEN ALGAE

Learning Objectives

Content Objectives

- Understand how differences in life history traits between red and green algae can be explained by differences in ecology
- Relate selection pressures to adaptations within each group
- Learn the life cycles of *Polysiphonia* and *Spirogyra*

Skill Objectives

- Use life history traits to differentiate between red and green algae
- Identify important structures in the *Polysiphonia* and *Spirogyra* life cycles. Know the function and ploidy of these structures.

18.1: Formative Questions

18.2: Introduction to Red and Green Algae

18.3: Phylum Rhodophyta - The Red Algae

18.4: Phylum Chlorophyta and Phylum Streptophyta

18.5: Pond Ecosystem Relationships

18.6: Design an Experiment

18.7: Summative Questions

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- Thumbnail: Tetrasporangium

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18.1: Formative Questions

1. Red and green algae share a common ancestor. How might natural selection have led to these two different lineages? What traits would natural selection be acting upon?
2. What role did meiosis have in the selection process described above?

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18.2: Introduction to Red and Green Algae

The red and green algae are descendents of the primary endosymbiosis event that resulted in the first chloroplast. Their plastids have two membranes, an inner membrane that was the cyanobacterial cell wall and an outer membrane from the organism that first engulfed it. The story of these algal groups is the evolutionary history of all plants. As time passes in this story and groups specialize for their given environments, we will see changes in cell wall composition, photosynthetic pigments, storage carbohydrates, and life cycles. Make note of these important differences between groups, as they represent the primary ways we classify these organisms.

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18.3: Phylum Rhodophyta - The Red Algae

The red algae represent a monophyletic group of organisms. Members of this group share the following characteristics:

- Morphology: Unicellular to multicellular, no flagellated stages. Cells of multicellular species are connected via incomplete cytokinesis, resulting in **pit connections**.
- Cell wall composition: Cellulose and **galactans**
- Chloroplasts: 2 membranes, pigments are chlorophyll a and phycobilins (primarily phycoerythrin, providing their red color)
- Storage carbohydrate: **Floridean starch**
- Life cycle: Alternation of generations with an extra diploid stage, the **carposporophyte**
- Ecology: Primarily marine (97% of species)

Selection Pressures and Drivers

An important aspect of understanding the life history traits of the Rhodophyta is understanding the challenges of living in a marine environment.

1. **Access to sunlight**: Most colors of light cannot penetrate into deeper water, as they are scattered by water molecules. The wavelengths of light that reach deepest into the ocean are blue and green. Many fish that live in the deep ocean are red. Because red light does not penetrate to the depths where they live, this makes them virtually undetectable by sight. Remember, we see things because of the light that bounces off of them. Red pigments reflect red light, so no red light, no reflected light. Red algae are using a similar strategy--absorb the wavelengths of light that are not red--with a different goal: to use that absorbed light to make food. The **phycoerythrin** in their chloroplasts reflects red light, giving them a red appearance, and absorbs the blue light that is able to penetrate to deeper areas in the water column.
2. **Fertilization**: The ocean is an expansive environment, often with large areas of open space between populations of organisms. In this environment, successful fertilization of an egg by a nonmotile sperm--red algae **lack flagella**--presents a challenge. Having multicellular haploid and diploid phases provides red algae more opportunities to produce gametes and spores. A diploid stage that clones the zygote, the **carposporophyte**, provides more opportunities to do meiosis from each fertilization event.
3. **Salinity:** Marine environments are relatively high in salinity. A possible adaptation for this is to have sulfated polysaccharides in the cell wall, such as the **galactans** present in Rhodophyta. This is a strategy present in (potentially all) marine algae and is inferred to be an adaptation for salinity-tolerance. See this open-access article for further information: https://doi.org/10.1371/journal.pone.0018862

Observing the Red Algal Life Cycle

Polysiphonia is the model organism for Rhodophyta. Red algae have an alternation of generations life cycle that has an extra diploid stage: the carposporophyte. The gametophytes of Polysiphonia are isomorphic (iso- meaning same, morph- meaning form), meaning they have the same basic morphology. Use prepared slides and the images in the following pages to label the life cycle diagram below.

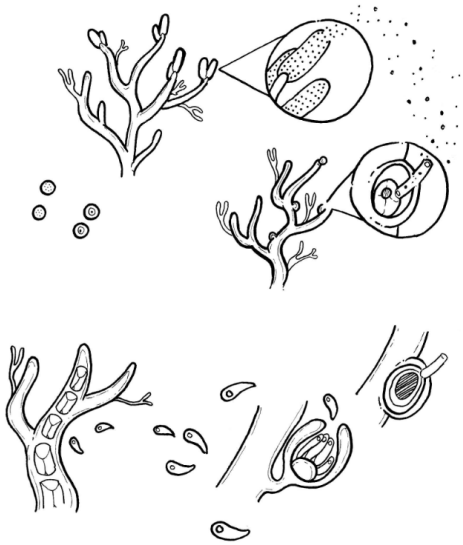


Figure 18.3.1: Polysiphonia Life Cycle Diagram

In the diagram above, indicate where meiosis and fertilization occur. Color the haploid and diploid tissue differently, and draw arrows to show when mitosis is happening.

Observe a prepared slide of a Polysiphonia male gametophyte. The male gametophyte (shown on right) has elongated structures that emerge from the tips of the thallus branches. These are **spermatangia**, where **spermatia** are produced by mitosis. Label the bolded features in the life cycle diagram.



Figure 18.3.2: Polysiphonia male gametophyte

Female gametophyte stages shown below:

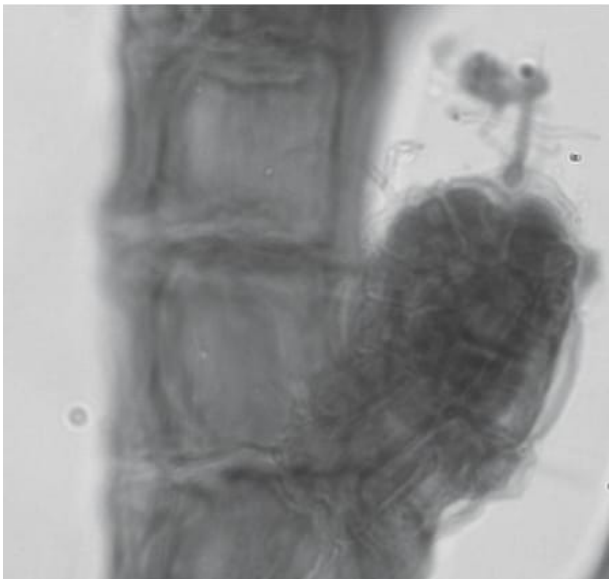


Figure 18.3.3: Polysiphonia female gametophyte

Observe a prepared slide of a Polysiphonia female gametophyte. The female gametophyte produces an egg that is contained within a structure called the **carpogonium**. This structure has a long, thin projection called a **trichogyne** (trich- meaning hair, -gyne meaning female). During fertilization, a spermatium fuses with the trichogyne and the nucleus of the spermatium travels down the tube to the **egg**. When the nucleus of the spermatium fuses with the egg, a **zygote** is produced. This zygote is retained and nourished by the female gametophyte as it grows.



Figure 18.3.4: Polysiphonia Carposporophyte

The globose structures you see growing from the female gametophyte thallus are called cystocarps. A **cystocarp** is composed of both female gametophyte tissue (n) and carposporophyte tissue (2n). The outer layer of the cystocarp, the **pericarp** (peri- meaning around) is derived from the female gametophyte and is haploid.

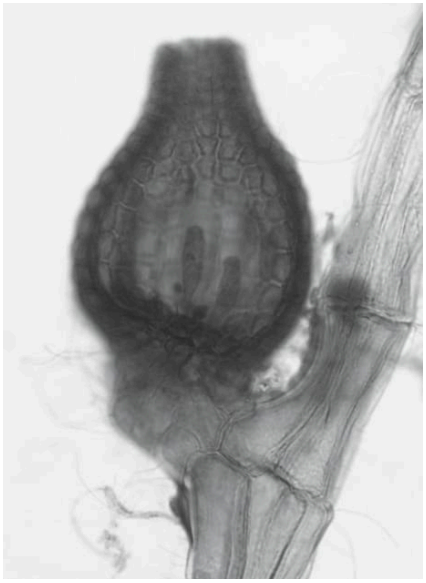


Figure 18.3.5: Polysiphonia Cystocarp

The interior of the cystocarp consists of the **carposporophyte**, which is diploid, and produces elongated structures called **carposporangia,** inside of which it produces **carpospores** by mitosis. All of these--carposporophyte, carposporangia, and carpospores--are diploid. Label the bolded features in the life cycle diagram and color them according to their ploidy.

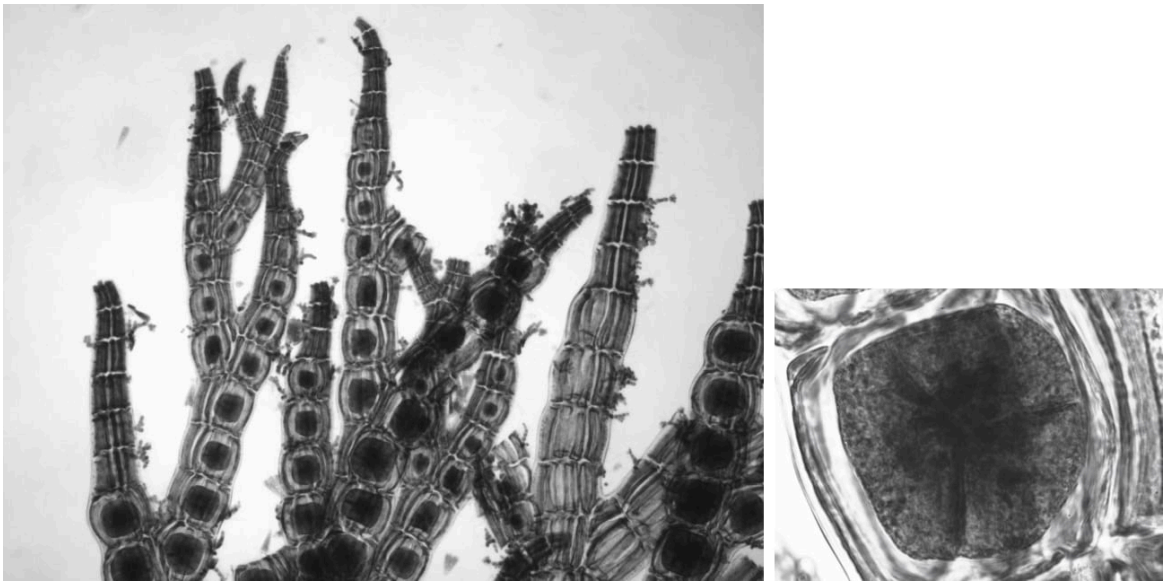


Figure 18.3.6: Tetrasporangium

Observe a prepared slide of a Polysiphonia tetrasporophyte. The diploid carpospores are released into the ocean waters, where they will be carried on currents to another location. If the carpospore lands in an appropriate environment, it will grow by mitosis into a **tetrasporophyte** (2n). The tetrasporophyte produces **tetrasporangia** (2n) within the branches of the thallus. Each tetrasporangium produces four unique, haploid **tetraspores** by meiosis.

Tetraspores (n) are released and will grow by mitosis into either male or female gametophytes, completing the life cycle. Label the bolded features in the life cycle diagram.

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18.4: Phylum Chlorophyta and Phylum Streptophyta

The nature of the evolutionary relationships between the green algae are still up for debate. As of 2019, genetic data supports splitting the green algae into two major lineages: chlorophytes and streptophytes. The streptophytes include several lineages of green algae and all land plants. Streptophytes and chlorophytes represent a monophyletic group called Viridiplantae (literally “green plants”).

Organisms that are classified as green algae share the following characteristics:

- **Morphology**: Unicellular to multicellular; two whiplash flagella on motile cells
- **Cell wall composition**: Cellulose
- **Chloroplasts**: 2 membranes, pigments are chlorophyll a, chlorophyll b, and carotenoids
- **Storage carbohydrate**: Starch
- **Life cycle**: Varies, but primarily haplontic. Some marine species have alternation of generations.
- **Ecology**: Freshwater, marine, and terrestrial species

Selection Pressures and Drivers

1. **Sun Damage**. Green algae represent a diverse group of organisms with diverse life history traits, many of which are shared with land plants. The development of **carotenoids**-- yellow, orange, and red pigments that act in both light harvesting and sun protection--offers this group increased access to sunlight while simultaneously protecting against UV damage. UV rays do not penetrate very far into the water column, so organisms moving into shallower waters or terrestrial environments would need to deal with this new challenge. Many terrestrial species of green algae appear orange, rather than green, due to the production of large amounts of carotenoids.

Observing the Life Cycle of Green Algae

Though green algae display a diversity of life cycles, many have a haplontic life cycle. A model organism for the green algae is *Spirogyra*. *Spirogyra* is a unicellular green algae that grows in long, filamentous colonies, making it appear to be a multicellular organism. Even though it is technically unicellular, its colonial nature allows us to classify its life cycle as haplontic. In the haploid vegetative cells of the colony, the chloroplasts are arranged in spirals, containing darkened regions called **pyrenoids** where carbon fixation happens. Each haploid cell in the filament is an individual, which makes sexual reproduction between colonies an interesting process. Note the nucleus suspended in the center of each cell in the colony on the right.

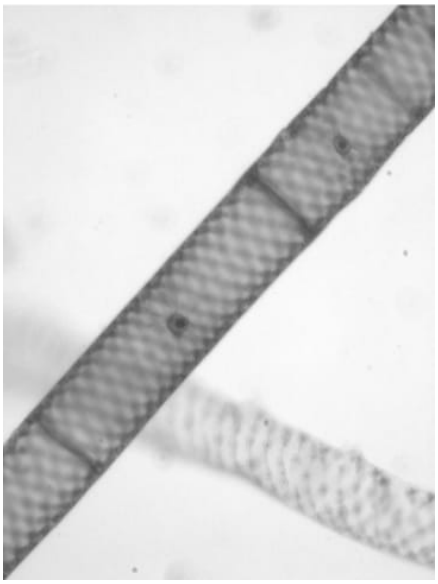


Figure 18.4.1: Spirogyra vegetative colony

When two colonies of Spirogyra meet that are of a complementary mating type (+/-), sexual reproduction occurs.

The two colonies align, each cell across from a complementary cell on the other filament. A **conjugation tube** extends from each cell in one colony, inducing formation of a tube on the cells in the other colony. The conjugation tubes from each colony fuse together.

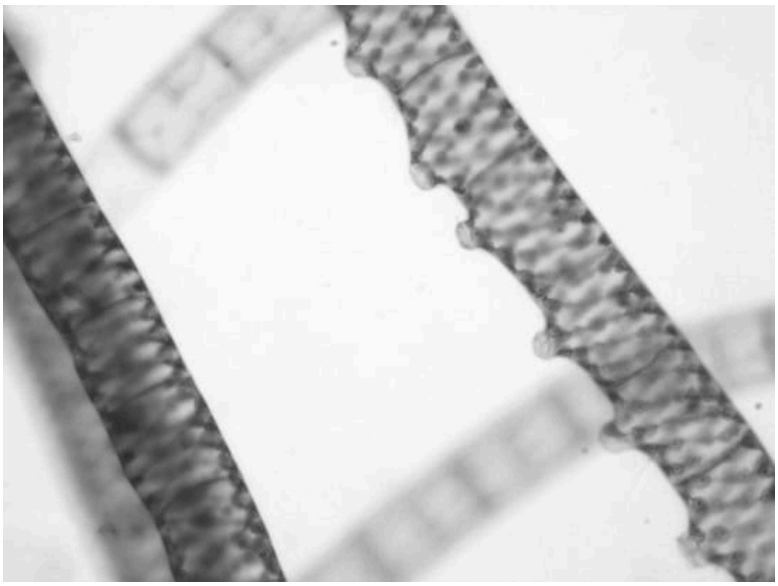


Figure 18.4.2: Spirogrya growing conjugation tubes

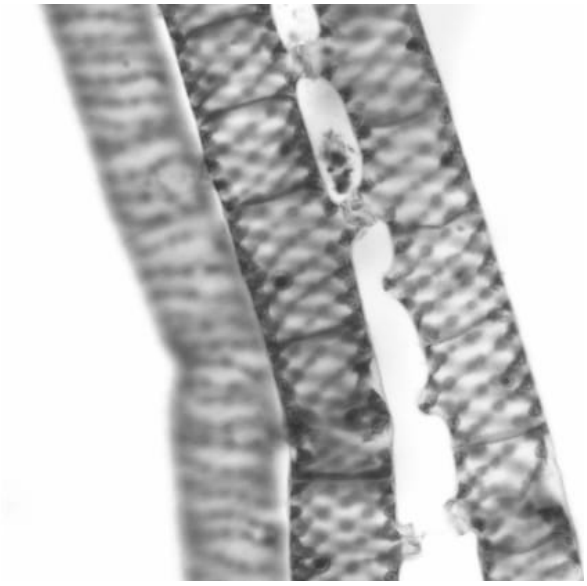


Figure 18.4.3: Spirogyra conjugatoin

The contents of one cell will move through the conjugation tube and fuse with the contents of the complementary cell, resulting in a diploid **zygote**.

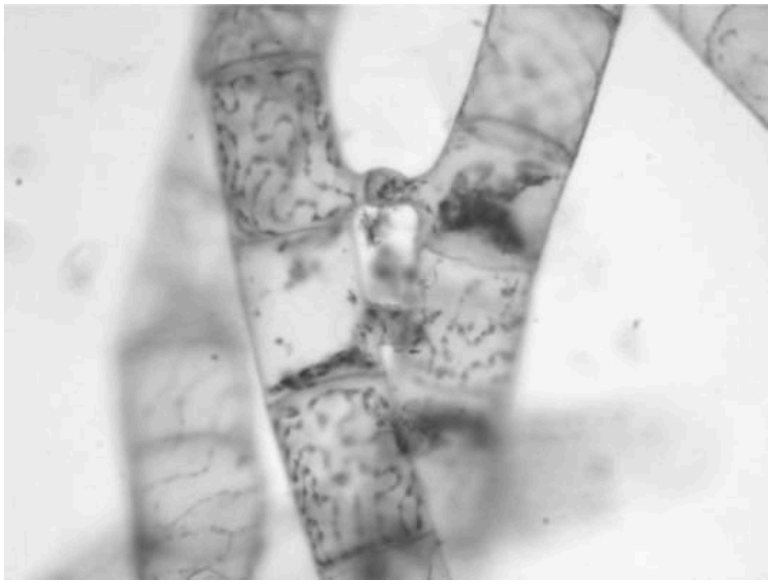


Figure 18.4.4: Spirogyra conjugation, part 2

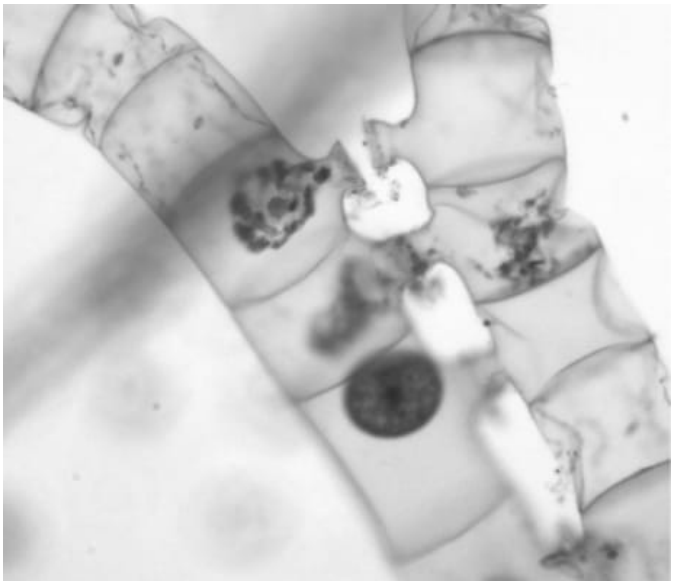


Figure 18.4.5: Spirogyra conjugation, part 3

The zygote appears as a large, egg-like structure contained within the complementary cell. It has a thick wall that provides resistance to desiccation and cold, allowing colonies of *Spirogyra* to overwinter, when needed. The other colony is now a filament of empty cells that will be broken down by some decomposer.

When conditions are right, the zygote undergoes meiosis to produce another vegetative colony of haploid cells.

> In the life cycle diagram below, indicate where meiosis and fertilization occur. Label a **vegetative cell, chloroplast, pyrenoid, nucleus, conjugation tube**, and **zygote**. Choose a color for the zygote to indicate that this structure is diploid.

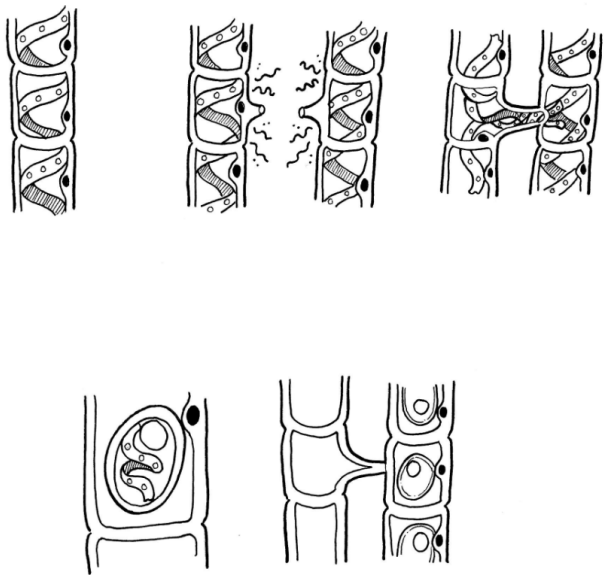


Figure 18.4.6: Spirogyra life cycle diagram

What type of life cycle is this?

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18.5: Pond Ecosystem Relationships

The following resource may be useful for this activity: https://www.msnucleus.org/watersheds/mission/plankton.pdf

A pond is an ecosystem teeming with life from across the tree of life. If available, view a sample of pond water in a petri dish under the dissecting scope. Try to identify any major groups of organisms you see (at least to phylum level) and make a catalogue of these in the space below.

Use a dropper to place a few drops of the pond water onto a slide. Add a coverslip and view your sample under the compound microscope. Document and attempt to identify any additional microorganisms you find in the space below.

As a class or with your lab group, make a collaborative list of the organisms in the pond ecosystem. Next, make a conceptual model that arranges these groups by relatedness. One way to do this is by building a phylogeny, much like you saw in Lab Microfungi - Slimes, Molds, and Microscopic True Fungi, organizing the evolutionary trajectory of these groups with a branching tree diagram. You can also see an example of this in Lab Evolution of the Embryophyta. However, a branching tree diagram is not the only way to communicate relationships. Feel free to get creative! What traits (such as photosynthetic pigments or cell wall components) differentiate these evolutionary lineages? How could you incorporate these into your model?

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18.6: Design an Experiment

You have learned about different groups of algae and the selection pressures that contributed to the differences between them. Use this information and your understanding of photosynthesis to design an experiment to test differences in photosynthesis between red and green algae. This is an open-ended prompt intended to give you some creative freedom to explore your own question. True science is rarely neatly packaged for you, so dig in and get messy!

Some suggested common lab materials to consider using for your experiment:

- Red, green, and blue transparent film
- Test tubes and flasks
- Saltwater and freshwater
- Baking soda (produces CO_2 when mixed with an acid or dissolved in water)
- Potassium hydroxide (absorbs CO_2)
- Full spectrum lamp, heat lamp, and other light sources

> Record your experimental design in the space below. What are the essential components you will need to consider? If time and supplies allow, set up and carry out the experiment.

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18.7: Summative Questions

1. If you were shown an algal species that produced large amounts of carotenoids, what would you infer about the ecology of this organism? Explain your reasoning.
2. If you were shown an algal species that produced a sulfated polysaccharide in its cell walls, what would you infer about the ecology of this organism? Explain your reasoning.
3. Many green algae have a haplontic life cycle. However, a few marine species exhibit alternation of generations. Why might you expect to see this in marine species?
4. Plants that specialize in shade-tolerance often have a dark red or purple pigment on the underside of their leaves. Why might this be?
5. What regions of the spectrum of light do chlorophylls absorb? Which part do they reflect?

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19: EVOLUTION OF THE EMBRYOPHYTA

Learning Objectives

Content Objectives

- View the different groups of land plants in the world around you and observe where and how they are growing
- Understand how the Earth has changed over time and how major lineages of plants evolved in response to these changes
- Understand the nested structure of classification and evolutionary relationships

Skill Objectives

- Distinguish between groups of plants using life history characteristics

19.1: Formative Questions

19.2: Introduction to the Evolution of the Embryophyta

19.3: Major Evolutionary Lineages

19.4: Summative Questions

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19.1: Formative Questions

1. What do plants need to survive?
2. Which of these do you think is the strongest driver for plant evolution and adaptations in your current environment? Explain.
3. Do you see evidence of this in the plants around you?

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19.2: Introduction to the Evolution of the Embryophyta

There are four major evolutionary groups of land plants: Bryophytes, Seedless Vascular Plants (SVPs), Gymnosperms, and Angiosperms. These groupings represent major changes in plant structure and life history characteristics over the course of time that coincide with major changes in the evolution of the Earth, as a whole. The classification “embryophytes” refers to the evolution of the **embryo**, a zygote that is retained and nourished by the female gametophyte as it grows.

Embryophytes share many common features, most corresponding to the selective pressures from the initial movement onto land. The embryo is one of these, providing higher likelihood of success for offspring in a new, harsh environment. In addition to the embryo, all plants have the same basic life cycle: **alternation of generations**. Much like the marine algae, the first plants were living in an environment where they needed to increase their chances of reproductive events. Multicellular stages on both sides of the life cycle increases the number of reproductive propagules. All plants are also **multicellular,** with **tissues** and **multicellular gametangia**.

Other adaptations to life on land include the desiccation-resistant compound **sporopollenin**. This is found in the cell walls of spores of early land plants and in pollen of seed plants, hence the name sporo - pollen - in. It is also found in the cell walls of a few green algae. On the exterior, plants are surrounded by a waxy **cuticle** that helps protect them from their outer environment.

Much like their green algal predecessors, plants store their carbohydrates as starch inside plastids, plastids with two membranes (the result of primary endosymbiosis), cell walls containing cellulose, and have the pigments chlorophyll a, chlorophyll b, and carotenoids. For this reason, along with genetic sequencing, land plants and green algae are grouped together in the Viridiplantae.

Phylogeny: A Hypothesis on Evolutionary Relationships

The diagram on the next page shows the nested relationships between lineages in the descendents of primary endosymbiosis. This diagram is a hypothesis for how these different lineages are related, based on a large amount of genetic information that was analyzed through the One Thousand Plant Transcriptomes Initiative (2019). In this project, they compared the genetic products (RNA transcripts) from over 1,000 species. The phylogeny summarizes their findings by grouping the organisms by who was most similar.

The red algae were most similar to the **outgroup**--a group thought to be prior to primary endosymbiosis--while the angiosperms were the least similar to the outgroup. It is most likely that these differences are because the angiosperms evolved later, after many differences had accumulated in their evolutionary history, differentiating them from the outgroup. The conclusions we draw about relatedness of major groups of plants and when these groups of plants evolved can also be supported by the fossil record. Rocks that fossils are found in can be dated and we can use morphological features found in those fossils to link them to extant plants.

We have no way of knowing the true evolutionary history of organisms, as we were not there to witness the events. However, we can use an assemblage of data to develop hypotheses about how the events occurred. The evolutionary groupings used in this lab manual are based largely on the findings from the following phylogeny.

As you work through the material today, reference the phylogeny and try to make sense of how it depicts the relationships described in the lab. Note the nested groups discussed. At the end, try to make your own simplified phylogeny.

Diagram below: Phylogenetic inferences of major clades; from One thousand plant transcriptomes and the phylogenomics of green plants by Leebens-Mack, J.H., Barker, M.S., Carpenter, E.J. et al. Nature 574, 679–685 (2019) [Open Access]

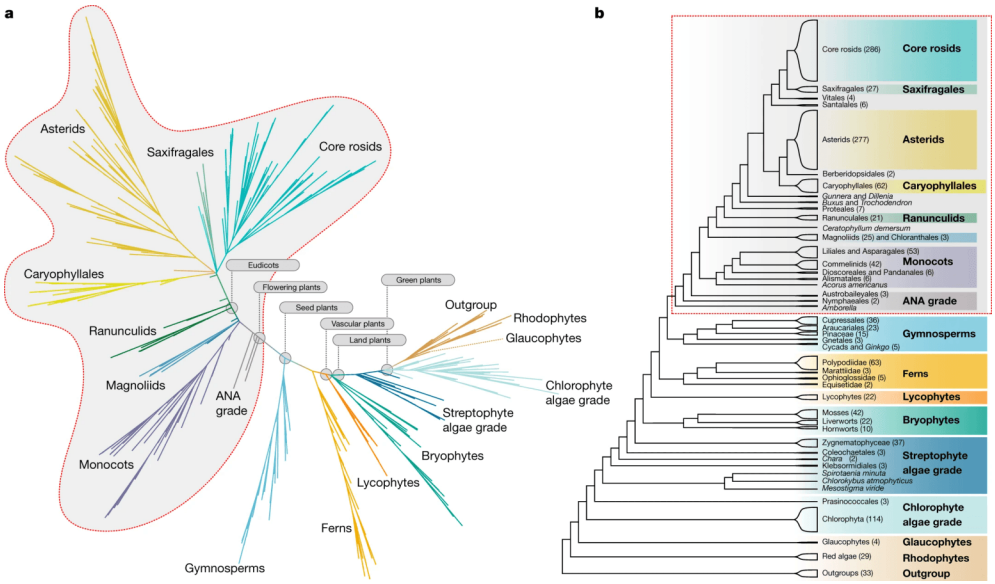


Figure 19.2.1: Phylogeny of Plants and Algae

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19.3: Major Evolutionary Lineages

The Bryophytes (~23,000 extant species)

Bryophytes arose in a period of Earth's history before soils had formed. The terrestrial surface was rocky and consisted primarily of crusts (microbial mats) composed of assemblages of prokaryotes. The exposure to sunlight would have been intense relative to the buffer provided by water. In addition, being surrounded by water would provide regulation of surrounding temperature and structural support. As green algae began to colonize the terrestrial surface, at least one of these lineages accumulated adaptations that were favorable to living on land--a waxy **cuticle** to prevent water loss, desiccation-resistant dispersal propagules called **spores**, and retention and feeding of the developing zygote. This lineage of green algae evolved into the ancestor of the bryophytes. This evolutionary group includes liverworts, mosses, and hornworts. These plants do not have true roots to absorb water, nor do they have vascular tissue to transport that water to other regions of the plant. Because of this, bryophytes tend to grow prostrate (close to the surface they are growing on) and stay quite small. They also tend to grow in moist areas where there is access to water and are reliant on water for the dispersal of gametes and fertilization.

> Draw any bryophytes that you see. Describe the environment where you found them. Were there features that the locations had in common (e.g. shaded)?
>
> What features did the bryophytes themselves share?

Tracheophytes

Seedless Vascular Plants (~20,000 extant species)

As bryophytes began to colonize the terrestrial surface, they produced organic acids during metabolism that aided in the breakdown of the rocky substrate. When they died, their organic matter mixed with the weathered rock, forming the Earth's earliest soils. Formerly abundant to the first terrestrial colonists, access to sunlight became competitive as bryophytes proliferated. This led to selection for individuals that could lift themselves higher and transport water throughout their tissues. Eventually, this selection resulted in the evolution of **vascular tissue** -- pipes that could bring water up from the ground so that parts of the plant could be raised upward, and those parts raised upward could transport their photosynthates down to the lower parts of the plant. The cells in the **xylem** (water-transporting vascular tissue) contained **lignin**, the tough, decay-resistant compound that wood is made out of. This rigid molecule in the vascular tissue allowed for structural support, allowing plants to grow taller -- some over 100 feet! The vascular system also allowed for the specialization of organs: roots for water absorption, leaves for photosynthesis, and stems for structural support.

Seedless vascular plants also began to rely more on the sporophyte stage. The sporophyte became the larger, nutritionally independent stage of the life cycle. **Branching sporophytes** offered more sites for meiosis to occur, resulting in increased opportunities for variation, which could be interpreted as more options in an increasingly competitive environment.

Seedless vascular plants that you might see today include club mosses, spike mosses, ferns, and horsetails. Though many modern taxa are relatively small in stature, extinct members of each of these groups had arborescent (tree-like) forms. Imagine a 100 ft tall horsetail -- this would be *Calamites*, an extinct member of the Equisetopsida from the Carboniferous period. The true era of the SVPs was 300-400 mya. The climate was tropical, with warm, shallow seas extending inland. Rapid growth of tree-like trunks with woody tissues that were difficult to break down resulted in the accumulation of large amounts of carbon-rich biomass that would become the coal deposits that this period is named for.

> Draw any SVPs you encounter. Describe the environment where you found them. Were there features that the locations had in common?
>
> What features did the plants themselves share?

Seed Plants

Gymnosperms (~1000 extant species)

Toward the end of the Carboniferous period, major changes in the climate occurred. The current day European and North American continents slammed together, forming the Appalachian mountains (which were taller, at that time, than the present-day Himalayas). Fossil and geologic records show a tendency toward a drier climate, with evidence of glaciation and lowered sea levels. Inland seas were increasingly diverted into distinct river channels as woody debris channelled the movement of waterways. In short, the terrestrial surface began to dry out and there was much more of it. The ancestors of birds, reptiles and mammals were adapting eggs that could survive outside of the water -- plants were working toward a similar strategy. Dry conditions would have selected for plants with thicker cuticles, leaves with less surface area to evaporate from, propagules that could survive through dry periods to germinate when water was available, and those that could grow taller than the current canopy. Around this time, a group of animals likely took flight for the first time -- the insects! This would present both new challenges and new opportunities for plants.

The plants that would become the gymnosperms evolved **xerophytic leaves** to prevent desiccation in the dry air. Some would have the ability to grow wider (and thus taller) via the production of a new layer of secondary xylem, AKA **wood**, each year. These plants could also produce exterior layers of dead cells, unlike the living epidermis, called **bark**. Together, the production of bark and wood are part of a process called **secondary growth**. To increase the chances of fertilization in the absence of water, gametes began to be dispersed aerially via **pollen**. Perhaps most importantly, the zygote and female gametophyte were surrounded in a protective coating and dispersed as **seeds**. Both seeds and pollen develop within structures called **cones**.

The first fossil records of gymnosperms are from a period called the Permian, just after the Carboniferous. Gymnosperms used to have many more species, but it is likely that the event that wiped out most of the dinosaurs also represented the end for most of those lineages. Extant groups of gymnosperms include the conifers, cycads (similar in appearance to palms), gnetophytes, and single species from the ginkgophytes, *Ginkgo biloba*. Of the approximately 1000 species of gymnosperms alive today, about 600 of these are conifers, 58 of which are found in California. Many lineages of gymnosperms are currently threatened with extinction.

> Why might so many conifers be found in California? Consider the unique climate of California -- Mediterranean -- and the climatic conditions during which gymnosperms evolved.
>
> Draw any gymnosperms you encounter. What features of their habitat and morphology did they share, if any? Were they all conifers?
>
> Consider the resin canals present in pine needles. What is their function and how does the presence of these canals reflect the conditions in which pines likely evolved?

Flowering Plants

Angiosperms (>370,000 extant species and counting)

At the end of the Permian period, there was the largest mass extinction this planet has ever experienced. It is estimated that 96% of species that lived at that time went extinct. This event signalled the downturn for some groups and opened up space for others to emerge. The exact timing of the emergence of angiosperms is unknown, so it is difficult to relate their evolution to specific climatic conditions. However, there is relatively new fossil evidence that may place flowering plants as early as the Jurassic period, 174 mya. This was the age of the dinosaurs and coincides with the emergence of the first feathered dinosaurs -- birds! Much like the insects, birds would present interesting opportunities for this new group of plants, working as both pollinators and seed dispersers.

Angiosperms can be distinguished from other plants by a set of specialized characteristics that allowed them to compete in an already full world. The (usually) easiest thing to identify about an angiosperm are its **flowers**. These collections of modified leaves allowed this group of plants to attract pollinators and increase the chances of successful fertilization. Once pollinated, the fertilized seeds are encased in a protective ovary whose structure can be specialized for different methods of dispersal, such as animal ingestion, animal attachment, flotation, or wind dispersal. This protective ovary and the encased seed(s) are more commonly called a **fruit**. Inside the developing seeds, angiosperms provide an additional food source to the developing zygote, the **endosperm**.

Competing with the gymnosperms for access to sunlight was perhaps hopeless, so the angiosperms adapted ways to work smarter, not harder. In the xylem, they evolved large diameter conducting cells for rapid water uptake called **vessel elements**, though this made them vulnerable to freezing conditions. In the phloem, sieve cells evolved into **sieve tube elements**, increasingly specialized for transportation of photosynthates.

As you might have guessed from the vast number of species, angiosperms occupy incredibly diverse habitats and span a range of morphologies, from tiny plants floating as a film on the surface of a pond to towering Eucalyptus trees dominating the forests of Tasmania, rivalling redwoods in height.

> Draw a few of the angiosperms you see. What did they have in common? Did they tend to grow in similar environments?
>
> Do you think any of these plants have the same pollinator? Why or why not?

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19.4: Summative Questions

1. Which of these major evolutionary groups appears to be the most abundant in your area? Why might this be? Consider your local climate, topography, and animal species.
2. If your climate were to become drier, which group would you expect to see more of? What if it were to become wetter? Explain your reasoning.
3. Which adaptations do all plants share for living on land?
4. Which traits do land plants share with green algae?
5. Place the following groups into the correct nested structure: Viridiplantae, flowering plants, tracheophytes, seed plants, embryophytes.
6. On the back of this page, draw a phylogeny that uses green algae as the outgroup. The traits you listed that are shared with green algae will be the **ancestral traits**. Use the information included in this lab to indicate where new traits evolve on your evolutionary timeline.

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20: BRYOPHYTES

Learning Objectives

Content Objectives

- Understand the difficulties organisms would face moving from an aquatic to a terrestrial environment
- Learn the characteristics that distinguish the bryophytes from green algae and from other land plants
- Learn the characteristics possessed by each group within the bryophytes
- Gain perspective on how the characteristics of early plants correspond with an Earth much different from today's, including how these plants would begin to shape that environment into our current one

Skill Objectives

- Correlate features of bryophyte anatomy and life history traits with adaptation to life on land
- Distinguish between multicellular green algae and thalloid bryophytes
- Distinguish between groups within the bryophytes, particularly between thalloid liverworts and hornworts, and between leafy liverworts and mosses

20.1: Formative Questions

20.2: Introduction to Bryophytes

20.3: Selection Pressures and Drivers

20.4: Anthocerotophyta - Hornworts

20.5: Marchantiophyta - The Liverworts

20.6: Bryophyta - Mosses

20.7: Summative Questions

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20.1: Formative Questions

1. What new environmental stressors would an alga need to adapt to if it were to try to move onto land?
2. Choose one of the stressors you mentioned above. Try to come up with a few ways that you could modify the alga to be adapted to that stressor (changes in specialized cells, changes in tissue composition and types of biomolecules present, changes in organ structure, etc...). Explain how these modifications would help the alga adapt to those conditions. Drawings or diagrams may help.

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20.2: Introduction to Bryophytes

Bryophytes arose in a period of Earth's history before soils had formed. The terrestrial surface was rocky and consisted primarily of crusts (microbial mats) composed of assemblages of prokaryotes. The exposure to sunlight would have been intense relative to the buffer provided by water. In addition, being surrounded by water would provide regulation of surrounding temperature and structural support. As green algae began to colonize the terrestrial surface, at least one of these lineages accumulated adaptations that were favorable to living on land--a waxy **cuticle** to prevent water loss, desiccation-resistant dispersal propagules called **spores**, and retention and feeding of the developing zygote. This lineage of green algae evolved into the ancestor of the bryophytes. This evolutionary group includes liverworts, mosses, and hornworts. These plants do not have true roots to absorb water, nor do they have vascular tissue to transport that water to other regions of the plant. Because of this, bryophytes tend to grow prostrate (close to the surface they are growing on) and stay quite small. They also tend to grow in moist areas where there is access to water and are reliant on water for the dispersal of gametes and fertilization. There are approximately 23,000 known extant species.

The evolutionary relationships between bryophyte lineages are currently unresolved.* Members of this group have the following characteristics:

- Morphology: Multicellular, can be leafy or thalloid. Complex tissues, including an exterior protective layer. Root-like structures called rhizoids provide anchorage.
- Cell wall composition: Cellulose
- Chloroplasts: 2 membranes, pigments are chlorophyll a, chlorophyll b, and carotenoids
- Storage carbohydrate: Starch
- Life cycle: Alternation of generations. Gametophyte dominant: sporophytes grow from and are nourished by the female gametophyte.
- Ecology: Terrestrial, gametes are dispersed in water

*Note: As of 2019, much is unresolved on the early lineages of plants and who was first on land. Recent genetic analyses interpret bryophytes as being monophyletic, all deriving from a common ancestor that branched from the main line of plants. Read this open-access paper for further information: https://doi.org/10.1073/pnas.1323926111

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20.3: Selection Pressures and Drivers

An important aspect of understanding the life history traits of the bryophytes is understanding the challenges of living in a terrestrial environment.

1. **Sun exposure**. Sunlight provides the power that drives our biosphere, but some wavelengths of sunlight can be damaging to cellular structure and even DNA. High frequency wavelengths, such as ultraviolet (UV), X-rays, and gamma rays can penetrate outer protective layers like skin, through cell membranes, and causing damage to DNA, proteins, and other biomolecules. Fortunately for organisms on Earth, almost all of these wavelengths are filtered by the atmosphere before they reach us, though some UV rays still make it through. These last UV rays are filtered out for aquatic organisms, but terrestrial organisms need adaptations to protect against UV radiation. Humans have skin with melanin pigments. Terrestrial plants have an **epidermis** and **carotenoid pigments**.
2. **Desiccation**. Transitioning from a completely aquatic environment to a terrestrial one leads to challenges of drying out, also known as desiccation. Temperatures are more extreme outside of the water and evaporation from tissues into the relatively dry air is constant. Terrestrial plants quickly adapted a waxy covering on the epidermis, called a **cuticle**. This water-tight covering required the evolution of **simple pores**, and eventually **stomata**, to allow gas exchange with the outer environment. Because these plants lack vascular tissue, water can only be transported around the organism via osmosis. Thus, these plants must keep all tissues close to water access.
3. **Lack of a soil environment**. The first organisms to move onto land would have found a relatively barren, rocky landscape. Soils did not yet exist. The rocky substrate experienced physical weathering from rain and wind that would help break it down. Chemical weathering through acidic rain or the interaction of water with compounds in the rock could also assist in breakdown. However, up to this point, contributions from organic matter would be minimal. Bryophytes lack true roots, instead producing structures called **rhizoids** whose function is anchorage. There are genes present in bryophytes, as well as some fossil evidence, that indicate bryophytes likely had mycorrhizal relationships with fungi that helped them acquire nutrients in this new landscape.

   View the bryophytes on display. Compare and contrast the overall morphology of bryophytes to the plants you can see outside. Why do you think the bryophytes all share such a similar growth form?

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20.4: Anthocerotophyta - Hornworts

- Gametophyte Morphology:
  - Exclusively thalloid, often with compartments of mutualistic cyanobacteria from the genus *Nostoc*
  - Hornwort cells are **monoplastidic**, containing one large chloroplast in each cell
  - Simple pores allow for gas exchange (no guard cells, meaning pores are permanently open)
- Sporophyte Morphology:
  - Linear sporangium that lacks a seta
  - Grows from a **basal meristem**
  - Stomata present for gas exchange

If available, observe an Anthoceros gametophyte with sporophytes under the dissecting microscope. Look for **simple pores, rhizoids, *Nostoc* colonies, sporangia,** and **stomata** on the sporangia**.** Draw/label these features in the space below.

Which part of the sporangium is the oldest? How do you know?

Make a wet mount of a small piece of hornwort thallus or obtain a prepared slide. Can you tell how many chloroplasts are in it? Draw this cell in the space below and label the chloroplasts and any other features you recognize.

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20.5: Marchantiophyta - The Liverworts

- Gametophyte morphology
  - **Leafy liverworts** have leaves arranged in a flat plane with a set of smaller underleaves
  - **Thalloid liverworts** have no leaves
  - Liverwort cells have multiple chloroplasts
  - Simple pores allow for gas exchange (no guard cells, meaning pores are permanently open)
  - Asexual clones, called **gemmae**, are sometimes produced
- Sporophyte morphology
  - Leafy liverworts produce single sporangium at the end of a seta (often fragile, transparent)
  - Marchantia, a thalloid liverwort, develops complex structures called where **gametangia** are produced

Leafy Liverworts

Cut off the end of a leafy liverwort and make a wet mount or obtain a prepared slide to view under the compound microscope. Draw the specimen below and indicate the three different rows of leaves (two in one plane, and a row of smaller underleaves running beneath the stem).

Still under the compound microscope, observe one of the leaf cells. Can you tell how many chloroplasts are in it? Draw this cell in the space below and label the chloroplasts and any other features you recognize.

Thalloid Liverworts: Marchantia

If available, observe a Marchantia polymorpha gametophyte under the dissecting scope. Look for **simple pores, rhizoids, archegoniophores, antheridiophores**, and **gemmae cups** containing asexual clones of the gametophyte, called **gemmae**. Label the bolded features in the life cycle diagram.

Marchantia life cycle:

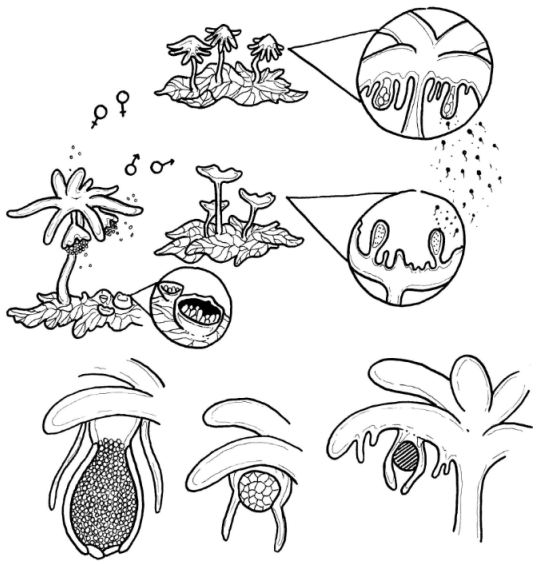


Figure 20.5.1: Marchantia life cycle diagram

In the diagram above, indicate where meiosis and fertilization occur. Color the haploid and diploid tissue differently, and draw arrows to show when mitosis is happening.

*Obtain a prepared slide of a Marchantia **antheridiophore**.* The male gametangia, **antheridia**, are produced on the top of

this structure. Each antheridium produces haploid, swimming **sperm** by mitosis. Label the bolded features in the life cycle diagram.

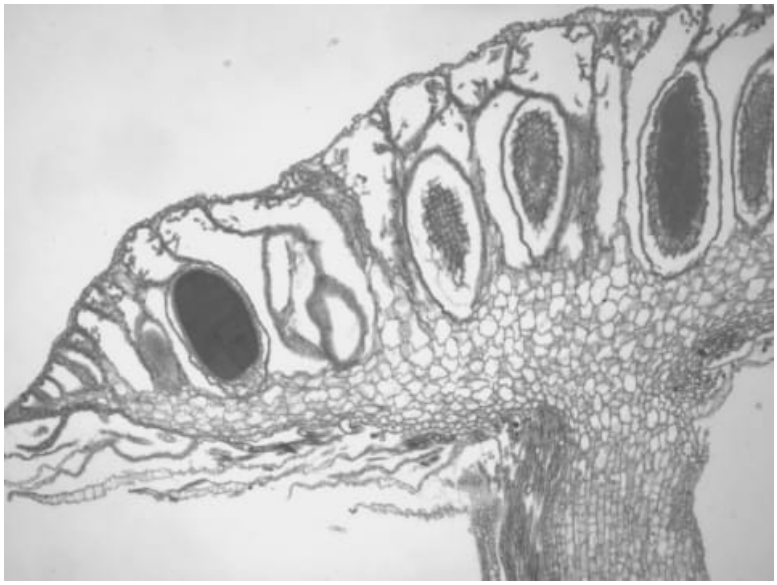


Figure 20.5.2: Marchantia antheridiophore

Obtain a prepared slide of an unfertilized Marchantia ***archegoniophore***. This is the structure that produces the female gametangia, **archegonia**. Each archegonium produces a single haploid egg by mitosis.



Figure 20.5.3: Marchantia archegniophore

A sperm will be transported by water to the archegoniophore, travel down the venter of the archegonium, and fertilize the **egg**. This forms a diploid **zygote**. Label the bolded features in the life cycle diagram.

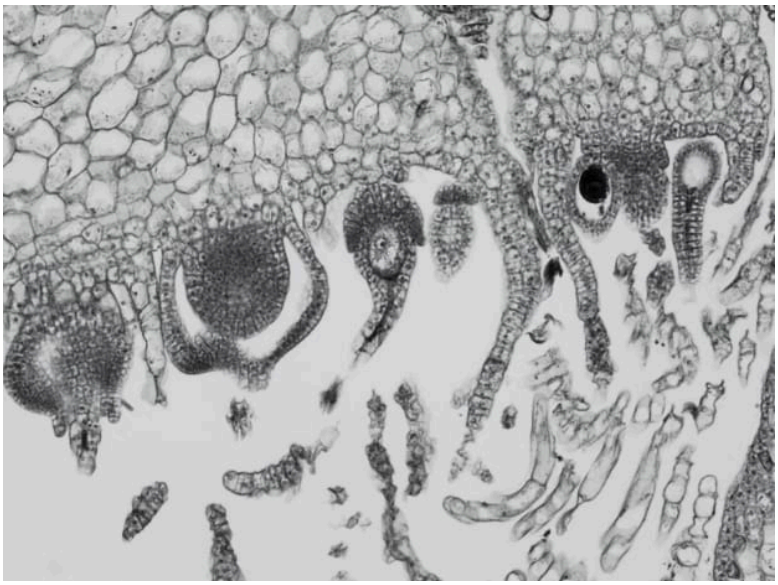


Figure 20.5.4: Archegonia close up

Obtain a prepared slide of a fertilized Marchantia archegoniophore with sporophytes. The zygote will be retained within the archegonium and nourished through the **placenta**, an area of gametophyte tissue adjacent to the **foot** of the sporophyte.

The mature sporophyte produces haploid spores via meiosis, which will grow into gametophytes. The sporophyte has a **seta** (the stalk), **sporangium** (also called a **capsule**), **spores**, and **elaters**, which aid in spore dispersal. Label the bolded features in the life cycle diagram.

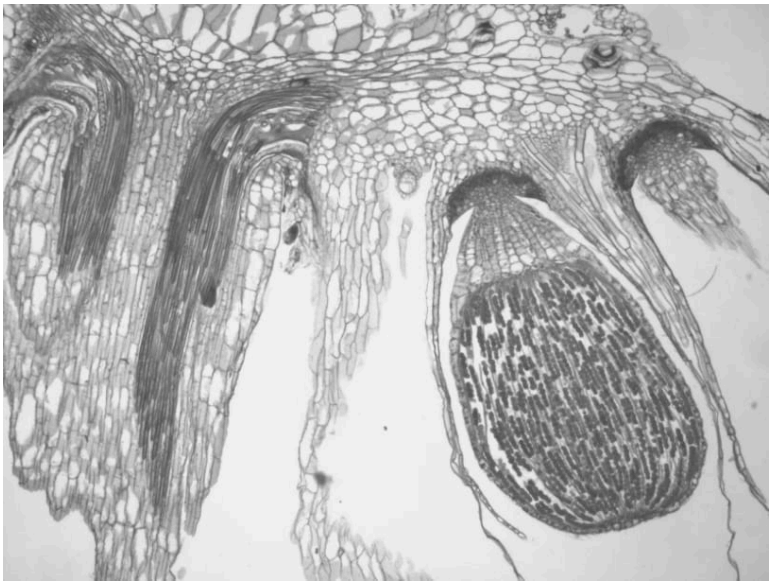


Figure 20.5.5: Marchantia sporophyte

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20.6: Bryophyta - Mosses

- Gametophyte Morphology:
  - Exclusively leafy. Leaves are arranged in a spiral and usually have a **costa**.
  - Simple pores allow for gas exchange (no guard cells, meaning pores are permanently open)
- Sporophyte Morphology:
  - Complex sporangium at the top of a seta
  - Stomata present for gas exchange

The Moss Life Cycle

If available, observe moss gametophytes with sporophytes under the dissecting scope. On the gametophytes, look for spirally arranged leaves, each with a **costa,** and **rhizoids** at the base. **Female gametophytes** will look tufted at the top. Within these tufts are hidden **archegonia,** each with a single **egg**. **Male gametophytes** will have a flat or cupped-looking top called a **splash cup** where **antheridia** produce sperm to be splashed out by rain drops. A **sporophyte** will grow from the top of a female gametophyte, emerging from one of the archegonia. Label the bolded features in the life cycle diagram.

Mnium life cycle:

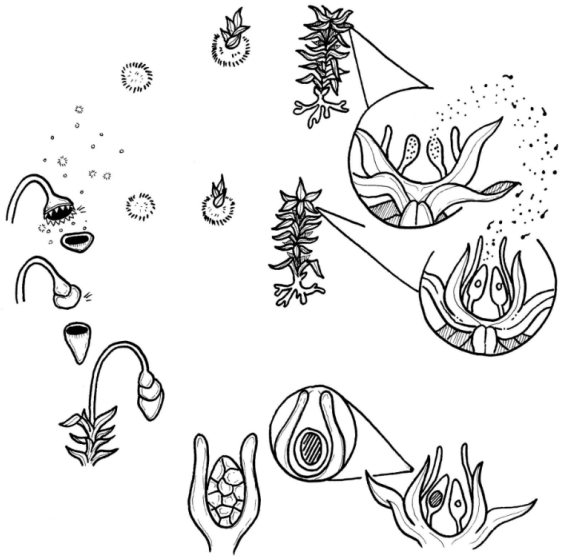


Figure 20.6.1: Moss Life Cycle Diagram

In the diagram above, indicate where meiosis and fertilization occur. Color the haploid and diploid tissue differently, and draw arrows to show when mitosis is happening.

Obtain a prepared slide of a Mnium male gametophyte (antheridial head). The **splash cup** at the top of the gametophyte holds the male gametangia, **antheridia**. Each antheridium produces haploid, swimming **sperm** by mitosis. Label the bolded features in the life cycle diagram.

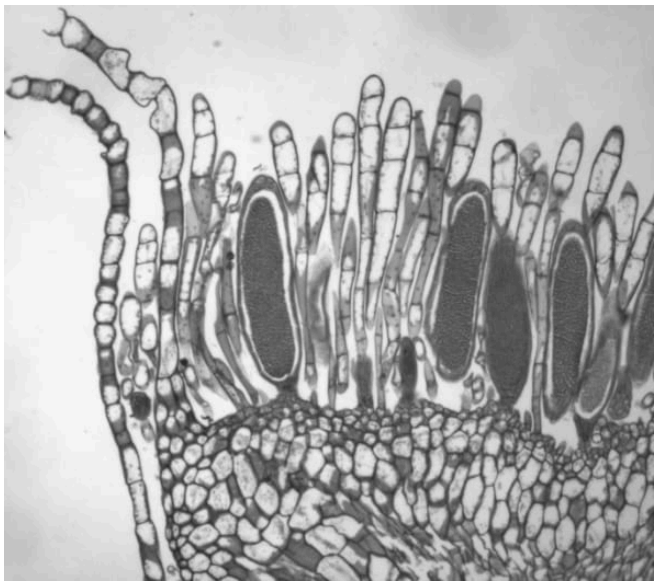


Figure 20.6.2: Antheridial head

Obtain a prepared slide of an unfertilized Mnium female gametophyte (archegonial head). This is the structure that produces the female gametangia, **archegonia**. Each archegonium produces a single haploid **egg** by mitosis. The process of fertilization is the same as in the liverworts, described above. Label the bolded features in the life cycle diagram.

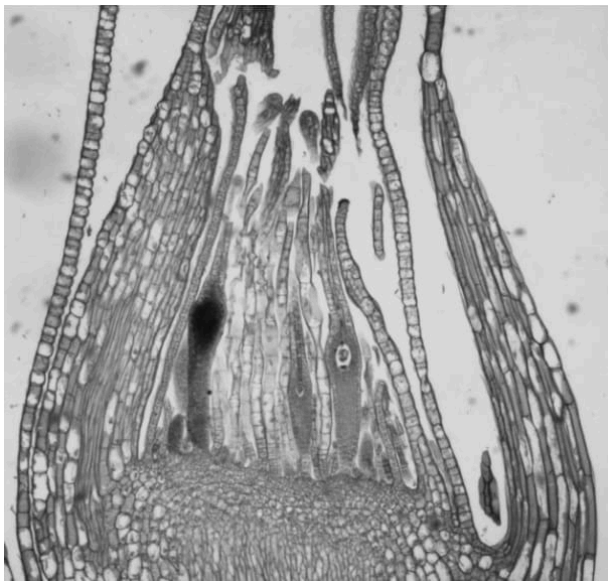


Figure 20.6.3: Archegonial head

Make a wet mount of a moss sporophyte or obtain a prepared slide of a Mnium sporangium. These complex sporangia contain several different parts. When the sporophyte emerges from the archegonium, it tears off the venter and creates a sort of cap on the sporangium, called a **calyptra**. This calyptra is haploid, as it originated from the female gametophyte tissue. Under the calyptra is a tiny lid-like structure called an **operculum** that keeps the **capsule** closed until the spores have developed. When the spores have matured, the operculum pops off and reveals the **peristome teeth**, which aid in spore dispersal via hygroscopic movements in response to desiccation. Label the bolded features in the life cycle diagram.

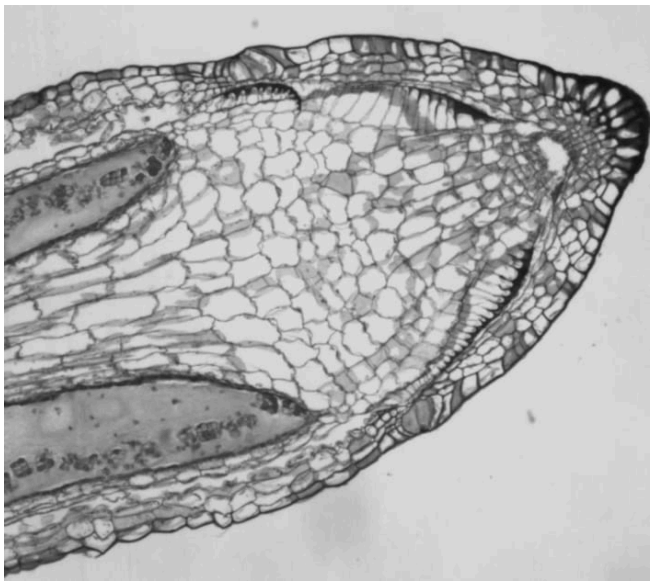


Figure 20.6.4: Moss capsule long section

This long section shows the developing sporangia (surrounding the grey areas), the operculum (covering the tip of the capsule), and the peristome teeth just below. The calyptra is not present.

> If your instructor has found fresh moss sporophytes that have peristome teeth (not all mosses do), place one or two of these sporophytes in a petri dish with a lid on and observe it under the dissecting scope. Draw what you see below and label all parts of the sporophyte.
>
> While looking through the dissecting scope and focused on the peristome, remove the lid of the petri dish. What happens to the peristome and what does this have to do with spore dispersal? If nothing happens, try lightly breathing on it and watching again through the scope.

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20.7: Summative Questions

1. Describe three adaptations that bryophytes have specifically for life on land.
2. Explain why bryophytes tend to be so small in stature and are often found growing appressed to a surface.
3. How would you tell the difference between a leafy liverwort and moss? Describe at least two things you could look for.
4. How would you tell the difference between a thalloid liverwort and hornwort? Describe at least two things you could look for.
5. Considering what you learned about the cyanobacterium *Anabaena*'s relationship to the water fern *Azolla*, how might the *Nostoc* living inside the hornwort tissues influence the hornwort's ability to survive on land?
6. What is the ploidy of the calyptra and where did this tissue come from? Does it have a function?

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21: SEEDLESS VASCULAR PLANTS

Learning Objectives

Content Objectives

- Understand the changing conditions on Earth during the period in which SVPs evolved and how those conditions selected for features found in SVPs
- Learn the characteristics that distinguish the SVPs from bryophytes
- Connect what you have learned about plant anatomy and photosynthesis to SVP structure
- Learn the sporophyte dominant life cycle of ferns

Skill Objectives

- Correlate features of SVP morphology and life history traits with adaptation to the changing environment
- Distinguish between mosses and lycophytes
- Distinguish between microphylls and megaphylls
- Identify SVPs based on strobilus anatomy
- Identify structures involved in the fern life cycle and describe their functions

21.1: Formative Questions

21.2: Introduction to Seedless Vascular Plants

21.3: Lycophytes (Class Lycopodiopsida)

21.4: Ferns (Class Polypodiopsida)

21.5: Summative Questions

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- Thumbnail: Equisetum sporangiophore

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21.1: Formative Questions

1. When bryophytes evolved on land, they didn't have to compete with other plants. What were the major selective pressures for the bryophytes?
2. If seedless vascular plants evolved after bryophytes began to colonize terrestrial surfaces, this would indicate a new major selective pressure: competition. What features might enable a fern to outcompete a moss?

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21.2: Introduction to Seedless Vascular Plants

As bryophytes began to colonize the terrestrial surface, they produced organic acids during metabolism that aided in the breakdown of the rocky substrate. When they died, their organic matter mixed with the weathered rock, forming the Earth's earliest soils. Formerly abundant to the first photosynthesizers to become terrestrial, access to sunlight became competitive as bryophytes expanded. This led to selection for individuals that could lift themselves higher and transport water throughout their tissues. Eventually, this selection resulted in the evolution of **vascular tissue** -- pipes that could bring water up from the ground so that parts of the plant could be raised upward, and those parts raised upward could transport their photosynthates down to the lower parts of the plant. The cells in the **xylem** (water-transporting vascular tissue) contained **lignin**, the tough, decay-resistant compound that wood is made out of. This rigid molecule in the vascular tissue allowed for structural support, allowing plants to grow taller -- some over 100 feet! The vascular system also allowed for the specialization of organs: **roots** for water absorption, **leaves** for photosynthesis, and **stems** for structural support.

Seedless vascular plants (SVPs) also began to rely more on the sporophyte stage. The sporophyte became the larger, nutritionally independent stage of the life cycle. **Branching sporophytes** offered more sites for meiosis to occur, resulting in increased opportunities for variation, which could be interpreted as more options in an increasingly competitive environment. There are approximately 20,000 known extant species, most of which are ferns.

SVPs are considered to be a paraphyletic group of organisms, forming two distinct lineages: Ferns and Lycophytes. These two lineages share the following characteristics:

- **Morphology:** Sporophytes develop complex tissues, including **lignified vascular tissue**, true roots, stems, and leaves. Sporophytes are branched, producing many sporangia. Gametophytes are reduced and thalloid. In some groups, the gametophyte is subterranean and parasitizes mycorrhizal fungi for sugars.
- **Life cycle:** Alternation of generations. **Sporophyte dominant**: sporophytes still grow from the gametophyte, but are now photosynthetic and the larger, longer-lived phase of the life cycle.
- **Ecology:** Gametes are still dispersed in water, so moisture is still required for fertilization.

Selection Pressures and Drivers

1. **Competition for sunlight**. To get access to sunlight, SVPs needed to grow taller than bryophytes. However, this presents a problem of distributing water around the plant body to prevent drying out. Seedless vascular plants solved this problem with the adaptation of lignified vascular tissue. The lignin in the secondary walls of sclerenchyma cells allowed SVPs the structural support to grow taller.
2. **The initial forming of soils**. Before the bryophytes, terrestrial surfaces were primarily rocky. The first land plants would have contributed to the chemical weathering of these rocks by producing acids during metabolism. After death, these plants add their organic matter to these weathering rocks, beginning to form Earth's early soils. Fungi were likely involved in this process, as there are genes in the bryophytes for mycorrhizal relationships.

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21.3: Lycophytes (Class Lycopodiopsida)

- **Microphylls**. Leaves have a single, unbranched vein of vascular tissue. *Note: The term microphyll, confusingly, is not an indication of the size of the leaf.*
- **Rhizomes**. Asexual propogation of the sporophyte through underground stems.
- **Homosporous or heterosporous**. Haploid spores grow into bisexual gametophytes in *Lycopodium*. In Selaginella, **microspores** develop into **microgametophytes** that produce sperm and **megaspores** develop into **megagametophytes** that produce eggs.

Extinct lycophytes like *Lepidodendron* and *Sigillaria* grew into tall trees, branching dichotomously and producing a moss-like canopy of microphylls. Some of these microphylls were several feet long! Lycophytes first appear in the fossil record over 400 million years ago. By the Carboniferous period (around 300 mya), the landscape was covered with lycophyte forests and shallow swamps. Much of the fossil fuels we use today are derived from these extinct arboreal lycophytes falling into swamps, slowing decomposition and creating layers of carbon-rich material that we now find as coal seams.

> Why would being submerged in water slow decomposition? Consider the cellular process normally associated with decomposition activity and what is required to perform this process.
>
> If available, observe fossil specimens or images of fossils from extinct lycophytes. Do these resemble any plants you see today?
>
> Extant lycophytes (those species still alive today) are represented by creeping forms, such as *Lycopodium* and *Selaginella*. Observe fresh specimens and prepared slides of *Selaginella* and/or *Lycopodium*. Draw and describe the important characteristics that differentiate these plants from bryophytes, including stem and leaf structure, below ground parts, and where spores are produced.

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21.4: Ferns (Class Polypodiopsida)

- **Megaphylls**. Leaves have branching veins of vascular tissue.
- **Rhizomes**. Asexual propogation of the sporophyte through underground stems.
- **Homosporous**. Haploid spores grow into bisexual gametophytes that produce both antheridia and archegonia.

Horsetails (Subclass Equisetidae)

- Gametophyte morphology
  - Reduced, thalloid. Bisexual gametophytes grow from homospores and produce both antheridia and archegonia.
- Sporophyte morphology
  - Leaves are dark, papery and non-photosynthetic.
  - Branches are photosynthetic and produced in whorls on the **vegetative shoot**.
  - Sporangia produced in a terminal strobilus on the **reproductive shoot**.
  - Shoots contain **silica**
  - Spores are photosynthetic and have four hygroscopic arms called **elaters**

Horsetails are one of the most ancient lineages of plants and are relatively unchanged from the fossil record. If you look closely at the nodes of a green vegetative shoot**,** you will see that branches and leaves have not only switched roles, they have also switched places, with the photosynthetic branches emerging below the papery, non-photosynthetic leaves. The stems of horsetails are covered in silica, giving them the common name scouring rush, as they were formerly used to clean pots due to the abrasive nature of silicate granules. This is what gives the epidermis of the shoot its rough texture.

> Observe a vegetative shoot of Equisetum. Draw what you see below and label a **node**, **internode**, **branch**, and **leaf**. Where would the rhizome be found?

You may notice that there are shoots without branches that appear more yellow than green. These are the reproductive shoots. Reproductive shoots of some *Equisetum* species (such as *E. arvense*) do not photosynthesize. Instead, they receive nutrients through the rhizome, which is connected to vegetative shoots. The function of the reproductive shoot is to produce a strobilus. In the strobilus, sporangia are produced on large, T-shaped structures called **sporangiophores**. Within the sporangia, photosynthetic homospores mature and develop projections called **elaters** that aid in spore dispersal via interaction with humidity in the air.

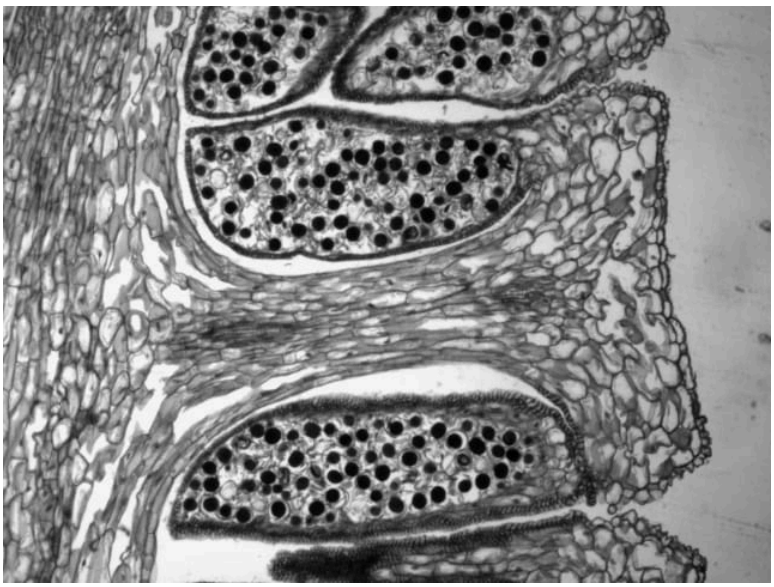


Figure 21.4.1: Equisetum sporangiophore

Obtain an *Equisetum* strobilus from a reproductive shoot. Tap the strobilus onto a dry slide to release mint green spores,

do not cover with a coverslip. View this slide under the compound microscope and draw what you see below.

As you are looking through the ocular lenses of the microscope, add a drop of water to the slide near your field of view. What happens to the spores that are close to the droplet of water? What happens when they are touched by the water? Describe and draw what you see below.

Comparing Strobili

Lycophytes and horsetails produce spores in a cone-like structure called a strobilus. Obtain a prepared slide of a long section of the strobilus of each of the following: *Equisetum*, *Lycopodium*, and *Selaginella*.

	Equisetum	Lycopodium	Selaginella
Homosporous or heterosporous?			
Sketch of the strobilus long section			
Distinctive features?			

Ferns (Subclass Polypodiidae)

- Gametophyte morphology
  - Reduced, thalloid, heart-shaped. Often referred to as a prothallus or prothallium.
- Sporophyte morphology
  - Megaphylls often pinnately compound **fronds**, emerging as **fiddleheads** in the spring.
  - Sporangia produced in clusters called **sori** (sorus, singular).

Fern Life Cycle

Observe a prepared slide of a fern gametophyte (sometimes referred to as a prothallus) under the compound microscope. Look for **rhizoids, archegonia** (each with a single **egg**), and **antheridia** containing many **sperm**. Label the bolded features in the life cycle diagram.

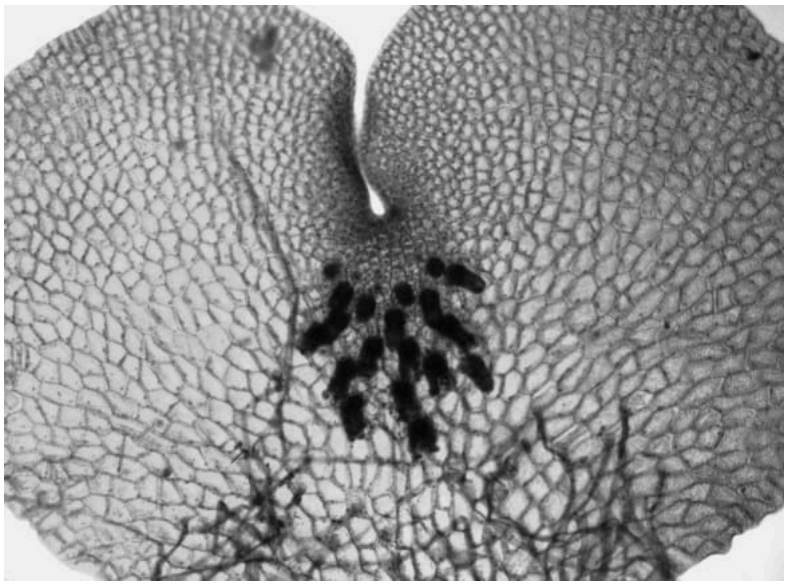


Figure 21.4.2: Fern Gametophyte

Archegonia and rhizoids are visible on the prothallium in the above figure.

Below: a side view of an archegonium

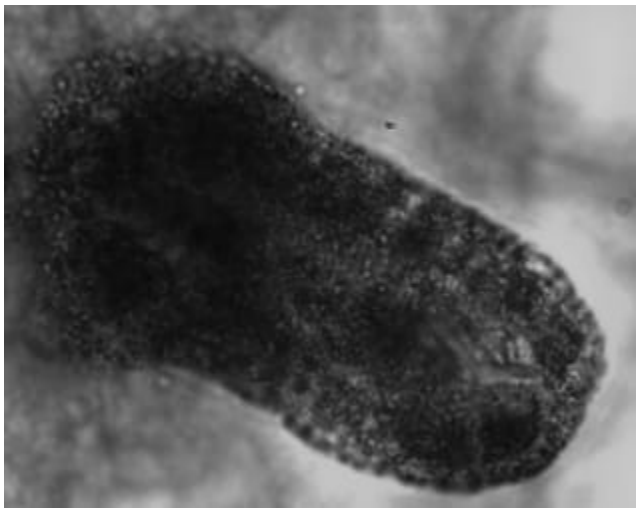


Figure 21.4.3: Fern archegonium

Antheridium with sperm (left) and an archegonium with an egg (right)

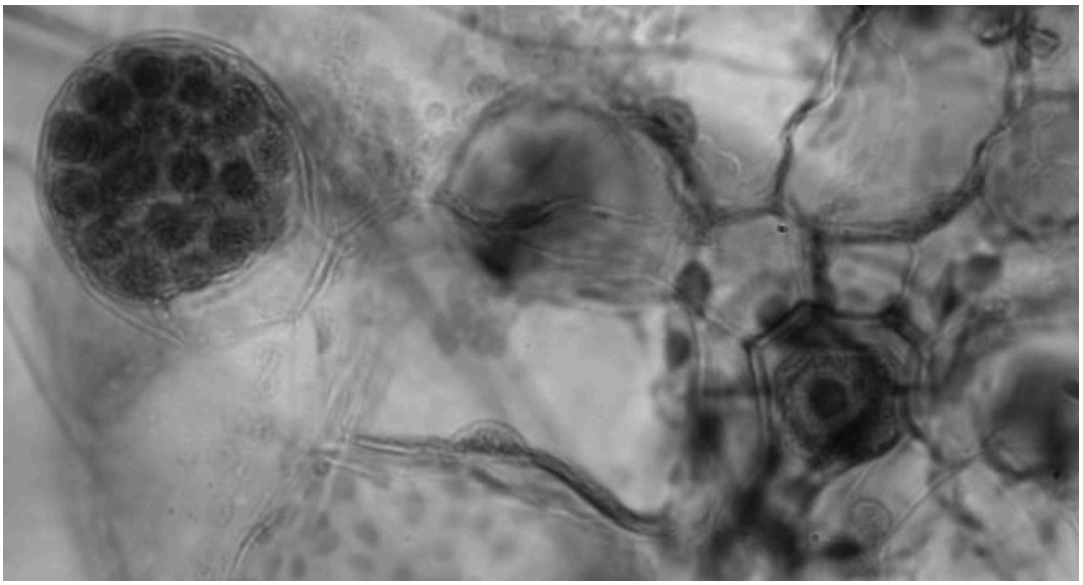


Figure 21.4.4: Fern gametangia

Note

One strategy ferns have evolved to avoid self-fertilization is to produce archegonia and antheridia at different times. Depending on the type of fern gametophyte you are looking at, you may need to view two different slides to see archegonia and antheridia.

Observe a fern **fiddlehead,** so named for its visual similarity to the scroll at the top of a violin. The fiddlehead uncoils in the spring by a process called **circinate vernation** (vernal meaning spring). Observe a mature fern **frond**. Locate the **rachis**, **pinnae**, and **sori**. Label the bolded structures in the life cycle diagram.

Obtain a prepared slide of a **sorus**. A sorus is a cluster of sporangia, often protected by an umbrella-like structure called the **indusium** as the spores mature. Each **sporangium** is lined by an inflated strip of cells called an **annulus**. When the spores have matured, the cells in the annulus begin to dry out, causing the cells to collapse and pull the sporangium open, releasing the spores. Label the bolded structures in the life cycle diagram.

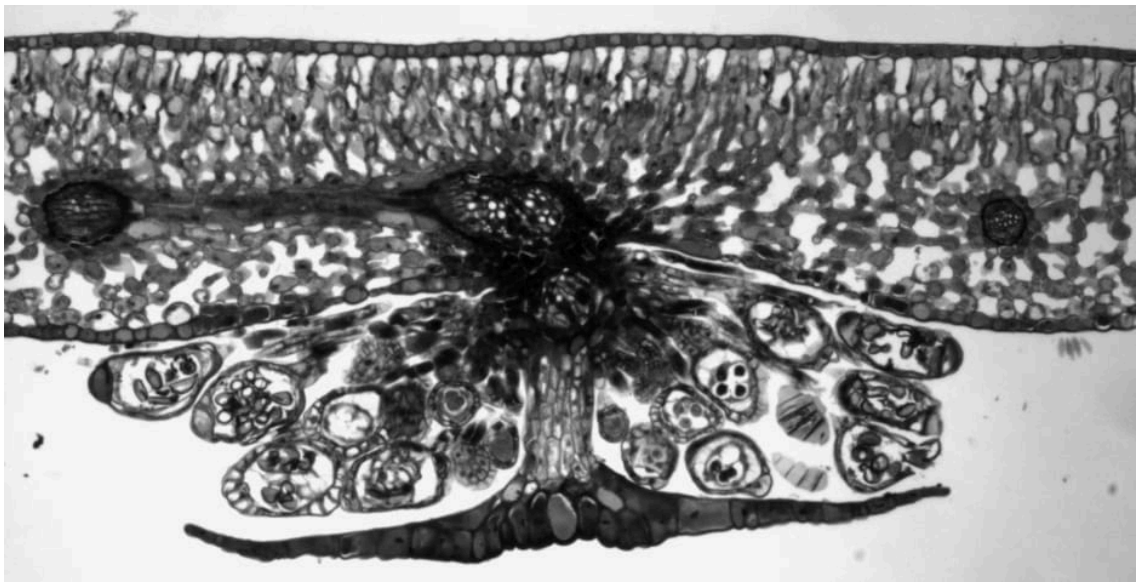


Figure 21.4.5: Fern Sorus

Based on the orientation of the palisade and spongy mesophylls in the leaf cross section above, is this sorus on the upper or lower surface of the leaf? Explain your reasoning.

Fern Life Cycle Diagram

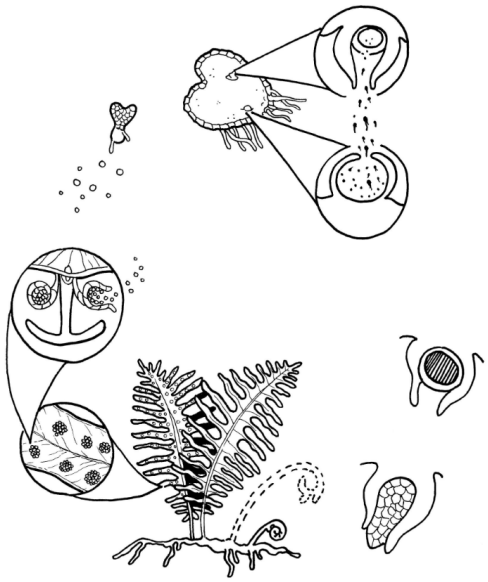


Figure 21.4.6: Fern Life Cycle Diagram

In the fern life cycle diagram, label the bolded structures described in the section above. Indicate where meiosis and fertilization occur and draw arrows to show where mitosis is happening. Choose different colors to represent haploid and diploid tissues.

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21.5: Summative Questions

1. Describe three adaptations that SVPs have that allow them to compete with bryophytes.
2. Commonly called spike mosses and club mosses, lycophytes aren't truly mosses at all. How could you distinguish between a moss and a lycophyte?
3. Each time a rhizome produces a new shoot, it also produces roots. What type of roots emerge from stem tissue, such as a rhizome?
4. Compare and contrast the role of the gametophyte in bryophytes and SVPs.
5. What are the advantages to having a branching sporophyte?

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22: GYMNOSPERMS

Learning Objectives

Content Objectives

- Understand the changing conditions on Earth during the period in which gymnosperms evolved and how those conditions selected for features found in this group.
- Learn the characteristics that distinguish gymnosperms from SVPs
- Connect what you have learned about secondary growth and xerophytic leaf anatomy to gymnosperm structure
- Learn the life cycle of pines

Skill Objectives

- Correlate features of gymnosperm morphology and life history traits with adaptation to the changing environment
- Identify structures involved in the gymnosperm life cycle and describe their functions
- Distinguish between different groups of gymnosperms
- Distinguish between gymnosperms and SVPs, particularly ferns and cycads

22.1: Formative Questions
22.2: Introduction to Gymnosperms
22.3: Selection Pressures and Drivers
22.4: Cycads and Ginkgos
22.5: Gnetophytes and Conifers
22.6: Using a Dichotomous Key
22.7: Summative Questions

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22.1: Formative Questions

1. When you think of plants adapted to dry conditions, what comes to mind? What features do these plants have?
2. Would a snowy environment be considered a dry environment for a plant? Why or why not?

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22.2: Introduction to Gymnosperms

Toward the end of the carboniferous period, major changes in the climate occurred. The current day European and North American continents slammed together, forming the Appalachian mountains (which were taller, at that time, than the present-day Himalayas). Fossil and geologic records show a tendency toward a drier climate, with evidence of glaciation and lowered sea levels. Inland seas were increasingly diverted into distinct river channels as woody debris channelled the movement of waterways. In short, the terrestrial surface began to dry out and there was much more of it. The ancestors of birds, reptiles and mammals were adapting eggs that could survive outside of the water -- plants were working toward a similar strategy. Around this time, a group of animals likely took flight for the first time -- the insects! The presence of flying insects allowed for another option for distributing pollen, as well as a large source of potential herbivory.

The plants that would become the gymnosperms evolved **xerophytic leaves** (see lab 7) to prevent desiccation in the dry air. Some would have the ability to grow wider (and thus taller) via the production of a new layer of secondary xylem (**wood**) each year. These plants could also produce exterior layers of dead cells, unlike the living epidermis, called **bark**. Together, the production of bark and wood are part of a process called **secondary growth**. To increase the chances of fertilization in the absence of water, gametes began to be dispersed aerially via **pollen**. Perhaps most importantly, the zygote and female gametophyte were surrounded in a protective coating and dispersed as **seeds**. Both seeds and pollen develop within structures called **cones**.

The fossil record shows gymnosperms diversifying in a dry period called the Permian that followed the swampy Carboniferous period. Extant groups of gymnosperms include conifers, cycads (somewhat similar in appearance to palms), gnetophytes, and a single species from the ginkgophytes, *Ginkgo biloba*. Of the approximately 1,000 species of gymnosperms alive today, about 600 of these are conifers, 58 of which can be found in California. In fact, some of the oldest (bristlecone pine), tallest (coast redwood), and most massive (giant sequoia) organisms on the planet are conifers and all are native to California.

See this open-access paper for recent genetic work on the evolutionary relationships between gymnosperms: http://dx.doi.org/10.1098/rspb.2018.1012

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22.3: Selection Pressures and Drivers

1. **Competition for sunlight**. Seedless vascular plants were able to reach heights up to 100 feet tall. In the lineage leading to the gymnosperms and angiosperms, some plants developed the ability to grow wider as they grew taller. This secondary growth allowed for increased stability and, eventually, to reach heights over 300 feet.
2. **Drought**. Dry conditions would have selected for plants with thicker cuticles, leaves with less surface area to evaporate from, and propagules that could disperse without water and survive through dry periods to germinate when water was available.
3. **Herbivory**. In addition to leaves that could resist drought, the presence of insects would have driven selection for plants that could defend against herbivory. The thick cuticle and tough texture of xerophytic leaves made them difficult to eat, while resin canals in both leaves and stems provided another line of defense.

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22.4: Cycads and Ginkgos

Ginkgos (1 extant species)

As of writing this manual, the most recent genetic studies have placed Ginkgos as the oldest of the extant gymnosperms. This does not mean that it was the first gymnosperm. From the fossil record, it seems that most early gymnosperms went extinct. The sole remaining species in this group, *Ginkgo biloba*, is a living fossil virtually unchanged from its fossilized ancestors. It is possible that this species was only kept alive due to cultivation efforts by Buddhist monks for its medicinal properties. This species is also long-lived, a single tree can live for thousands of years, and resistant to most pests. *Ginkgo biloba* can be recognized by the following features:

- Leaves deciduous, but tough, fan-shaped
- **Dioecious** (di- meaning two, oecious meaning house), with male and female strobili on separate plants**.** Females plants have paired ovules at the tips of branches, males have catkin-like structures that produce pollen.
- Wind pollinated

Observe the *Ginkgo biloba* specimens available in lab. Make notes and drawings of features that would help you recognize this species in the space below:

Cycads (approximately 300 extant species)

Cycads are another of the more ancient gymnosperm lineages, appearing in the fossil record around 300 million years ago. Currently, many extant species are in danger of extinction in the wild. However, during the Jurassic period, these plants would have dominated the landscape. Though their large, compound leaves make them appear to be ferns at first glance, cycads can be classified as gymnosperms by the production of seeds instead of spores and xerophytic leaves. These plants share the following features:

- Dioecious. Male and female strobili on separate plants.
- Large compound, xerophytic leaves
- Insect pollinated

Observe the cycad specimens available in lab. Make notes and drawings of features that would help you recognize this group in the space below:

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22.5: Gnetophytes and Conifers

Gnetophytes (approximately 70 extant species)

Gnetophytes represent an anatomically and genetically difficult group to classify. They have several traits in common with angiosperms, such as vessel elements in the xylem, double fertilization, and a covering over their seeds (more on this in labs 21 and 22). Even their leaves are angiosperm-like, with netted venation. However, these traits are convergently evolved, meaning that angiosperms and gnetophytes each evolved these traits separately. Genetically, recent studies have placed the gnetophytes as a sister group to the Pinaceae (pine family) within the conifers. This would mean that pines, firs, and spruces are more closely related to strange gnetophytes like *Ephedra* than they are to other conifers like redwoods, cedars, and Pacific yew. However, the true nature of this evolutionary relationship remains murky and contentious.

- Angiosperm-like features: vessel elements, double fertilization, fruit-like ovule coverings
- Dioecious. Female plants have covered ovules, while male plants have pollen cones.
- Leaves xerophytic with opposite arrangement
- Primarily insect pollinated; brightly colored seeds are dispersed by birds

Observe the gnetophyte specimens available in lab. Make notes and drawings of features that would help you recognize this group in the space below:

Conifers (approximately 600 extant species)

Conifers are the most species-rich lineage of gymnosperms. From the fossil record, we think there were over 20,000 species of conifers. However, their diversity declined with the dinosaurs. As discussed in the introduction, these amazing plants represent some of the oldest, tallest, and most massive organisms on the planet. Though currently low in diversity, these amazing plants make up 30% of Earth's forests. Conifers share the following characteristics:

- **Monoecious**. Plants produce both male and female strobili on the same plant.
- Wind pollinated with winged pollen
- Xerophytic leaves with a low surface area to volume ratio. Primarily evergreen, but some species are deciduous (e.g. Dawn redwood and larch).

Note

The Pinaceae is currently the largest family of conifers, so many of our examples for this group of gymnosperms will be from the type genus *Pinus* (pines).

Pine Life Cycle

In the pine life cycle, the pine tree is the **sporophyte**. Because pines are monoecious, one sporophyte will produce both **microstrobili** and **megastrobili**. The microgametophytes are formed within the **microsporangia** of the microstrobilus, or **pollen cone**. These structures are all diploid. Within the microsporangium, there are **microsporocytes**, diploid cells that undergo meiosis to become haploid gametophytes.

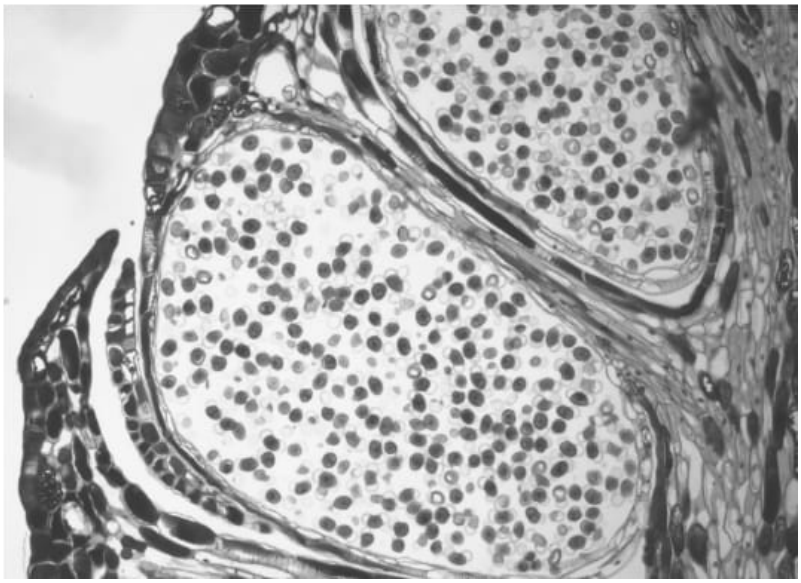


Figure 22.5.1: Microsporangium in a pollen cone

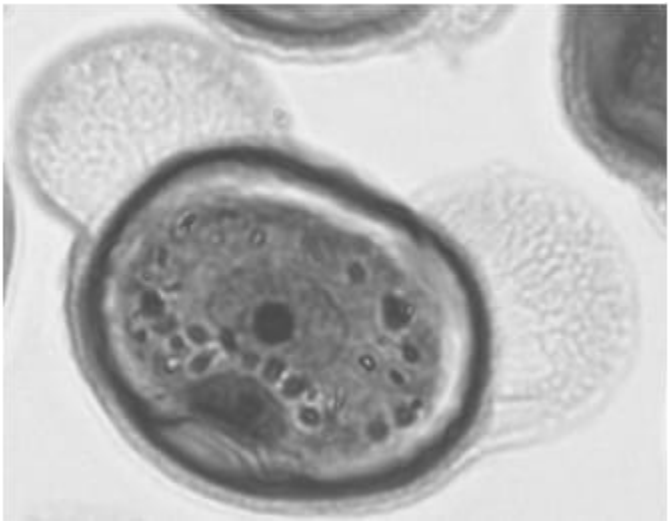


Figure 22.5.2: Pine pollen

The **microgametophyte** in gymnosperms is the four-celled, winged **pollen** grain. Within the pollen grain, you can distinguish the generative cell and the tube cell nucleus. The two prothallial cells are not apparent under the microscope. On either side of the pollen grain, two ear-like structures emerge. Thes air sacs may help orient the pollen grain toward the ovule.

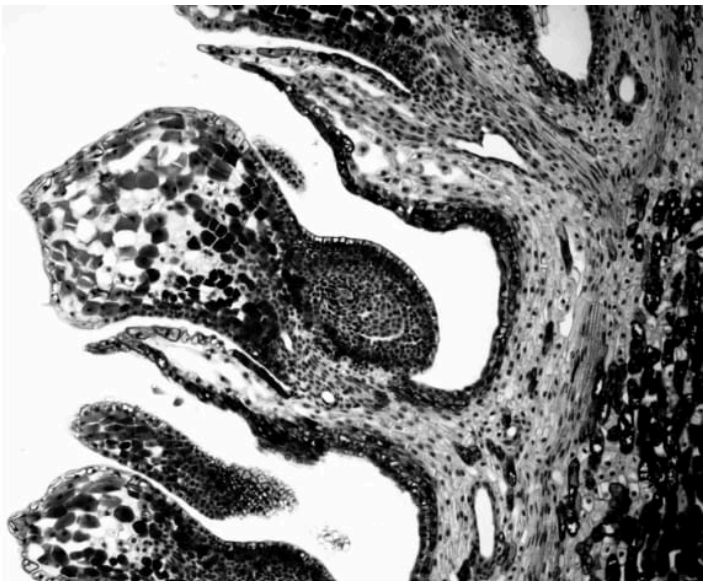


Figure 22.5.3: Megastrobilus long section

Similarly, the megastrobilus, or **seed cone**, contains diploid **megasporocytes** that are produced within a **megasporangium**. Each megasporocyte undergoes meiosis. However, unlike the microsporocytes, only one of the four cells will survive to develop into a **megagametophyte** and the other three will die.

The megagametophyte is part of the **ovule** and contains (usually) two **archegonia**, each with an egg cell inside. The megagametophyte is retained within the megasporangium, which becomes the **nucellus**. Surrounding the nucellus is the **integument**, which is initially continuous with the **ovuliferous scale** and has a small opening called a **micropyle**.

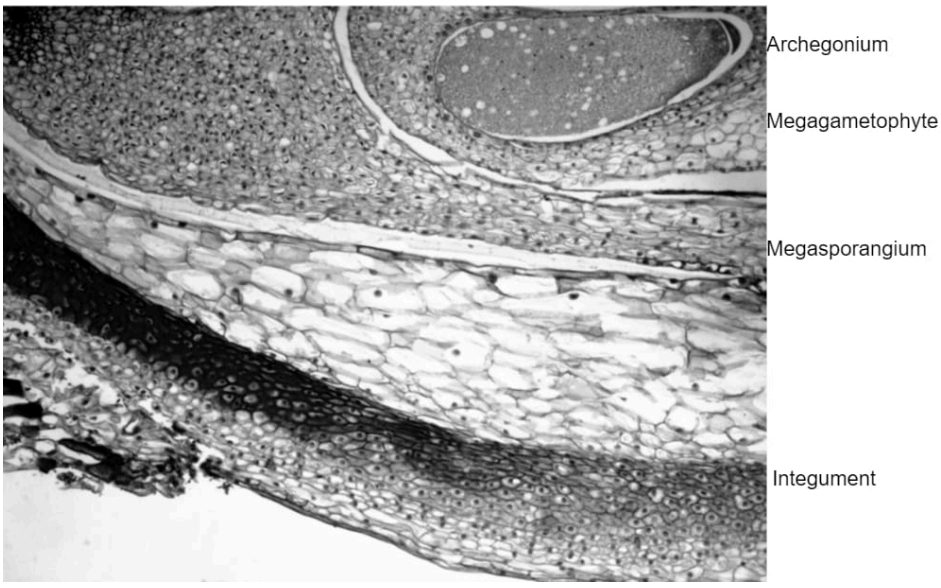
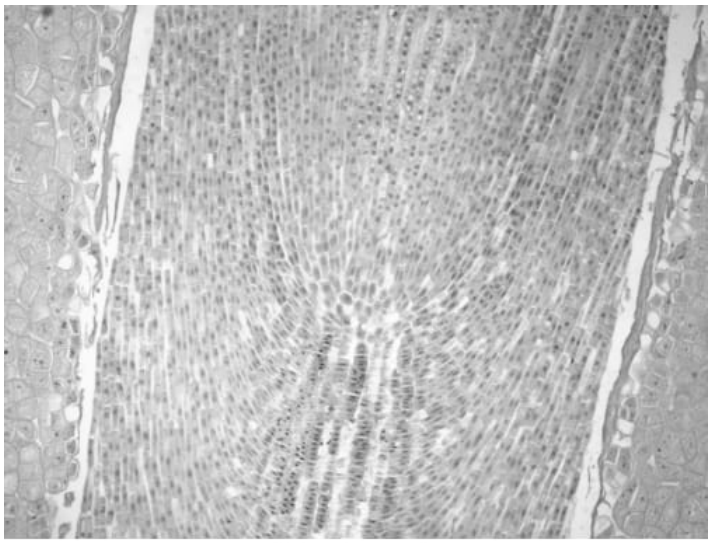


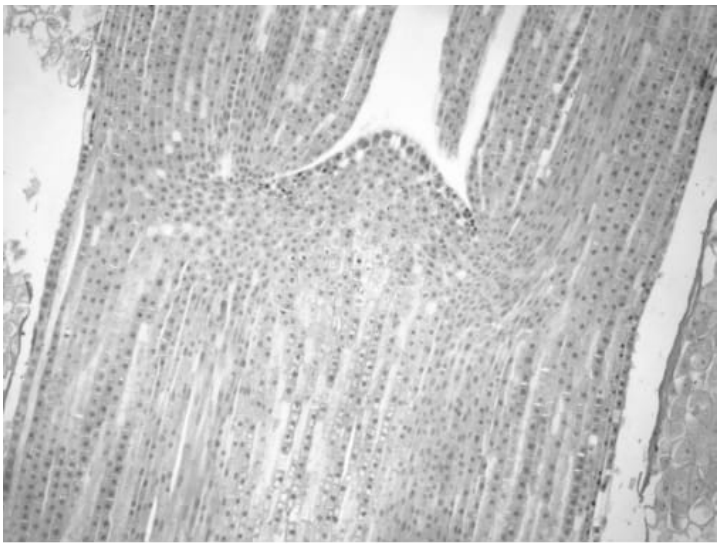
Figure 22.5.4: Close up of pine ovule long section

A grain of pollen will be transported on the wind and, if lucky, it will land on a seed cone. The seed cone has a drop of sugary liquid that it secretes, then retracts, pulling the pollen in toward the ovule. This stimulates the tube cell to germinate a pollen tube, while the generative cell divides by mitosis to produce two sperm. These sperm travel down the pollen tube, through the micropyle, and into an archegonium where one will fertilize an egg. When fertilization occurs, the micropyle closes and the integument becomes the **seed coat**.



RAM of embryo

Figure 22.5.5: Embryo RAM



SAM of embryo

Figure 22.5.6: Embryo SAM

The zygote will grow and develop as an **embryo**, nourished by the megagametophyte tissue, as well as the nucellus. If you look in a long section of a pine seed, you can see the embryo's RAM and SAM. The seed will be dispersed by wind or animals and germinate to grow into a diploid pine tree once again.

Pine Life Cycle Diagram

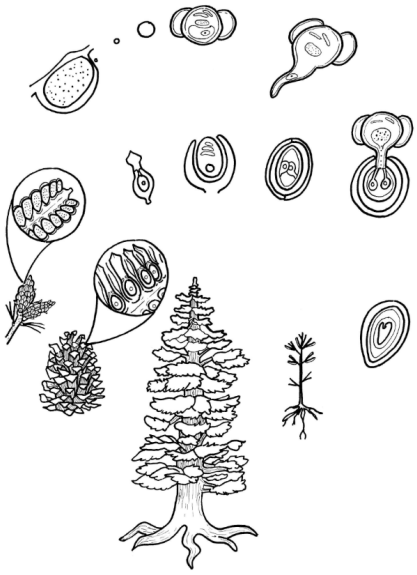


Figure 22.5.7: Pine Life Cycle Diagram

Label the pine life cycle diagram above with the bolded terms from the “Pine Life Cycle” section. Indicate where fertilization and meiosis occur. Draw and label arrows to indicate mitosis. Choose a different color to represent haploid and diploid tissues.

Pine Leaf

In lab Leaf Anatomy, you learned about leaf anatomy and were introduced to the concept of xerophytic leaves. One of the examples in that lab of xerophytic leaves was the pine needle. In the image below, you can see a cross section through a pine needle. Label the following features: **xylem, phloem, transfusion tissue, endodermis, mesophyll, hypodermis, epidermis,** and **cuticle**.

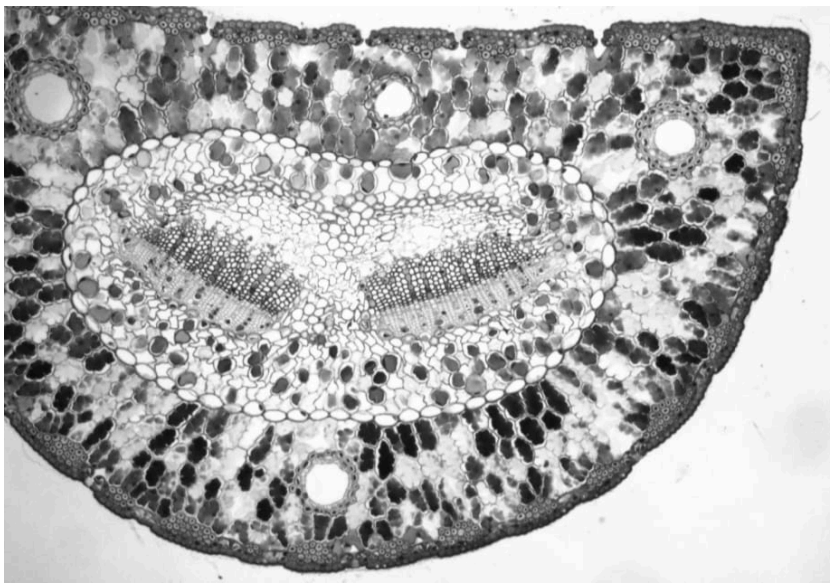


Figure 22.5.8: Pine needle cross section

The three large holes you see in the leaf above are **resin canals**. These conduct a thick, sticky compound called resin that aids in plant defense. What might the resin in the pine needle help pines defend against? Explain your reasoning.

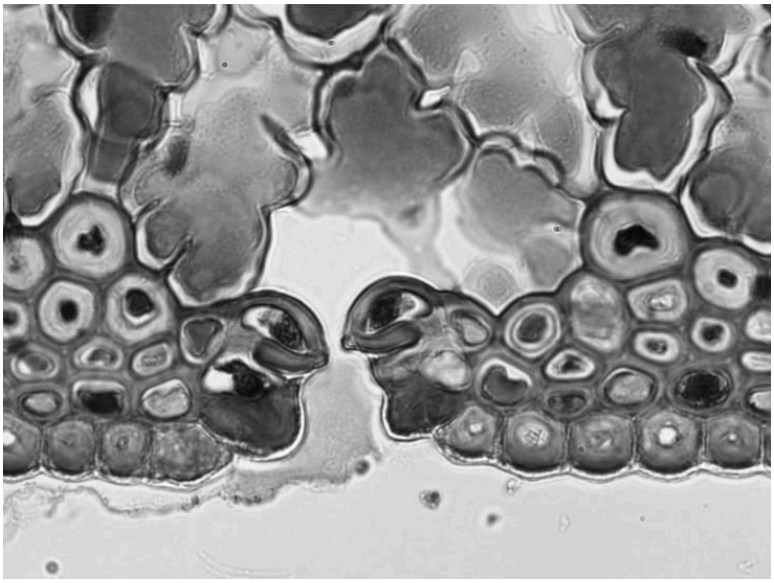


Figure 22.5.9: Sunken stoma

The image above shows a close up of a sunken stoma. Label the **mesophyll, guard cells, stoma, hypodermis, epidermis,** and **cuticle**.

How do sunken stomata help leaves reduce water loss?

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22.6: Using a Dichotomous Key

In Appendix A there is a key to common campus trees. Note that this key was written for a campus on the far north coast of California, so the trees in your area may be different. A dichotomous key is a tool people use to determine the identity of different organisms. At each step in the key, you are presented with a pair of options, such as “leaves are blue” and “leaves are some color other than blue”. You choose which of these options matches your specimen, then follow the path to either the next set of questions, or the end result. Here is an example from the key:

6a. Leaves palm-shaped, deeply dissected, and emerging opposite from each other on the branch....

Maple

6b. Leaves are not as above ... 7

If the leaves you were looking at matched the description in 6a, you would determine that your specimen as a maple. If they were not palm-shaped, or in some other way didn’t match the description, you would would choose 6b and proceed to the set of questions labelled 7a and 7b to make your next choice.

Use the attached key to identify trees on campus or samples provided in the lab.

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22.7: Summative Questions

1. What is pollen?
2. Why was pollen an important adaptation for gymnosperms, considering the changing global conditions?
3. What adaptations do gymnosperms share that allowed them to compete with SVPs?
4. Describe the advantages provided by the adaptations you listed in the previous question and relate them to changes in global climate.
5. How would you differentiate a fern and a cycad?
6. What features do gnetophytes have that classify them as gymnosperms?
7. Which features do gnetophytes have that lead people to believe they might be more closely related to angiosperms?
8. What other explanation could there be for gnetophytes and angiosperms sharing these traits?
9. In what climate(s) would you be most likely to find gymnosperms? Explain your answer.

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23: ANGIOSPERMS I - FLOWERS

Learning Objectives

Content Objectives

- Understand the changing conditions on Earth during the period in which angiosperms evolved and how those conditions selected for features found in this group.
- Learn the characteristics that distinguish angiosperms from other plant groups
- Learn the gross anatomy and function of flowers
- Discover different pollination syndromes

Skill Objectives

- Correlate features of angiosperm morphology and life history traits with adaptation to the changing environment
- Identify components of a flower based on location and describe their functions
- Identify the most likely pollinator of a flower based on morphology, color, and smell

23.1: Formative Questions

23.2: Introduction to Angiosperms

23.3: Selection Pressures and Drivers

23.4: Specialized Vascular Tissue

23.5: Anatomy of a Flower

23.6: Stimulating Pollen Tube Growth

23.7: Pollination Syndromes

23.8: Inflorescence Types

23.9: Summative Questions

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23.1: Formative Questions

1. When you think of a flower, what characteristics come to mind?
2. How might those characteristics relate to the function of a flower?
3. Flower petals are not involved in photosynthesis, yet they have stomata. Provide a possible explanation for this.

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23.2: Introduction to Angiosperms

The exact timing of the emergence of angiosperms is unknown, so it is difficult to relate their evolution to specific climatic conditions or other circumstances. However, there is relatively new fossil evidence of flowering plants as early as the Jurassic period, 174 mya. This was the age of the dinosaurs and coincides with the emergence of the first feathered dinosaurs -- birds! Angiosperms represent a single origin of related organisms, the phylum Anthophyta, that experienced an exceptional radiation in species. As of 2019, there are approximately 370,000 known extant species. Most of the plants that you see, eat, and otherwise interact with in your daily life are likely to be in this group.

Angiosperms can be distinguished from other plant groups by the production of **flowers**. These collections of modified leaves allowed angiosperms to attract pollinators and increase the chances of successful fertilization. Over time, angiosperms evolved different flower morphologies, smells, and colors that corresponded to their particular pollinators. These sets of characteristics, called **pollination syndromes**, allow scientists to predict the pollinators for different plants.

In the xylem, this group of plants evolved large diameter conducting cells for rapid water uptake called **vessel elements**, though this made them vulnerable to freezing conditions. In the phloem, sieve cells evolved into **sieve tube elements** with their associated **companion cells**, increasingly specialized for transportation of photosynthates.

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23.3: Selection Pressures and Drivers

1. **Competition for space**. Present day gymnosperms include the tallest, most massive, and some of the oldest organisms on the planet. With this in mind, you can imagine that they would be difficult to compete with. Angiosperms needed to evolve more efficient methods of transporting water and photosynthates, fertilization, and survival of offspring.
2. **Insects and birds**. The primary response to insects that we see in gymnosperms is prevention of herbivory. While herbivory is still a driver of selection for angiosperms, insects also served as a more efficient method of pollen delivery. Insects and birds could be lured in with sugary nectar or scents and colors that mimicked other resources, then dusted with pollen as they investigated. If the lures were specialized enough, they would continue seeking the same resource, leading them to another plant of the same species. These scents, colors, and nectar resources were produced by structures that also produced pollen and ovules -- the flower.

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23.4: Specialized Vascular Tissue

When you looked at vascular tissue during the anatomy portion of this class, you learned that the conducting cells in xylem are tracheids and vessel elements, while in phloem they are sieve cells, sieve tube elements, and companion cells. However, not all plants have the same vascular composition. In SVPs and gymnosperms (with the exception of gnetophytes), the xylem contains only tracheids, while the phloem contains only sieve cells. These were the earliest versions of conducting cells. It was not until the angiosperms that vessel elements, sieve tube elements, and companion cells evolved.

> Recall the experiment you did in Lab Roots and the Movement of Water. How did the diameter of the straw influence the height the water moved up the straw?
>
> How does this relate to the ability of angiosperms to compete with gymnosperms?

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23.5: Anatomy of a Flower

Flowers are composed of sets of highly modified leaves arranged in whorls. The outermost whorl of a flower is called the **calyx** and is composed of **sepals**. Inside the calyx is the **corolla**, which is composed of **petals**. The sepals are often smaller and less colorful than the petals, but this general rule can be misleading. For example, lilies often have identical sepals and petals. The only way you can distinguish between them is by location: Which whorl is on the outside?

Together, the calyx and corolla are called the **perianth** (peri- meaning around, anth- meaning flower). Inside the perianth is the **androecium** (house of man), a whorl composed of **stamens**. Each stamen has a long **filament** holding up pollen sacs called **anthers**. Inside the androecium is the **gynoecium** (house of woman), which is composed of **carpels**. Each carpel has an **ovary** at the base where **ovules** are housed. The **style** emerges from the ovary and is topped by the **stigma**. Pollen grains land on the stigma and must grow a tube down the style to reach the ovule and complete fertilization.

All of these whorls attach to an area called the **receptacle**, which is at the end of the stem that leads to the flower. This stem is called the **peduncle**. In the case of an inflorescence, where multiple florets are produced in place of a single flower, the stems leading to the florets are called pedicels.

> In the diagram of the flower below, add labels for all of the bolded terms above and assign each whorl a different color. Make a key for the colors and whorls.

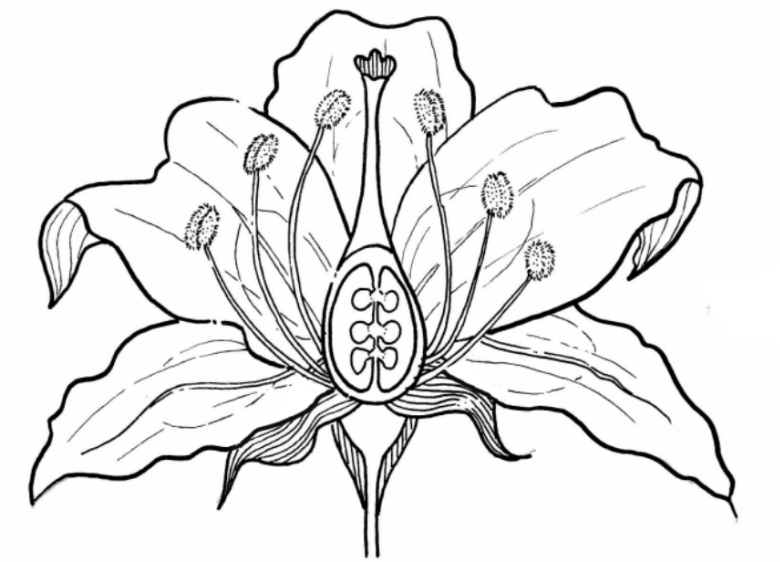


Figure 23.5.1: Floral Structure

Symmetry and Quantity

Two other features used to identify flowers are symmetry and the number of parts in each whorl.

Flowers that have multiple lines of symmetry (like a starfish) are **radially symmetrical**, also called actinomorphic. Flowers with only a single line of symmetry (like you) are **bilaterally symmetrical**, also called zygomorphic.

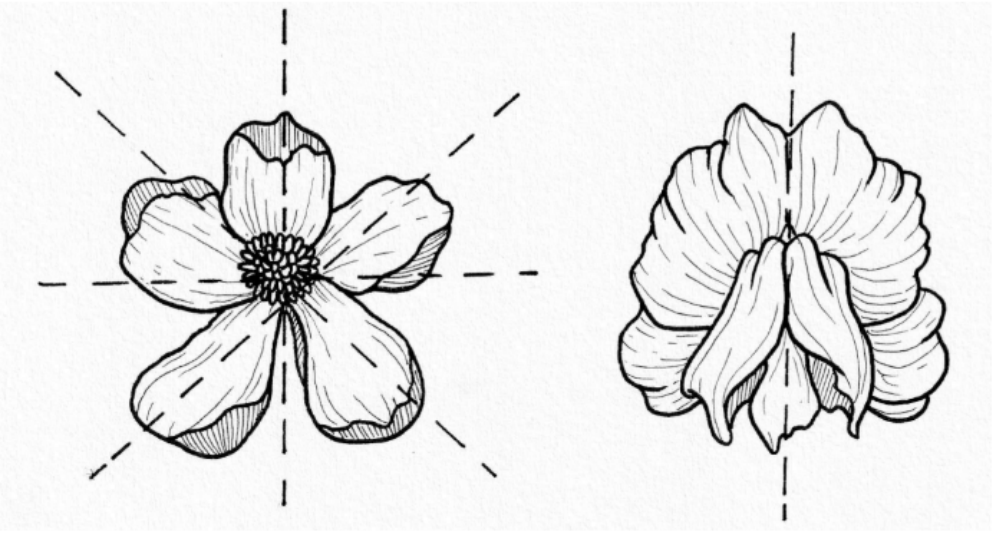


Figure 23.5.2: Flowers and symmetry

Flowers with parts in sets of 3 are generally monocots. Flowers with parts in sets of 4 or 5 are generally eudicots. Sometimes these parts are fused together and can be difficult to count. For example, in the diagram of the lily above, there are three fused carpels. You would only be able to determine this by counting the lobes on the stigma or by looking at a cross section of the ovary to count the different compartments (called **locules**).

Notes on other terms

Many wind pollinated flowers have evolved to be either male or female, containing either an androecium or gynoecium, but not both. These flowers are called **imperfect**, while flowers containing both internal whorls are called **perfect**. Flowers that contain all whorls are called **complete**. However, there are also **incomplete** flowers that have lost other whorls during the course of their evolution. Wild ginger, *Asarum caudatum* (shown below), has lost its corolla and has a large showy calyx in its place. This strange plant has fly pollinated flowers and ant dispersed seeds.



Figure 23.5.3: Asarum caudatum

Dissecting a Flower

Obtain a fresh flower specimen. Dissect a flower and carefully remove the individual pieces. Draw (or assemble and press) the individual components onto the following table. Label the parts of the stamen and carpel.

Table 23.5.1: Dissected Floral Whorls

Drawing with labels:	Sepals	Petals	Stamen	Carpels
Whorl:				
Quantity:				
Fusion? (yes/no)				

Is this flower a monocot or a eudicot? How can you tell?

How would you describe the symmetry of this flower?

What other terms could you use to describe it?

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23.6: Stimulating Pollen Tube Growth

Throughout the evolution of plants on land, there is a trend in reduction of the gametophyte. Pollen is the microgametophyte in both gymnosperms and angiosperms. Recall that conifer pollen has four cells and inflated air sacs that serve as wings. In angiosperms, the pollen lacks wings and is reduced to only two cells: the generative cell and the tube cell.

Below are two microgametophytes. On the left is pine pollen, a gymnosperm microgametophyte. On the right is lily pollen, an angiosperm microgametophyte.

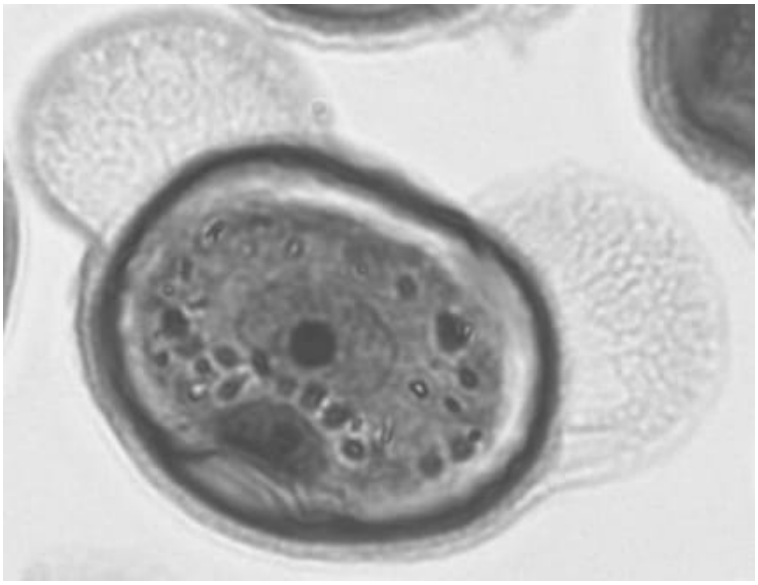


Figure 23.6.1: Pine pollen



Figure 23.6.2: Lily pollen

Which cells were lost in angiosperm pollen (present in gymnosperms)?

What are the functions of the tube cell and the generative cell?

The stigma contains compounds that trigger the production of the pollen tube. This trigger can be as simple as a high concentration of carbohydrates, which we can mimic by using corn syrup. However, sometimes there are extra triggers present on

a stigma, such as lipids or calcium. For the next part of the lab, you are going to develop and conduct an experiment to test the best method for stimulating production of pollen tubes.

Questions to consider:

1. How will you determine what “best” means? Is it number of pollen grains to produce a pollen tube? Average length of pollen tube?
2. How will you standardize other variables? Will you have controls?
3. Will you have replicates within your experiment? Will other scientists be able to replicate your work in future experiments?

Record your experimental design and steps of the process of science on "Pollen Tube Germination Experimental Design" below.

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23.7: Pollination Syndromes

Pollination is essential for producing offspring. Because of this, it serves as a strong driver of selection in angiosperms. Flowering plants have evolved to utilize different pollinators, such as wind or birds, to transport their pollen to other flowers of the same species. Some of these pollinators, such as wind, are not selective and rely on producing large quantities of pollen. Others, like hummingbirds, require large quantities of nectar and are attracted by particular colors. Use the table of pollination syndromes below to determine the likely pollinator for the flowers available in your lab.

Table 23.7.1: Pollination Syndromes (adapted from US Forest Service)

	Color	Structure	Scent	Nectar or Pollen
Wind	Dull, perianth often absent or reduced	Large feathery stigmas, large anthers	None	No nectar, large amounts of pollen
Birds	Reds and pinks	Often tubular or cupped	None	Lots of hidden nectar, moderate pollen
Bees	Purples, blues, yellows, white, UV	Flat and shallow or tubular, with landing area	Sweet, fresh, mild	Pollen often sticky and scented, nectar usually present
Bats	White, dull green, or purple	Often bowl-shaped or pendant, anthers protruding	Musty or fruity, strong, emitted at night	Lots of hidden nectar
Moths	White, pale pink or purple	Often tubular or cupped, no landing pad	Strong and sweet, emitted at night	Lots of hidden nectar, limited pollen
Butterflies	Bright colors	Tubular, with wide landing pad	Faint, fresh	Lots of hidden nectar, limited pollen
Flies	Dark red, purple, brown	Shallow, funnel, or trap-like	Putrid, rotting	No nectar, moderate pollen

Who is the pollinator?

Record the most likely pollinator and the trait(s) in the flower that lead you to this conclusion:

1.

2.

3.

4.

5.

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23.8: Inflorescence Types

Much like leaves, flowers can be compound, becoming an **inflorescence** made up of many **florets**. And, just like leaves, inflorescences can be distinguished from individual flowers by the nodes they emerge from. A **peduncle** will emerge from a node in place of a branch, subtended by a leaf. A **pedicel**, the stem that leads to a floret, will not emerge from a node.

An important feature used in identifying angiosperms is the type of inflorescence. There are many inflorescence types, but the following are some of the most commonly encountered.

Head (also called a capitulum). Florets are clustered on an enlarged receptacle. Heads can contain one or more of the following types of florets

- Disc florets - petals are separate and all the same length; radially symmetrical
- Ray florets - petals are fused together; bilaterally symmetrical

Umbel. Pedicels converge on a single point, where they attach to the peduncle.

Spike. Florets are sessile, attached directly to a central axis

Raceme. Similar in structure to a spike, but the florets have pedicels

Panicle. A branched raceme

Use the information above to identify the inflorescence types present in your lab. In the space below, make a sketch of each inflorescence type that will help you make these determinations in the future.

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23.9: Summative Questions

1. How could the coevolution of angiosperms and pollinators explain the vast radiation in species that angiosperms experienced?
2. What would a bird pollinated raceme of bilaterally symmetrical eudicot flowers look like? What would it smell like? Draw one below and label any important features.
3. How does the structure of a vessel element relate to the ability of angiosperms to compete with gymnosperms?
4. Where does meiosis occur in the flower?
5. Where does the name “Anthophyta” derive from? Consider the root words.

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24: ANGIOSPERMS II - FRUITS

Learning Objectives

Content Objectives

- Learn the angiosperm life cycle
- Learn the gross anatomy and function of fruits
- Learn the different types of fruits and associated dispersal agents

Skill Objectives

- Identify components of the angiosperm life cycle and describe their functions
- Distinguish between the different layers of the pericarp
- Use a dichotomous key to identify fruit types
- Determine the most likely dispersal agent based on fruit morphology

24.1: Formative Questions

24.2: Introduction

24.3: Selection Pressures and Drivers

24.4: Angiosperm Life Cycle

24.5: Fruits

24.6: Using a Dichotomous Key to Identify Fruit Type

24.7: Dispersal Syndromes

24.8: Summative Questions

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24.1: Formative Questions

1. When you think of a fruit, what characteristics come to mind?
2. How might those characteristics relate to the function of a fruit?

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24.2: Introduction

The term angiosperm means “seed vessel” and refers to the production of fruits. Every flower becomes a fruit, though these fruits might not always fit with our cultural perception of what it means to be a fruit. Once pollinated, the fertilized seeds are encased in a protective ovary whose structure can be specialized for different methods of dispersal, such as animal ingestion, animal attachment, flotation, or wind dispersal. This protective ovary and the encased seed or seeds are more commonly called a **fruit**. Inside the developing seeds, angiosperms provide an additional food source to the developing zygote, the **endosperm**. The endosperm is produced by a process called **double fertilization** where one sperm fertilizes the egg and another fertilizes a pair of haploid nuclei, which makes the endosperm triploid (3n).

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24.3: Selection Pressures and Drivers

1. **Competition with gymnosperms.** Gymnosperms were large, successful organisms adapted to a variety of severe conditions. To compete with this group, angiosperms would need to work smarter, not harder.
2. **Birds and mammals**. The diversity of animals present on Earth when angiosperms evolved would have resulted in increased seed predation. Fruits allowed for the dual purpose of protecting seeds and co-opting animals as dispersal agents, whether by ingestion or attachment. Some fruits evolved production of sugary tissues and bright colors to attract animals, while others evolved hairs or spines to latch onto their bodies.

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24.4: Angiosperm Life Cycle

Observe a prepared slide of mature pollen in a *Lilium* anther cross section. Within the anthers, there are pollen grains. Each pollen grain contains two cells. The **tube cell** takes up the majority of the pollen grain, engulfing the smaller **generative cell**. The tube cell will grow a pollen tube down the length of the style and into the ovary. The generative cell divides to produce two sperm by mitosis.



Figure 24.4.1: Angiosperm pollen

In the image above, you can see three pollen grains. In two of them, you can see the generative cell and the tube cell nucleus.

Observe a prepared slide of a *Lilium* ovary cross section (pre-fertilization). A *Lilium* pistil consists of three fused carpels. This is why there are three compartments, called **locules**, within the ovary.

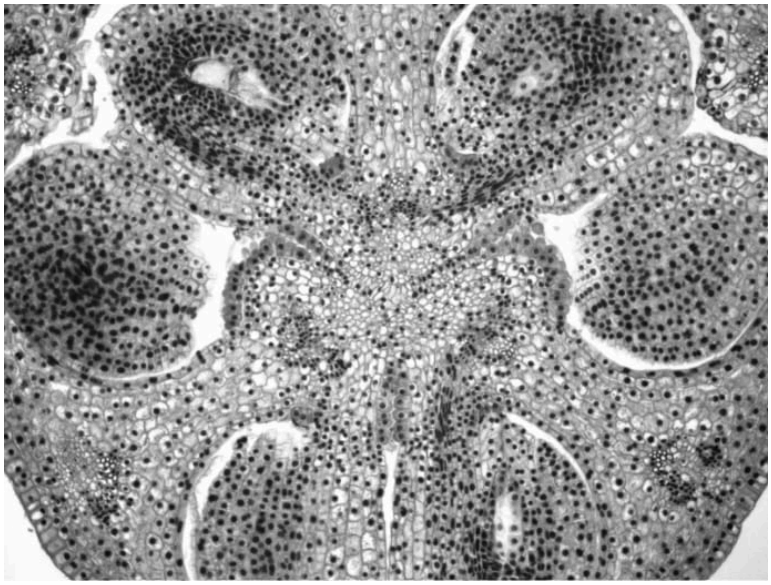


Figure 24.4.2: Ovary cross section

Inside each locule, there are two **ovules**, each connected to the **ovary wall** by a **funiculus**. The funiculus is much like an umbilical cord, providing nutrition to the developing ovule from the sporophyte through the **placenta**. The tissue surrounding the ovule is

called the **integument**. The small opening in the integument is the **micropyle**.

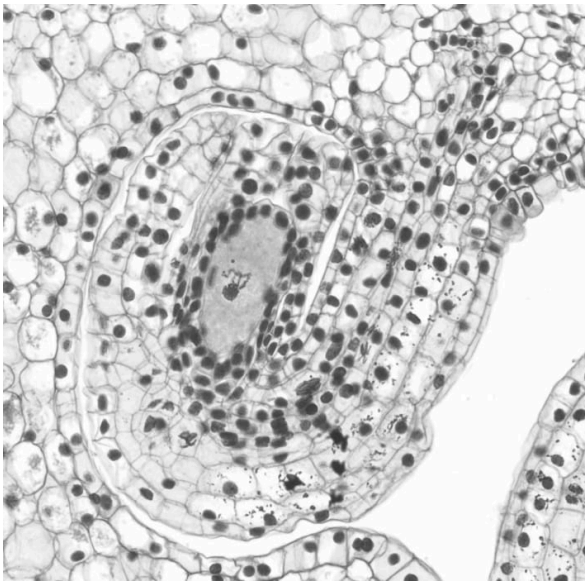


Figure 24.4.3: Lillium ovule

Depending on the pre-fertilization phase you are looking at, the ovule can appear quite differently. In the image above, the ovule is in the earliest stage of development. Currently, all of this tissue is diploid. The large cell in the center, the **megasporocyte** (2n), will undergo meiosis to produce four haploid cells: the **egg** and three other cells that will die. This egg will undergo three rounds of mitosis to produce a structure called the embryo sac, which is essentially the megagametophyte (n).

Observe a prepared slide of an **embryo sac** (this should also be a cross section of a *Lilium* ovary). The megagametophyte is housed at the center of the ovule and, when it is fully developed, is composed of 7 cells and 8 nuclei.

- The **egg** sits at the end closest to the micropyle, flanked by two **synergids**.
- On the other side of the embryo sac, there are three **antipodals**.
- In the center, there is a large cell with two nuclei. This is alternately called the **central cell** or the polar nuclei.

Note

Due to the way slides are made (a thin slice of a three dimensional structure), it is difficult to catch all 7 cells in one section unless they happen to be on the same plane.

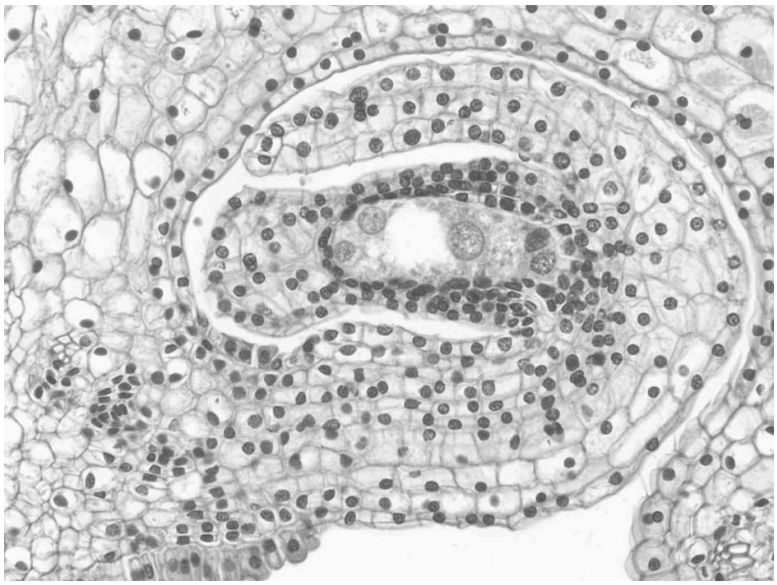


Figure 24.4.4: Lillium embryo sac

In the image above, you can see what is probably the egg and one synergid on the micropylar (left) side of the embryo sac. The large central cell is just to the right of the blank white area, and two of the three antipodals are visible on the far right.

The egg and the central cell will each be fertilized by one of the two sperm produced by the generative cell. The fertilized egg becomes a diploid **zygote**. The fertilized central cell becomes the triploid **endosperm**.

Observe a prepared slide of a *Lilium* ovary cross section (post-fertilization). Once fertilized by a pollen grain, the ovules become **seeds**, the megasporangium becomes the nucellus, the micropyle is closed, the integument becomes the **seed coat**, and the ovary wall begins to develop into the **pericarp**.

Within the seed, the **embryo** grows by mitosis and is nourished by the nucellus and endosperm. The seeds develop within the **fruit** until they are ready for dispersal.

> Label all of the bolded components of the angiosperm life cycle in the diagram below. Indicate where meiosis and fertilization occur. Choose a different color to represent haploid, diploid, and triploid tissues and color the tissues accordingly.

Angiosperm Life Cycle Diagram

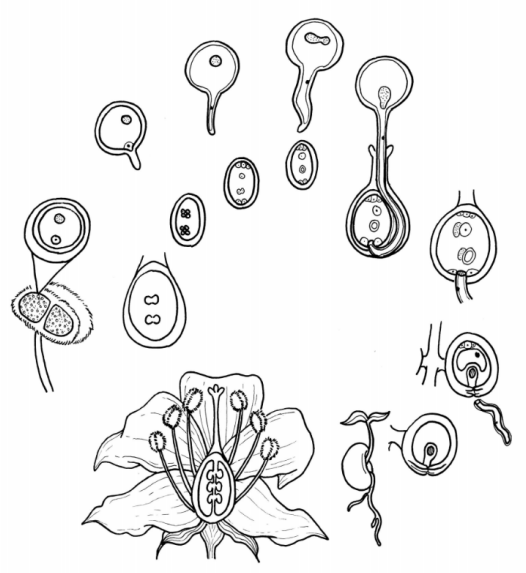


Figure 24.4.5: Angiosperm Life Cycle Diagram

Seed Germination

In the diagram below, watch a bean seed germinate and develop into a bean plant. Label the **seed coat, radical, cotyledons, roop apical meristem**, and **shoot apical meristem**.

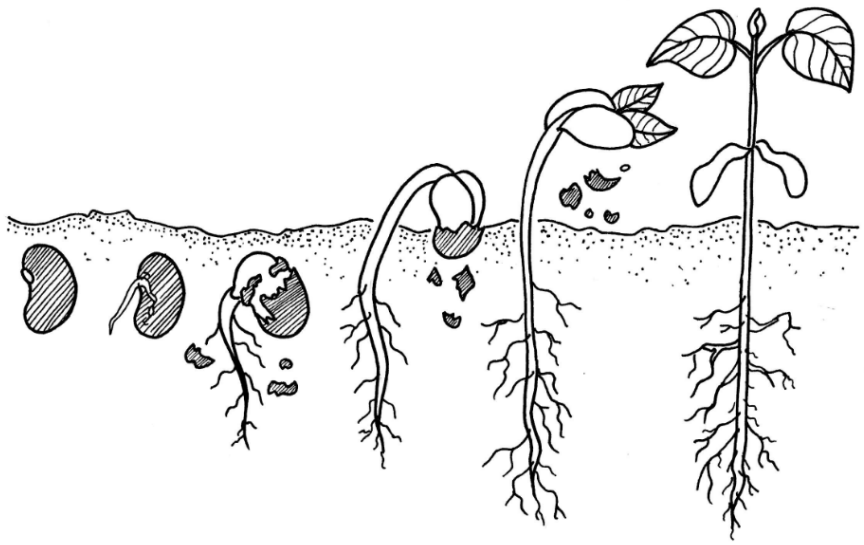


Figure 24.4.6: Germinating seed

Why would a plant develop a root system before the shoot?

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24.5: Fruits

All flowers become fruits. If you are unsure whether something is a fruit or not, check for seeds. Vegetables originally got their name for being derived from the vegetative (non-reproductive) part of the plant, such as a stem, root, or leaf.

The Pericarp

The ovary wall surrounds the developing seeds and becomes the **pericarp** (peri- meaning around, carp- meaning fruit or body). The pericarp is composed of three layers:

- **Exocarp** - the outermost layer, making up the exterior surface of the fruit
- **Mesocarp** - the tissue located between the exocarp and endocarp
- **Endocarp** - the innermost layer, located just outside the seed coat

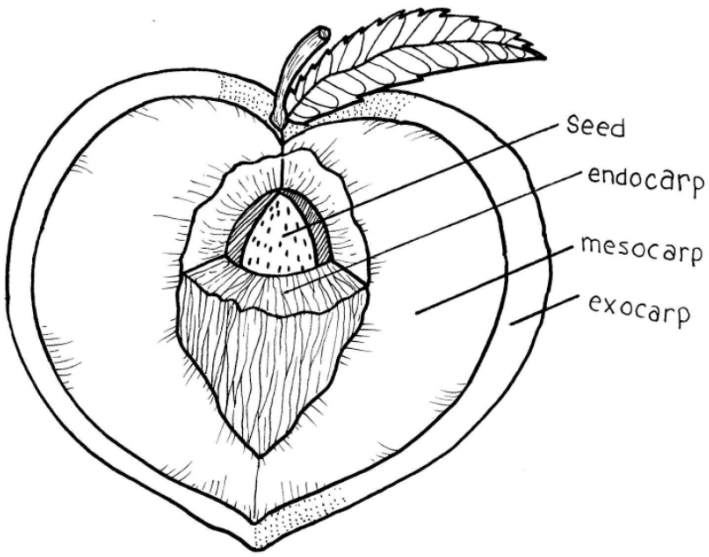


Figure 24.5.1: Diagram of a peach

In some fruits these layers are distinctly different and easy to distinguish. In other fruits, the layers are fused together and nearly impossible to differentiate. Fruit identification is primarily based on the structure of these three layers.

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24.6: Using a Dichotomous Key to Identify Fruit Type

Some fruits are **fleshy** at maturity, like the peach pictured above, while others are **dry**. This is not always obvious, due to our cultural uses of fruits. For example, a green bean is a legume, which is a dry fruit at maturity. However, we harvest green beans while they are still immature and fleshy because that makes for a more enjoyable dining experience.

Some dry fruits break apart at maturity into separately packaged seeds (**schizocarps**), while others split open to release their seeds (**dehiscent** fruits). Other dry fruits don't break open at all (**indehiscent** fruits). All of this terminology, in addition to identifying layers of the pericarp, is essential when you are identifying fruit types.

Use the dichotomous key at the end of this lab to identify the fruits available in your lab today. Record your findings in the space below, making drawings where helpful to do so.

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24.7: Dispersal Syndromes

Different fruits have evolved in response to different **dispersal agents**. The fruits that we buy at the grocery store are tasty because they have evolved for animal ingestion. The burrs that get stuck to your socks when you walk through a field have evolved for animal attachment. How can we use characteristics of fruits to predict the dispersal agent?

> Observe the fruits available and use the table below to predict which characteristics are related to each of the following dispersal agents.

Table 24.7.1: Predictive Characteristics for Fruit Dispersal Agents

Dispersal Agent	Expected Characteristics
Animal ingestion	
Animal attachment	
Wind	
Water	
Ballistic (explosive, projectile)	

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24.8: Summative Questions

1. What is the function of a fruit?
2. How could you distinguish between a fruit and a vegetable at the grocery store?
3. In the diagram below, an apple blossom is developing into a fruit. Label all of the parts of fruit and flower anatomy that you can see. What type of fruit is this?

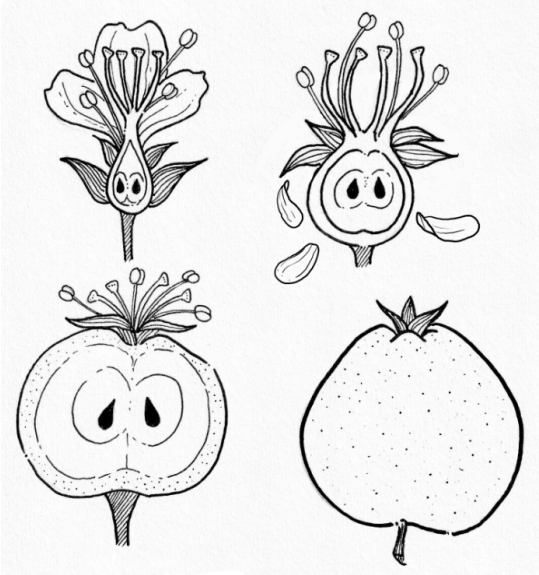


Figure 24.8.1: Copy and Paste Caption here

4. What food sources does the embryo have before it opens its first leaves in the sunlight?
5. Oaks and alders are both angiosperms that grow into trees. Oaks produce nuts with large seeds, while alders produce tiny samaras. In a year in the life of a black oak, it might grow 50 cm and produce 6500 nuts. In that same year, a red alder might grow 1-2 meters and produce around 5 million samaras. What are the tradeoffs between these two very different strategies? How might they relate to the different life histories of oaks and alders?

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25: GLOSSARY

25.1: Key to Common Local Tree Genera (Written for Humboldt County, California)
25.2: Dichotomous Key to Common Fruits
25.3: Evolutionary Profile - Photosynthetic Groups
25.4: Glossary of Terms and Root Words

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25.1: Key to Common Local Tree Genera (Written for Humboldt County, California)

1a. Foliage is broadleaved--composed of a flat blade, often with a distinct central vein....2 (Hardwoods: Angiosperms)

1b. Foliage is not leaf-like--composed needles or small, thick, scale-like leaves... 9 (Softwoods: Conifers)

2a. Edges of the leaves are smooth (the leaf margin is entire) 3

2b. Edges of the leaves are toothed or lobed 6

3a. Younger bark is reddish and peeling, leaves are relatively tough and approximate a rounded oval. Produces clusters of bell-shaped flowers and red berries 4

3b. Bark is not as above; leaves are long and pointed (lanceolate) 5

4a. Leaves are large and shiny, upper and lower surfaces of leaves are different in appearance. Older portions of the trunk are covered in grey, finely scaled bark. Exposed inner bark is often a pale yellow to orange. Berries are warty. Can grow to be large trees.... Pacific madrone (*Arbutus menziesii*)

4b. Leaves are small and often upper and lower surfaces look the same (isofacial). Most exposed bark is dark red and smooth, often interspersed with blackened-to-grey portions lacking bark. Berries are smooth. Growth form can be creeping ground cover to large shrub/small tree... Manzanita (*Arctostaphylos* spp.)

5a. Leaves have a golden underside. Fruits are nuts surrounded by spiny case...Chinquapin (*Chrysolepis chrysophylla*)

5b. Leaves are green on both sides. When crushed or cut, leaves have a strong, spicy smell. Not mycorrhizal. Often host wood-decay species, such as Ganoderma brownii...California bay laurel (*Umbellularia californica*)

6a. Leaves palm-shaped, deeply dissected, and emerging opposite from each other on the branch.... Maple (*Acer* spp. In our area, most likely big leaf maple, *Acer macrophyllum*)

6b. Leaves are not as above ... 7

7a. Leaf edge has larger teeth, the edges of which are lined with smaller teeth (doubly serrate). Bark is smooth, often covered with lichens. Produces clusters of small, woody "cones" (each about the size of an olive). Tree is growing near water or in a low area where water might collect seasonally...Red alder (*Alnus rubra*)* Note: If leaf edges are smooth and the tree produces berries, it is *Cascara*!

7b. Leaf edge has a single row of teeth or lobes. Bark is usually grey to brown and furrowed (though can be smooth when young). Fruit is an acorn...8

8a. Leaf edge has a single row of teeth. Entire underside of leaf is covered in tan fuzz. Acorn cups have scales that scoop outward, giving them a fuzzy or hairy appearance... Tanoak (*Notholithocarpus densiflorus*)

8b. Leaf edges are lobed (sometimes lobes end in sharp points). Acorn cups are formed of tightly overlapping scales that do not scoop outward... True oaks (*Quercus* spp.)

9a. Leaves needle-like: rounded, long, and emerging in bundles (fascicles). Cones are woody and tough, not easily broken apart... Pines (*Pinus* spp.)

9b. Leaves in flattened sprays. scale-like, or emerging around the branch, like a bottlebrush... 10

10a. Leaves flattened with a distinct upper and lower surface, the lower surface often silvery. Emerging from either side of the branch in a single plane (in some species, may be pointing upward, but not oriented all the way around the branch like a bottlebrush). Foliage not sharp.....11

10b. Leaves scale-like or leaves might be as above, but emerging around the branch from all sides, like a bottlebrush...14

11a. Leaves fall to the ground in feather-like branchlets. Cones are small (smaller than a grape) and rounded, forming distinct segments. Bark is reddish and fibrous, can form incredibly tall trees... Coast redwood (*Sequoia sempervirens*)

11b. Leaves fall to the ground as individual needles. Cones and bark not as above...12

12a. Leaves are all similar in length, usually around 2-3 cm. Cones are not often found because they deteriorate quickly. When present, cones sit upright on top of branches....True firs (*Abies* spp.)

12b. Leaves with two distinctly different lengths (shorter and longer).....13

13a. Leaves are short, less than 2 cm. The leader (top) of the tree is droopy and the cones are small (about the size of a dime) with relatively large scales. Bark is greyish with shallow furrows..Hemlock (*Tsuga*)

13b. Leaves are all over 2 cm long. Smooth bark in younger areas of the tree, often with a pinkish cast due to organisms growing on the bark. On the coast at low elevation.....Grand Fir (*Abies grandis*)

14a. Leaves as needles, emerging around the branch like a bottlebrush. Cones oval and papery (not woody)...17

14b. Leaves scale-like. Other features not as above....15

15a. Leaves as tiny, overlapping scales, forming dense clusters of dark green sprays. Cones woody, globose, and composed of distinct plates (like a soccer ball). Found in coastal areas....Monterey cypress (*Hesperocyparis macrocarpa*)

15b. Leaves as overlapping, awl-shaped scales that occur in flattened sprays. Other features not as above..16

16a. Scales are elongated, forming a champagne glass shape. Cones are small and dangle from the branch. They resemble duckbills, pistachio shells, or upside down tulips. Bark is deeply furrowed and often has an orangey cast. Found more commonly in inland areas or at higher elevations in our area...Incense cedar (*Calocedrus decurrens*)

16b. Scales are short with a bloom of stomata on the underside (appearing as a lighter green) in the shape of a bow or set of wings. Cones are small and sit erect on the branch. They resemble a blooming rose. Bark is fibrous. Found more commonly in wet, lowland areas...Western red cedar (*Thuja plicata*)

17a. Needles are sharp, cones composed of uniform overlapping scales (like a fish). Bark looks chippy, like peeling paint. On the horizon, branches angle upward. Found in coastal forests....Sitka spruce (*Picea sitchensis*)

17b. Needles are soft, not sharp. Cones have bracts that emerge between the scales, often referred to as a "mouse butt" because it looks like two feet and a tail hanging out. Bark is deeply furrowed and plated....Douglas-fir (*Pseudotsuga menziesii*)

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25.2: Dichotomous Key to Common Fruits

> **Note**
>
> If the fleshy part of the fruit is composed of something other than the ovary, it is an **accessory fruit**.

1. Fruit from one carpel (can be several fused together) of one flower .....[Simple Fruit].... 2

1. Fruit from more than one free carpel in a single flower or from an inflorescence 16

    2. Fleshy at maturity 3

    2. Dry at maturity 8

Fleshy Fruits

3. Thin exocarp, fleshy mesocarp, stony endocarp surrounding single, large seed ..... **Drupe**

3. Fruit not as described above..... 4

    4. Seeds in a linear order, separate from ovary wall, pericarp splits on two seams ...Legume (immature)

    4. Fruit not as described above..... 5

5. Papery endocarp forms a core. Derived from a perigynous flower.....**Pome**

5. Endocarp fleshy (not a papery core) 6

    6. Thin exocarp, fleshy mesocarp, one to many seeds ..... **Berry**

    6. Exocarp thickened and leathery (modified berries) 7

7. Exocarp and mesocarp form leathery rind, locules filled with juice-filled trichomes .....**Hesperidium**

7. Exocarp forms tough skin/rind, thick mesocarp, not divided into separate locules ..... **Pepo**

Dry Fruits

8. Dehiscent (splits open at maturity), usually many seeds 9

8. Indehiscent (does not split open), usually one seeded 12

    9. Derived from a carpel with one locule 10

    9. Derived from a carpel with more than one locule 11

10. Dehiscent along one seam ..... **Follicle**

10. Dehiscent along two seams ..... **Legume**

    11. From two locules with a central partition ..... Silique (elongate) or silicle (round)

    11. From more than two locules..... **Capsule**

12. Ovary wall extends to form a wing ..... **Samara**

12. Fruit not winged 13

13. Outer wall not especially thick or hard, seed small ... 14

13. Outer wall hardened, seed relatively large 15

14. Seed not tightly attached to pericarp ..... **Achene**

14. Seed fused to pericarp, grains ..... **Caryopsis**

15. Stony pericarp surrounds one large seed ..... **Nut**

15. Relatively thin exocarp, fibrous mesocarp, single large seed ..... (dry) Drupe

Aggregates & Multiple Fruits

16. Derived from one flower with many free carpels ..... **Aggregate Fruit**

16. Derived from an inflorescence (many florets) ..... **Multiple Fruit**

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25.3: Evolutionary Profile - Photosynthetic Groups

Group:

Model organism(s):

Characteristics:

- Morphology:
- Habitat:
- Photosynthetic pigments:
- Storage carb:
- Cell walls:
- Life cycle:

Notable features:

Economic uses and important ecological roles:

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Glossary of Terms and Root Words

Use this document to look up the definitions for bolded terms in the lab manual, as well as the meanings of root words. See the image of the compound microscope for the bolded terms relating to this device.

A

Abscission - the natural detachment of plant parts, such as with leaves in the winter

Abiotic - nonliving

Accessory fruit - a fruit where the fleshy material is not derived from the ovary. Ex. A strawberry or rose hip

Achene - a dry fruit with a single seed surrounded by a pericarp that can be peeled away. Layers of the pericarp are not distinguishable with the naked eye. Ex. A sunflower seed.

Actinomorphic - See “Radial symmetry”

Adhesion - attraction between dissimilar molecules or substances (such as tape to paper)

Adventitious root - a root that emerges from stem tissue

Aerenchyma - parenchyma tissue with large air pockets for flotation

Aggregate fruit - a fruit derived from a flower with multiple free carpels. Ex. A blackberry.

Akinete - a form some cyanobacteria can take. Larger, thick-walled cells that tend to be more granular in appearance. Akinetes store large amounts of lipids and carbohydrates so that they have enough energy to begin a new colony if conditions become too cold or too dry for survival. Formation of akinetes can be triggered by dry or cold conditions.

Alcohol fermentation - a form of fermentation performed by yeasts that converts pyruvate into ethanol and CO_2 to replenish NAD^+

Alternate (leaf arrangement) - one leaf emerges at a node

Alternation of generations - See “Haplodiplontic”

amylo- starch (amylose)

Amyloplast - a type of plastid that produces and stores starch. An amyloplast is a type of leucoplast, which are plastids that do not contain pigment.

Anaphase - the stage of mitosis where spindle fibers pull sister chromatids to either side of the cell, splitting them into two separate chromosomes

Anaphase I - the stage of meiosis I where spindle fibers pull homologous chromosomes to either side of the cell

Anaphase II - the stage of meiosis II where spindle fibers pull sister chromatids to either side of the cell, splitting them into two separate chromosomes

andro- male, man

Androecium - the floral whorl composed of stamens

Annual growth ring - a light and dark region of secondary xylem that forms in response to environmental conditions. The light portion of the ring is composed of larger cells, formed when water is abundant (also called early wood). The dark portion of the ring is composed of smaller diameter, densely packed cells, formed when water becomes more scarce (also called late wood).

Annulus - a ring-like structure. In fungi, this refers to the partial veil remnants left around the stipe. In ferns, it refers to the ring of inflated cells around the sporangium that dries and pulls the sporangium open, releasing the spores.

anth- flower

Anther - pollen sacs in flowering plants

Antheridiophore - a structure that bears antheridia

Antheridium - a multicellular structure on the gametophyte that produce sperm by mitosis

Antipodals - three haploid cells in the embryo sac located on the opposite end of the micropyle

angio/angium- vessel

Apical growth - growth extending from the tips (such as the tips of roots or shoots in plants)

Apothecium - a (usually) cup-shaped fruiting body produced by some ascomycetes

Arbuscule - a highly branched structure formed by endomycorrhizal fungi on the plasma membrane of plant root cells. The increased surface area increases the ability to exchange materials.

Archegoniophore - a structure that bears archegonia

Archegonium - a multicellular structure on the gametophyte that produce an egg by mitosis

Ascocarp - a fruiting body (sexually reproducing structure) produced in the fungal phylum Ascomycota

Ascospore - a haploid spore produced by meiosis, then mitosis, within the ascus of an ascomycete

Ascus - a sac-like structure where meiosis occurs to produce spores in ascomycetes. Asci, plural.

Asexual reproduction - a form of reproduction that produces identical copies of the parent cell (e.g. mitosis, binary fission, and budding)

Astrosclereid - a sclereid cell that transverses the leaves of *Nymphaea* and forms star-like shapes

ATP - (adenosine triphosphate) a high energy molecule with three negatively charged phosphate groups. ATP can “donate” a phosphate group to a reaction, breaking a high energy bond and releasing energy. This process is called phosphorylation. Most work done in cells is powered by ATP.

ATP Synthase - an enzyme that uses the flow of H+ ions back down their concentration gradient (secondary active transport) to phosphorylate ADP into ATP.

auto- self

Autotroph - an organism that forms organic molecules from inorganic molecules. This can also be thought of as an organism that makes its own food (self-feeding).

Auxospore - an enlarged spore produced by diatoms during sexual reproduction (and apparently sometimes through asexual reproduction)

Axillary bud - a structure located in the axil of the leaf that produces a branch, flower, or inflorescence

B

Bark - layers of periderm (phelloderm, cork cambium, and cork) form the outer bark, while the secondary phloem forms the inner bark.

Basal meristem - meristematic tissue located at the base of a structure. Most plants grow from apical meristems, producing new

tissue at and elongating from the tips. Basal meristems produce tissue where the tips are the oldest parts.

Basidiocarp - a fruiting body (sexually reproducing structure) produced by some basidiomycetes

Basidiospore - a haploid spore produced by meiosis within the basidium

Basidium - a (usually) club-shaped structure that produces spores in the basidiomycetes

Benthic - at the bottom of a body of water

Berry - a fleshy fruit with a thin exocarp, fleshy mesocarp, and one to many seeds not enclosed within an endocarp derived from the ovary wall

bi- two

Bilateral symmetry - having one line of symmetry

Binary fission - a form of asexual reproduction used by prokaryotic cells where the original cell expands as internal contents are replicated, then a new cell wall forms in the middle, dividing into two new, identical cells

bio- life

Bioavailable - a form that can be absorbed by and assimilated into an organism.

Biotic - living

Blade - the (usually) flat, photosynthetic portion of the leaf located at the end of the petiole. In brown algae, this is the leaf-like structure (or structures) on the thallus.

Bud primordium - the early developmental stage of the axillary bud

Bud scar - the scar left behind on a stem where the axillary bud has fallen off via abscission

Budding - a form of asexual reproduction used by yeast where a smaller cell is made from the original cell, leaving a bud scar. The smaller cell grows to normal size after separation from the parent cell.

Bulb - a rosette of fleshy leaves modified for storage, surrounding a short stem

Bulliform cells - enlarged cells in the epidermis that respond to water loss by collapsing, causing the leaf to roll or fold and reducing sun exposure

Bundle scars - scars left behind inside a leaf scar where the vascular bundles of the leaf travelled into the stem

Bundle sheath - the ring of cells that surround a vascular bundle. This could be in the stems of monocots or in the leaves of either group.

C

C3 - the “standard” and most energy efficient form of photosynthesis

C4 - a form of photosynthesis performed by plants adapted to hot weather. RuBisCO is located in the bundle sheath cells, where CO2 is actively transported in the form of an acid to keep concentrations high. This occurs when stomata close to prevent water loss, limiting CO2 intake.

Calvin cycle - the light independent phase of photosynthesis where RuBisCO fixes CO2 and the end product is glucose. This process occurs in the stroma of the chloroplast.

Calyptra - tissue from the female gametophyte that is carried on top of the developing sporophyte in the bryophytes

Calyx - the floral whorl composed of sepals

CAM - Crassulacean acid metabolism. This is a form of photosynthesis performed by plants adapted to dry weather. Stomata close during the day to prevent transpiration and open at night to let in CO2. The CO2 is actively transported into the central vacuole and converted into an acid. During the day, it is converted back into CO2 so photosynthesis can occur.

Cap (pileus) - the top of a mushroom. The spore producing surface is on the underside of the cap (usually).

Capillary action - the tendency of a liquid to rise or fall as a result of surface tension

Capsule - a dry fruit with multiple fused carpels that open at maturity. Ex. Cotton. Note: this term is also often used to describe the structure that encases the sporangia in mosses.

Carotenoids - red, orange, and yellow pigments found in plants, green algae, and photosynthetic heterokonts. These are often used to protect from sun damage or to signal ripening in fruits, as well as absorb some of the green parts of the spectrum of light.

carp- of the fruit or fruiting body

Carpogonium - a structure produced on the red algae female gametophyte. It consists of the egg and the trichogyne and may also be called the **carpogonial branch**.

Carposporangium - a structure that produces carpospores

Carpospore - a diploid spore that is identical to the zygote in the red algae life cycle. Carpospores grow by mitosis into a tetrasporophyte.

Carposporophyte - a multicellular diploid phase in the red algal life cycle that produces clones of the zygote called carpospores

Caryopsis - a dry fruit similar to an achene, but the pericarp is fused to the seed. This fruit type is produced by members of the Poaceae (grass family). Ex. A corn kernel.

Casparian strip - a layer of suberin that coats the endodermis in roots. This layer forms in patches, leaving passage cells at the xylem poles.

Cell wall - a rigid structure that encloses the plasma membrane. The presence and composition of the cell wall are useful features in classifying and identifying organisms.

Cellulose - a polysaccharide found in plant cell walls. Cellulose is also found in the cell walls of oomycetes and red, green, and brown algae.

Central cell - a cell in the embryo sac containing two polar nuclei

Central vacuole - a (generally) large, fluid-filled organelle enclosed by a membrane (the tonoplast). The central vacuole often takes up the majority of a plant cell and is responsible for storage of compounds (ex. toxins, anthocyanins, and salts) and turgidity of the plant cell, which contributes to rigidity of the entire plant.

Centric - (a diatom) with radial symmetry

Centromere - the central region of a chromosome where sister chromatids are attached (in replicated chromosomes)

Chemical energy - energy stored in the bonds between atoms within molecules

Chemiosmosis - the movement of ions from areas of high concentration to low concentration across a semipermeable membrane. This happens with H+ flow through ATP synthase in both cellular respiration and photosynthesis.

Chemosynthesis - a cellular process that uses chemical energy derived from oxidizing (stealing electrons from) inorganic compounds to build organic molecules. In this process, the inorganic compound is the electron donor. The waste product will depend on what the initial inorganic compound is (for example, if hydrogen sulfide is used, sulfur and water could be produced as waste products).

Chitin - polysaccharide (carbohydrate) found in fungal cell walls and arthropod exoskeletons

Chlorenchyma - parenchyma cells with chloroplasts for photosynthesis

Chlorophyll - a photosynthetic pigment that reflects light in the green portion of the spectrum. These molecules can harvest energy from the blue and, to a lesser extent, red part of the spectrum of light by emitting an electron after absorbing a photon. All photosynthetic organisms covered in this class contain chlorophyll a, which is the primary molecule involved in the light-harvesting portion of photosynthesis.

Chloroplast - a double-membrane bound organelle derived from bacterial endosymbiosis that contains chlorophyll and is responsible for photosynthesis. Chloroplasts can be converted into chromoplasts or leucoplasts, when needed.

Chromatin - DNA wound around histone proteins

chromo/chroma- color

Chromoplast - a double-membrane bound organelle derived from bacterial endosymbiosis that contains pigments other than chlorophyll, such as carotenoids. Often found in ripening fruits to attract animals with the red hues.

Chromosome - chromatin that has been tightly packaged in preparation for cell division

Chytrid - an aquatic fungus with swimming spores (zoospores)

Circinate vernation - the process by which fern fiddleheads unfurl in the spring

Citric acid cycle - a process that takes place in the matrix of a mitochondrion during cellular respiration. ATP, NADH, and FADH2 (as well as some CO2) are produced.

Cladode - a stem that has been modified for photosynthesis, often green with increased surface area

Clamp connection - a rounded structure that forms on the side of a basidiomycete hypha as nuclei divide

Classification - a system of categorizing organisms into like groups

Cleistothecium - an enclosed, microscopic fruiting body produced by some ascomycetes

Coenocytic - this can refer to fungal hyphae with no septations (cross walls) or, more generally, to any cell with many nuclei

Coevolution - the linked evolution of two interacting species

Cohesion - attraction between like molecules (for example the attraction of a partial positive charge on the hydrogen atom of one water molecule to the partial negative charge on the oxygen atom of another water molecule)

Collenchyma - cells with unevenly thickened primary walls, often involved in flexible support in young growing tissues

Community - multiple interacting populations living in the same area at the same time

Companion cell - a cell with a nucleus paired with a sieve tube element. The companion cell acts as the command center for that sieve tube element.

Complete (flower) - a flower containing all four floral whorls

Complex septation - also called a dolipore septum. The walls around the pore in the septum are swollen and two structures that look like parentheses (aptly called parenthesomes) flank the pore.

Conceptacle - a chamber inside the Fucus receptacle that houses the gametangia

Cone - see “strobilus”

Conidiophore - a structure that bears conidia

Conidium - a spore produced by mitosis (asexual reproduction) in molds

Conjugation tube - a structure produced in Spirogyra that allows mating to occur between compatible colonies. Cell contents are transferred through the conjugation tube.

Consumer - an organism that eats other organisms as an energy source. A primary consumer eats producers, a secondary consumer eats primary consumers (though it may also eat producers), and a tertiary consumer eats secondary consumers (though it may also eat both primary consumers and producers, as well).

Cork - suberized cells that are dead at functional maturity produced in the periderm during secondary growth. Cork cells form the outermost layer of stems and roots in secondary growth.

Cork cambium - the secondary meristem that produces cork to the outside and phelloderm to the inside

Corm - a stem that has been modified for storage. Nodes on the corm produce papery leaves.

Corolla - the floral whorl composed of petals

Cortex - tissue produced by the ground meristem, located between the vascular tissue and the epidermis

Costa - the central “vein” in a moss leaf. Note: mosses do not have true vascular tissue, particularly not in the gametophyte.

Cotyledon - the first leaf or leaves to appear as a seed germinates

Crossing over - during prophase I of meiosis, homologous chromosomes align and can swap regions of DNA, resulting in increased genetic variety within an organism’s gametes.

Crustose - a lichen that is completely appressed (stuck up against) what it is growing on. Cannot be (easily) removed from this substrate.

Cuticle - a waxy layer made of the lipid cutin that coats the epidermis in plants

cyan- blue

cyst- a sac or bladder containing fluid

Cystocarp - a structure produced on the female gametophyte of red algae. The carpogonium enlarges and the zygote develops inside, growing by mitosis into the carposporophyte. Female gametophyte tissue (the pericarp) surrounds the carposporophyte. These two components together comprise the cystocarp.

cyto- cell, cellular

Cytokinesis - division of the cytoplasm through the formation of a new cell wall during mitosis and meiosis, which happens concurrently with telophase.

Cytoplasm - everything inside the plasma membrane, excluding the nucleus. This term is often confused with the term cytosol, which refers to the jelly-like matrix that fills the cell and surrounds the organelles, if present.

Cytoplasmic streaming - movement of the cytoplasm around the cell to transport nutrients, organelles, or other materials

D

Decomposer - an organism that breaks down dead organic matter, transforming the molecules trapped within those organisms into forms that are released into the environment and their respective nutrient cycles. This term is synonymous with the terms saprobe and saprophyte.

Dehiscent - a dry fruit that opens on its own at maturity, usually to disperse the seeds

Dendrochronology - a process used to determine the order and timing (chronology) of events using information in tree rings

Dependent variable - the variable(s) in a scientific experiment that you record data on during and/or after your experiment

di- two; double

Diffusion - the tendency of particles to move from areas of high concentration to areas of lower concentration due to random movements and entropy

Dikaryon - a dikaryotic fungal thallus

Dikaryotic - having two unfused, haploid nuclei per cell (n+n)

Dioecious - male and female reproductive structures are produced on different plants

Diploid - having two sets of chromosomes (2n)

Diplontic - a life cycle where the multicellular stage is diploid

Dispersal agent - in angiosperms, the organism or phenomenon that aids in dispersal of the seeds

Double fertilization - the fertilization of both the egg (producing a zygote) and the polar nuclei (producing the endosperm) in the angiosperm life cycle. A form of double fertilization also occurs in gnetophytes, but the result is two fertilized eggs.

Drupe - a (typically) fleshy fruit with a thin exocarp, fleshy mesocarp, stony endocarp, and (typically) a single seed. Ex. A peach.

E

Ecosystem - the biotic and abiotic components of an environment and the interactions between these components

Ectomycorrhizal - a mycorrhizal association formed by some Ascomycota and Basidiomycota (and at least one zygomycete) around the cells of plant roots, forming a fungal sheath around the roots and a hartig net within the roots. See “mycorrhizal” for more information.

Egg - the haploid cell produced by the megagametophyte that must fuse with a sperm to produce a zygote

Elaters - elongate structures that promote spore dispersal by interacting with moisture in the air (hygroscopic movement). Found on the spores of Equisetum and in the sporangia of bryophtyes.

Electromagnetic energy - energy that travels as a wave and does not require a medium. For example, light is a form of electromagnetic energy because it can travel as a wave through the vacuum of space. Sound, even though it travels as a wave, is not a form of electromagnetic energy because it requires a medium, such as air or water, to transmit it. Sound does not travel in space! So, laser gun battle in space = totally silent.

Electron transport chain - a series of protein complexes that transfer electrons between each other. The energy from the electrons allows some of these protein complexes to pump H+ across the membrane.

Embryo - a zygote that is retained and nourished by the female gametophyte.

Embryo sac - the mature megagametophyte of an angiosperm, containing 7 cells and 8 nuclei

endo- inside, internal, inner

Endocarp - the innermost layer of the pericarp in a fruit. In a peach, the endocarp is the stony pit enclosing the seed.

Endodermis - the innermost layer of the cortex in the root (also present surrounding the transfusion tissue in a pine needle)

Endogenous - formed from within

Endomycorrhizal - fungi that penetrate between the cell wall and plasma membrane of plant roots, establishing a mutualistic exchange of materials. This is a trait shared by all of Glomeromycota.

Endosperm - the result of a sperm fertilizing the polar nuclei (central cell) in the embryo sac. This triploid tissue is consumed by the growing zygote in an angiosperm seed.

epi- on top of

Epidermis - the outermost layer of the plant, composed of a single cell layer. These cells are parenchyma and often include specialized cells, such as trichomes or guard cells.

Epiphyte - growing on a plant

eryth- red

eu- true

Eudicot - (alternatively called dicot) flowering plants that produce two cotyledons

Eukaryote - an organism that can be unicellular or multicellular, but each cell with contain a nucleus (though this may be lost in some plant cells). Eukaryotes have linear DNA that is stored inside the nucleus and their cells contain membrane-bound organelles like mitochondria and the endoplasmic reticula.

exo- outer

Exocarp - the outer layer of the pericarp in a fruit. In a peach, the exocarp is the fuzzy skin.

Exogenous - formed on the exterior

F

Fascicular cambium - residual procambium within vascular bundles that joins with the interfascicular cambium to form the vascular cambium in eudicots

Fermentation - a process that occurs after glycolysis to restore NAD+, such as the production of lactate or ethanol

Fiber - an elongated sclerenchyma cell with tapered ends whose function is structural support

Fiddlehead - a frond that has yet to unfurl via circinate vernation

Filament - (in flowers) the stem-like structure that holds the anthers aloft

Flagellum - a long projection that can be present on both prokaryotic and eukaryotic cells that is used for movement

Floret - a flower in an inflorescence

Floridean starch - the form of starch used by red algae as a storage carbohydrate

Flower - a set of modified leaves that promote fertilization (pollination)

Foliose - leaf-like. In lichens, a flattened thallus with two distinct sides (can be removed from substrate).

Follicle - a dry fruit composed of a single carpel that splits open along a single seam at maturity

Food - compounds your body can break down to get energy, usually carbohydrates

Food web - an interconnected network of organisms participating in the flow of energy through an ecosystem. A food web involves primary producers, consumers, and decomposers. At each transition in a food web from one organism to another, about 90% of the available energy is lost as heat.

Foot - the base of the sporophyte seta, where it attaches to the gametophyte

Frond - the megaphyll of plants in subclass polypodiidae in the Ferns

Fruit - the swollen ovary and enclosed seeds produced by angiosperms

Frustule - the silica cell wall of diatoms, composed of two valves

Fruticose - a lichen that is three dimensional, but without two distinct sides. Often called “busy” or “shrubby”

Fucoxanthin - a carotenoid found in photosynthetic heterokonts

Funiculus - transitional tissue between the angiosperm ovary and the developing ovule, much like an umbilical cord

G

G0 - the stage of the cell cycle when a cell ceases to divide and specializes

G1 - the stage of the cell cycle when cytoplasmic contents are duplicated

G2 - the final stage of the cell cycle, where a cell is verified to be ready for division

Galactans - sulfated polysaccharides present in the cell walls of red algae

Gametangium - a structure that produces gametes

Gamete - a haploid cell that must fuse with another haploid cell to form a zygote

Gametophyte - a haploid, multicellular generation that produces gametes by mitosis

gamy- union, marriage

Gametophyte dominant - a life cycle where the gametophyte is larger, longer-lived, and nutritionally responsible for the sporophyte

Gas bladder - a pocket in the thallus of brown algae that traps gases to act as a float

Gemma - an asexual clone of plant tissues, such as in thalloid liverwort gametophytes (gemmae, plural)

Gemmae cup - a cup-like structure where gemmae are produced

Generative cell - the haploid cell in pollen grains that divides to produce sperm

Gills (lamellae) - structures in some mushrooms where the spore producing basidia are located

glyco- relating to sugar (often glucose)

Glycogen - a polysaccharide (carbohydrate) used to store sugars in fungi, animals, and other heterotrophs

Glycolysis - the first stage in cellular respiration or fermentation, where glucose is broken down into two molecules of pyruvate. This occurs in the cytoplasm.

Granum - a stack of thylakoids in a chloroplast (grana, plural)

Gravitropism - movement or growth with respect to the pull of gravity (toward or away from)

Ground meristem - the primary meristem that produces ground tissue, cortex, and pith. In the root, it also produces the endodermis (the innermost layer of the cortex).

Ground tissue - tissue produced by the ground meristem with no particular organizational structure, such as in the stems of monocots.

Guard cell - a parentheses-shaped parenchyma cell in the epidermis of a plant that regulates the opening and closing of a stoma, depending on water availability

gyn- female, woman

Gynoecium - the floral whorl composed of carpels

H

H+ - a hydrogen atom that is missing an electron. A hydrogen ion. A proton.

Haploid - having one set of chromosomes (n)

Haplodiplontic - a life cycle where there is a multicellular haploid phase and a multicellular diploid phase (also called alternation of generations or, occasionally, sporic meiosis)

Haplontic - a life cycle where the multicellular phase is haploid

Head (flower) - an inflorescence where florets are directly attached to the receptacle. There can be ray florets and/or disc florets present. Also called a capitulum.

Heartwood - secondary xylem that is no longer conducting water. Often darker in color and is located in the center of the stem.

Heliotropism - movement or growth with respect to the sun

Hesperidium - a modified berry with a leathery rind. Locules are filled with juicy trichomes. Ex. An orange.

hetero- other

Heterocyst - a form some cyanobacteria can take. Heterocysts are larger, round, thick-walled cells that can appear yellow and have two polar bodies, one on each end where they attach to other cells in the colony. These individuals are involved in nitrogen fixation and so cannot perform photosynthesis.

Heterosporous - producing two different spore types: microspores and megaspores

Heterotroph - an organism that consumes other organisms, living or dead, as a carbon source.

Holdfast - a structure at the base of brown algal thalli that attaches the thallus to a surface

homo- same

Homologous chromosomes - chromosomes from different parental origin that contain the same genes in the same order. For example, you have homologous copies of chromosome 1, one from each parent.

Homosporous - producing a single spore type that grows into a bisexual gametophyte

hydro- water

Hydrophyte - a plant adapted to aquatic environments (or high water levels)

hyper- over, above

Hypertonic - a solution with a higher ratio of dissolved solutes to water than the solution on the other side of a semipermeable membrane

Hypha - a walled, thread-like cellular structure that fungal body plans are composed of

hypo- under, below

Hypodermis - a layer or multiple layers of cells just under the epidermis

Hypothesis - a proposed explanation for a phenomenon that is both testable and falsifiable

Hypotonic - a solution with a lower ratio of dissolved solutes to water than the solution on the other side of a semipermeable membrane

I

Imperfect (flower) - a flower containing either an androecium or gynoecium, but not both

Incomplete (flower) - a flower missing at least one floral whorl

Indehiscent - a dry fruit that does not open on its own at maturity

Independent assortment - an event in meiosis that results in increased genetic diversity. During metaphase I, homologous chromosomes line up randomly on either side of the metaphase plate, resulting in different combinations of chromosomes in each meiotic event.

Independent variable - the variable in a scientific experiment that you change between treatment groups

Indusium - an umbrella-like structure in a fern sorus that protects the developing sporangia

Inflorescence - a compound flower composed of multiple florets

Inner bark - secondary phloem

Integument - the protective layer surrounding a developing ovule in seed plants. After fertilization, it becomes the seed coat.

Interfascicular cambium - cells in the pith rays that join with the fascicular cambium to form the vascular cambium in eudicots

Intermembrane space - the area between two membranes, such as between the inner and outer membranes in a mitochondrion

Internode - the region of the plant stem between nodes

Interphase - cells spend most of their time in this part of the cell cycle. It is broken into three distinct phases that prepare a cell for division.

iso - same

Isomorphic - sharing the same overall form

Isotonic - two solutions on either side of a semipermeable membrane that have the same ratio of dissolved solutes to water

J

No current entries under “J”.

K

karyo- seed (in biology, this term refers to the nucleus)

Karyogamy - fusion of two nuclei

Kinetochore - a region on the centromere of a chromosome where spindle fibers attach during cell division

Krebs cycle - see “citric acid cycle”

L

Lactic acid fermentation - a form of fermentation performed by animal cells and bacteria that converts pyruvate into lactate to replenish NAD+. H+ are produced as a byproduct, hence the name lactic acid.

Latex - a compound produced by some groups of plants that often serves a protective function. It can contain toxic compounds and/or gum up the mouthparts of insects

Leaf - a plant organ with lignified vascular tissue that emerges from a node in the position of the leaf, below the axillary bud (away from the growing tip of the branch)

Leaf axil - the area formed in the angle between the petiole of the leaf and the stem

Leaf scar - the scar left behind on a stem where the leaf has fallen off or was removed

Leaf primordium - the early developmental stage of a leaf

Legume - a dry fruit composed of a single carpel that splits open along two seams at maturity. This is the fruit of plants in the Fabaceae (bean family). Ex. A lupine pod or a peanut.

Lenticel - a tear in the periderm of woody plants that allows for the exchange of gases with the exterior environment

leuco- white or colorless

Leucoplast - a double-membraned organelle derived from bacterial endosymbiosis that does not contain pigment. Leucoplasts synthesize and store lipids or starch, such as in amyloplasts.

Lichen - a symbiotic relationship between a fungus and an alga and/or a cyanobacterium

Life cycle - a summary of the major events in a species' development, including fertilization, growth, and reproduction

Lignin - a tough, complex polymer in the secondary walls of sclerenchyma cells. A primary component of wood, along with cellulose.

Link reaction - the transportation of pyruvate from the cytoplasm of the cell into the matrix of the mitochondrion. In the process, pyruvate is converted to acetyl-CoA.

Locule - a compartment of an angiosperm ovary representing one carpel

lyse- to break apart

M

Mannitol - a type of carbohydrate produced by fungi involved in lichen symbiosis

Matrix (mitochondrion) - the fluid-filled area enclosed by the inner membrane in a mitochondrion

Megagametophyte - a haploid, multicellular stage in heterosporous alternation of generations that produces eggs by mitosis

Megaphyll - a leaf with branching vascular tissue

Megaspore - a haploid cell produced via meiosis of the megasporocyte. This cell grows by mitosis into a megagametophyte.

Megasporocyte - a diploid cell produced by the sporophyte that will divide by meiosis to produce the megaspore(s) that grow into megagametophyte(s)

Megastrobilus - a structure on the sporophyte that produces the megagametophytes

Meiosis - a type of cell division that halves the number of chromosomes and results in 4 genetically distinct daughter cells. For example, one diploid cell could go through meiosis to produce 4 haploid cells. This type of division is used for sexual reproduction.

Meristem - a region of cells that divides by mitosis to produce new tissues

Mesocarp - the middle layer of the pericarp in a fruit. In a peach, the mesocarp is fleshy.

Mesophyll - the tissue in a leaf between the upper and lower epidermis that is not the vascular tissue

Mesophyte - a plant adapted to moderate environmental conditions

meso- middle

Metaphase - the stage in mitosis where chromosomes align in the center of the cell

Metaphase I - the stage in meiosis I where homologous chromosomes align across from each other in the center of the cell. The alignment is random, so each time meiosis occurs, there can be a different arrangement of chromosomes on either side. See “independent assortment”.

Metaphase II - the stage in meiosis II where chromosomes align in the center of the cell

Metaphase plate - a region in the center of a dividing cell, equidistant from the poles, where chromosomes line up

Middle lamella - a pectin-rich layer between plant cell walls

Microgametophyte - a haploid, multicellular stage in heterosporous alternation of generations that produces sperm by mitosis

Microphyll - a leaf with a single, unbranched vein of vascular tissue

Micropyle - a gap in the integument where the pollen drop is secreted and pollen grains (or tubes) can access the ovule

Microspore - a haploid cell produced via meiosis of the microsporocyte. This cell grows by mitosis into a microgametophyte.

Microsporocyte - a diploid cell produced by the sporophyte that will divide by meiosis to produce the microspore(s) that grow into microgametophyte(s)

Microstrobilus - a structure on the sporophyte that produces the microgametophytes

Middle lamella - a pectin-rich region between adjacent cells

Mitosis - a type of cell division that results in two identical daughter cells, both identical to each other and to the parent cell. This type of division is used for growth, repair, and asexual reproduction. Mitosis refers strictly to the division of the nucleus, while cytokinesis is the division of the rest of the cell contents.

Mitosporangium - a structure that produces spores by mitosis, such as in asexually reproducing *Rhizopus*

Mold - asexually reproducing mycelial fungus

mono- one, singular

Monocot - flowering plants that produce a single cotyledon

Monoecious - male and female reproductive structures are produced on the same plant

Monomer - a molecule that can bind to other molecules of the same type and form a polymer. A repeating subunit of a larger molecule.

Monoplastidic (cell) - a cell having only a single plastid, such as the single large chloroplast in the cells of Anthocerophyta

morph- form

Multicellular - an organism composed of multiple interacting cells

Multiple fruit - a single fruit that is composed of many florets from the same inflorescence. Ex. A pineapple.

Mutualism - a type of symbiosis in which both partners get a net benefit from the interaction.

Mycelium - the fungal body, composed of hyphal filaments

myco- fungus

Mycobiont - the fungal partner in a lichen

Mycorrhizal - a type of mutualistic relationship between plants and fungi. The fungus enters the plant through the roots and takes sugars from the plant. In exchange, the plant takes water and dissolved nutrients (particularly nitrogen and phosphorus) from the fungus.

N

NADH - a molecule that carries two high energy electrons from glycolysis or the citric acid cycle to the electron transport chain in cellular respiration

NADP+ reductase - reduces (adds electrons to) a molecule of NADP+ to create high-energy NADPH. The H+ is added to balance the negative charge from one of the added electrons.

NADPH - a molecule that carries two high energy electrons from the electron transport chain to the Calvin cycle in photosynthesis

Negative control - a group in your experiment that should show no change from initial conditions. If change occurs in the negative control, your experiment could have false positives.

Netted root system - a root system where there is no central, larger root. Most roots are relatively the same diameter.

Nitrogen fixation - the process of converting atmospheric nitrogen (N2) into bioavailable forms, such as ammonia (NH3). This process is carried out by certain bacteria using the enzyme nitrogenase and by the action of lighting ripping through the atmosphere, splitting molecules apart.

Node - the region on a stem where a leaf and axillary bud emerge. The axillary bud emerges on the side of the node closest to the growing tip of the stem.

Nonpolar - a type of covalent bond that is equally shared, resulting in no residual charges on the atoms. Nonpolar compounds “like” to interact with other nonpolar compounds.

Nucellus - the nutritive tissue provided by the megasporangium to the growing embryo in seed plants

Nuclear envelope - a double-membraned structure composed of phospholipids that encloses the genetic material of the cell

Nucleoid - a region in prokaryotes that contains all or most of the genetic material. A nucleoid is not surrounded by a membrane.

Nucleolus - a dense region within the nucleus that often appears as a dark dot. A single nucleus can contain several nucleoli. This region is where ribosomes are synthesized and contains a large amount of RNA.

Nucleus - a double-membrane bound organelle in eukaryotes that contains the organism’s genetic material. The nucleus is often referred to as the command center of the cell, both DNA replication and transcription occur within this organelle. In multicellular organisms, some eukaryotic cells may lack a nucleus at maturity, such as sclerenchyma.

Null hypothesis - an “anti-hypothesis” that predicts no relationship between the dependent and independent variables

Nut - a dry fruit with a stony pericarp encasing a single, large seed. Ex. An acorn.

O

Oogonium - a structure in heterokonts where the eggs are produced

Oospore - a thick-walled zygote produced in the oogonium of oomycetes

Operculum - a cap-like structure that covers the opening of the moss capsule until the spores are ready to be dispersed

Opposite (leaf arrangement) - two leaves emerge at a node

Organ - a collection of tissues working toward the same function, such as a leaf, stem or root

Osmosis - the diffusion of water across a semipermeable membrane

Ostiole - a small opening, such as at the top of a *Fucus* conceptacle

Outer bark - periderm or layers of periderm

ova- egg

Ovary - a structure that encloses the ovules in angiosperms and will develop into the pericarp when fertilized

Ovule - a structure in seed plants that contains the megagametophyte and will develop into a seed when fertilized

Ovuliferous scale - a cone scale in the megastrobilus of conifers where seeds develop

P

Palisade mesophyll - tissue in eudicot leaves that is composed of elongated cells that look like columns, full of chloroplasts photosynthesizing

Panicle - a branched raceme inflorescence

Parasitism - a type of symbiosis in which one partner gets a net benefit, while the other gets a net negative impact.

Parenchyma - cells with an even, thin primary wall and no secondary wall that are alive at functional maturity.

Passage cells - cells where the xylem is closest to the endodermis in the root where the Casparian strip forms last. This allows water to be transported into the xylem from root hairs.

Pedicel - the stem that attaches to a floret

Peduncle - the stem that attaches to a flower at the receptacle

Pennate - (a diatom) with bilateral symmetry

Peptidoglycan - a substance found in bacterial cell walls that consists of interlinked carbohydrates and polypeptides. Antibacterials like penicillin work by inhibiting the formation of peptidoglycan.

Pepo - a modified berry with a tough, rind-like exocarp. Ex. A pumpkin.

Perfect (flower) - a flower containing both an androecium and a gynoecium

peri- around

Perianth - the outer whorls of a flower, composed of the calyx and corolla

Pericarp (fruits) - tissue that develops from the ovary wall in angiosperms and encloses the developing seeds. The pericarp is composed of the exocarp, mesocarp, and endocarp.

Pericarp (Rhodophyta) - the female gametophyte tissue that surrounds the carposporophyte in the cystocarp

Pericycle - a layer of meristematic tissue in the root, just inside the endodermis, that produces lateral roots and secondary meristems

Periderm - an exterior layer produced during secondary growth composed of phelloderm, cork cambium, and cork. Also called outer bark.

Peristome teeth - sheets of cells that look like papery teeth that interact with moisture in the air (hygroscopic movement) to help spores disperse from the capsule in some mosses

Perithecium - a microscopic, flask-shaped fruiting body produced by some ascomycetes

Perforation plate - an opening at the end of a vessel element that allows for the passage of water and dissolved nutrients from cell to cell.

Petiole - the structure that attaches the leaf blade to the stem. Some plants lack petioles and these leaves are called sessile.

phaeo- dusky (often refers to organisms with golden brown hues)

Phagocytosis - to consume by engulfing. The process of engulfing creates a compartment called a phagosome, where acids or other digestive fluids can be secreted for breakdown of the engulfed material.

Phelloderm - large storage cells produced to the inside of the cork cambium in secondary growth

Phloem - the conducting tissue in plants that transports sugars produced during photosynthesis.

Phloem fibers - clusters of fibers located in the phloem that provide structural support (other phloem cells lack a secondary wall).

Phloem rays - parenchyma cells that connect the secondary phloem to the secondary xylem

phore- bearer of

photo- light

Photobiont - the photosynthetic partner in a lichen, such as green algae or cyanobacteria

Photon - a particle of light

Photorespiration - a process that occurs when RuBisCO binds to oxygen instead of CO_2; no glucose is made and energy is wasted in the process. This occurs when concentrations of CO_2 are low.

Photosynthesis - a cellular process that uses electromagnetic energy (sunlight) to assemble molecules of glucose from carbon dioxide. Water is used as an electron donor and oxygen is produced as a waste product (in oxygenic photosynthesis). Chemical formula: $6CO_2 + 6H_2O$ --(in the presence of sunlight)--> $C_6H_{12}O_6 + 6O_2$

Photosystems I & II - complexes containing chlorophyll, located in the thylakoid membrane, that absorb photons during photosynthesis.

Phototropism - movement or growth with respect to a light source

Phycobilins - polar pigments found in red algae and cyanobacteria

Phycocyanin - a blue phycobilin, more prominent in cyanobacteria

Phycoerythrin - a red phycobilin, more prominent in red algae

Phyllode - a modified petiole that is flattened to function like a leaf

phyll- leaf

Phylogeny - a hypothesis on the evolutionary relationships between organisms depicted as a branching tree diagram

phyte/phyto- plant

Phytoplankton - microscopic, photosynthesizing organisms in aquatic environments

Pilus - a projection from a prokaryotic cell that is used to interact with other cells. Pili, plural.

Pinnae - leaflets on a pinnately compound leaf (pinna, singular), such as a fern frond

Pit connection - a connection of the cytoplasm between adjacent cells formed due to incomplete cytokinesis. Found in Rhodophyta.

Pith - tissue produced by the ground meristem that is enclosed by vascular tissue

Placenta - a region of tissue in the ovary wall that supplies nutrition to the developing ovule and then seed through the funiculus

Planktonic - free-floating; wandering

plasm- living substance, tissue

Plasma membrane - a semi-permeable membrane composed of a phospholipid bilayer and a fluid mosaic of proteins, lipids, and associated carbohydrates that encloses the cytoplasm. In general, plasma membrane controls what enters and exits the cell. Nonpolar molecules like oxygen and carbon dioxide, and small molecules like water, can freely diffuse across. Molecules that are too large or too polar (charged) must be transported across.

Plasmid - a small loop of DNA that can be transmitted between organisms. Antibiotic resistance genes are often carried on plasmids.

Plasmodesma - a tube of plasma membrane that traverses the cell wall and middle lamella, connecting the cytoplasm of adjacent cells (plasmodesmata, plural).

Plasmogamy - fusion of the cytoplasm of two cellular structures

Ploidy - the number of sets of chromosomes an organism has

Pneumatophore - a root that has been modified to grow above ground and access oxygen for plants that live in flooded environments, e.g. mangroves

Polar - a type of covalent bond that is unequally shared, resulting in partial charges on the atoms. Polar compounds are partially charged and “like” to interact with other polar or ionic (charged) compounds.

Pollen - the microgametophyte of gymnosperms and angiosperms. Pollen grains deliver the sperm to the egg.

Pollen cone - see “microstrobilus”

Pollination - the successful transfer of pollen from one plant to another. This process is often mediated by insects, wind, or other vectors.

Pollination syndrome - a set of floral characteristics that have evolved in response to a particular pollinator

Pome - a fleshy fruit encased in a swollen hypanthium, the papery endocarp forms a “core”. Ex. An apple.

Population - individuals of the same species living in the same environment at the same time

Positive control - a group in your experiment that should show normal/expected results. If no change occurs in the positive control, your experiment could have false negatives.

Prickle - a modified region of the epidermis that functions as a sharp armament for protection

Primary consumer - an organism that eats primary producers, often called herbivores.

Primary endosymbiosis - an evolutionary process by which, in this case, a photosynthetic cyanobacterium was engulfed by a heterotrophic ancestor of the red algae. The cyanobacterium was not digested and evolved into a double membrane chloroplast. This process also occurred with mitochondria.

Primary meristem - a region of cells produced by the apical meristem that divides to produce primary tissues

Primary phloem - phloem tissue produced by the procambium

Primary producer - an organism that uses some external, abiotic energy source, such as electromagnetic or chemical energy, to build organic molecules. Example: plants use energy derived from sunlight to molecules of glucose.

Primary tissue - a region of cells produced by a primary meristem that collaborate toward a shared function

Primary wall - a semi-rigid structure that surrounds the plasma membrane. All plant cells have a primary wall composed of cellulose.

Primary xylem - xylem tissue produced by the procambium

pro- before

Procambium - the primary meristem that produces the primary xylem and primary phloem. In the root, it also produces the pericycle.

Prokaryote - a unicellular organism that lacks a nucleus or membrane-bound organelles. The DNA in a prokaryote occurs as a single, circular chromosome. Prokaryotic cells are surrounded by a cell wall, though the composition can vary depending on whether it is a bacterium or an archaean.

Prop root - an adventitious root used to provide stability or to attach onto other organisms

Prophase - the first stage of mitosis, where the nuclear envelope and nucleoli break down, spindle fibers form, and chromatin condenses into chromosomes

Prophase I - the first stage of meiosis I, where the nuclear envelope and nucleoli break down, spindle fibers form, and chromatin condenses into chromosomes. Homologous chromosomes pair and crossing over occurs.

Prophase II - the first stage of meiosis II, similar to prophase of mitosis. In meiosis of a diploid cell, cells are haploid when prophase II begins.

Protoderm - the primary meristem that produces the epidermis

Pyrenoid - a dense region where carbon fixation happens within chloroplasts of many groups of algae and hornworts

Pyruvate - a three carbon compound formed from the breakdown of glucose during glycolysis

Q

No current entries under “Q”.

R

Raceme - an inflorescence where florets are attached to a central axis by pedicels

Rachis - the central stem in a pinnately compound leaf, where the leaflets attach

Radial symmetry - multiple lines of symmetry can be drawn

Random fertilization - reproductive propagules (such as eggs and sperm) are not individually selected by the parents for the production of offspring, but are paired on chance

Raphide - a needle-like crystal of calcium oxalate that forms in the tissues of certain plants

Receptacle - in flowers, the point where all of the whorls attach to the peduncle. In *Fucus*, the swollen ends of the thallus.

Residual procambium - procambial tissue (the primary meristem that forms the vascular tissue) remaining between the xylem and phloem of eudicot vascular bundles in primary growth

Resin - a sticky substance produced in some gymnosperms and angiosperms that works to seal wound damage and prevent infection and herbivory

Resin canal - a channel that runs through the tissues of some gymnosperms and angiosperms to secrete and transport resin

rhiz- root

Rhizoid - a root-like structure that lacks vascular tissue and has the function of anchorage

Rhizome - a modified stem that travels horizontally below ground, producing new shoots and adventitious roots at nodes, resulting in asexual reproduction of the shoot

Ribosomes - complexes of proteins and RNA that function as an enzyme. This enzyme reads RNA to build proteins during a process called translation. The ribosome forms a peptide bond between amino acids, releasing a water molecule in the process. This is why proteins are called polypeptides.

Root - a plant organ whose function is anchorage and water absorption. Roots have a specific sequence of development and organization of tissues that is different from stems and leaves.

Root apical meristem (RAM) - the meristem responsible for producing the primary meristems in the root. All cells in the root ultimately derive from this meristem.

Root cap - cells that are produced by the RAM to the outside of the root and sloughed off continually. These cells protect the growing tip, lubricate its journey through the soil, and interact with microbes in the vacinity of the root.

Root hair - a single epidermal cell that elongates to maximize surface area. Root hairs are only produced at the growing tips of the root system.

RuBisCO - Ribulose-1,5-bisphosphate carboxylase/oxygenase. This enzyme fixes CO_2 during the Calvin cycle of photosynthesis. If CO_2 concentrations are low, it may bind to oxygen instead, causing photorespiration.

S

S-phase - the stage of interphase where DNA is replicated

Samara - a winged achene. Ex. A maple helicopter is both a samara and a schizocarp.

Sapwood - secondary xylem that is still actively conducting water. Often lighter in color than the heartwood

sapro- death, decay

Saprobe - see “Decomposer”

Saprophyte - see “Decomposer”

Schizocarp - a fruit that breaks into multiple pieces (separate carpels) when mature

scler- hard, tough

Sclereid - a sclerenchyma cells that (generally) serves a protective function. In pears, these cells dominate unripened fruits, making them difficult to eat.

Sclerenchyma - a cell with a secondary wall that is dead at functional maturity

Secondary consumer - see “Consumer”

Secondary endosymbiosis - an evolutionary process by which, in this case, a red alga was engulfed by a heterotrophic oomycete. The red alga was not digested and evolved into a four membrane chloroplast. This type of endosymbiosis has occurred multiple times.

Secondary growth - the production of secondary tissues, resulting in lateral growth. Occurs in gymnosperms and some angiosperms

Secondary phloem - phloem tissue produced by the vascular cambium. Also called inner bark.

Secondary wall - a wall in plant cells that is formed within the primary wall. The secondary wall contains lignin, providing structural support, but its formation kills the cell eventually. This cell wall is present in sclerenchyma cells.

Secondary xylem - xylem tissue produced by the vascular cambium. Also called wood.

Seed - a structure produced by gymnosperms and angiosperms that houses the growing embryo and supplies nutrition via the nucellus and the megagametophyte.

Seed coat - the integument forms the seed coat after fertilization of the egg. This structure surrounds and protects the seed.

Seed cone - see “megastrobilus”

Septum - division; divider. For example, the cross walls between cells in hyphae.

Serpentine - a mineral that, when present in soils, results in low Ca:Mg ratios and often contains heavy metals

Seta - a stem-like structure that holds up the sporangium in the sporophytes of some bryophytes (setae, plural)

Sexual reproduction - production of offspring through the fusion of cells that were produced during meiosis

Shoot apical meristem (RAM) - the meristem responsible for producing the primary meristems in the shoot. All cells in the shoot ultimately derive from this meristem.

Sieve cell - a conducting cell in the xylem

Sieve tube element - a conducting cell in the xylem of angiosperms that lacks a nucleus

Simple pore - a hole in the epidermis that is not regulated by guard cells

Simple septation - in ascomycetes, the cross walls between cells have a hole in the center

Sister chromatid - one of two replicated, attached, identical chromosomes

som(e)- body

Sorus - a cluster of sporangia, such as on a fern frond (sori, plural)

Sperm - a gamete that fuses with an egg. Generally smaller than the egg and often with flagella.

Spermatangium - a structure that produces spermatia

Spermatium - the nonmotile male gametes of red algae. This term is also used to describe a stage in the life cycle of rust fungi.

Spike - an inflorescence where florets are sessile, attached directly to a central axis

Spindle - a network of microtubules that organizes and separates chromosomes during cell division

Spine - a leaf that has been modified into a sharp armament for protection

Splash cup - the head of a male gametophyte in mosses, where antheridia await raindrops to splash sperm out

Spongy mesophyll - tissue in eudicot leaves that is full of air pockets for gas exchange during photosynthesis, located below the palisade mesophyll

Sporangiophore - a structure that holds up sporangia (such as the T-shaped projections on Equisetum strobili)

Sporangium - a structure that produces spores

Spore - a propagule that grows by mitosis (it does not fuse with another propagule)

Sporophyll - a leaf where spores are produced

Sporophyte - the multicellular, diploid phase of the plant life cycle that produces spores by meiosis

Sporophyte dominant - a life cycle where the sporophyte is larger, longer-lived, and nutritionally independent from the gametophyte

Stamen - a floral structure composed of anthers and a filament

Standardized variables - variables in your experiment that are kept the same across all treatment groups and control groups

Stem - a plant organ with lignified vascular tissue that emerges from a node in the position of the axillary bud (toward the growing tip of the branch)

Sterigma - a projection from a basidium that the basidiospore sits atop in phylum Basidiomycota. Sterigmata, plural.

Stigma - the pollen receiving part of the carpel, located at the end of the style

Stipe - the stem-like structure in brown algae and fungi

Stipular spines - stipules modified as sharp armaments for a protective function

Stipules - paired appendages at the base of a leaf

Stolon - a stem that grows horizontally above ground, producing new shoots and adventitious roots at nodes, resulting in asexual reproduction of the shoot

Stoma - an opening in the epidermis of a plant that is flanked by two guard cells, allowing for regulated gas exchange with the exterior environment.

Stomatal crypt - a cavity in the lower epidermis of a leaf where stomata are located

Strobilus - a structure where gametophytes are produced in most SVPs and gymnosperms. The strobilus is composed of sporophylls (or similar structures) and sporangia.

Stroma - the fluid inside a chloroplast, much like the cytosol of a cell

Stromatolite - a formation created by the layering of photosynthetic bacteria, mucilage, and calcium carbonate. The first widely agreed upon evidence of life can be found in fossilized stromatolites.

Storage root - a root modified to store water or carbohydrates

Style - the structure that the pollen tube grows down to reach the ovary, located between the ovary and stigma

Suberin - a waxy lipid that forms the Casparian strip and is present in cork cells

Succulent - a plant or swollen tissue that stores water and can use this water for metabolic purposes during periods of drought

Sunken stoma - a stoma located in a depression in the epidermis to prevent water loss

Surface tension - a property caused by the attraction of partial charges between molecules in a liquid. This property minimizes surface area.

sym- shared

Symbiosis - when two or more organisms of different species live in close proximity to one another, sharing some aspect of their life cycle.

Synergids - two haploid cells that flank the egg in the embryo sac

synthesis- to form or put together

T

Taproot - a root system that has a larger central root with smaller lateral roots, such as a carrot or a turnip.

Telomere - the region at the end of a chromosomal arm

Telophase - the stage of mitosis where the chromosomes decondense into chromatin, the spindle breaks down, and the nuclear envelope and nucleoli reform. Cytokinesis happens during this stage of mitosis.

Telophase I - the stage of meiosis I where the chromosomes decondense into chromatin, the spindle breaks down, and the nuclear envelope and nucleoli reform. Cytokinesis happens during this stage of meiosis, resulting in two haploid cells.

Telophase II - the stage of meiosis II where the chromosomes decondense into chromatin, the spindle breaks down, and the nuclear envelope and nucleoli reform. Cytokinesis happens during this stage of meiosis, resulting in four haploid cells.

Tendril - a modified leaf or branch used for attachment and/or climbing

Terminal bud - the bud at the end of a stem where the next year's growth is formed

Terminal bud scales - modified leaves (bracts) that cover and protect the developing terminal bud

Terminal bud scale scars - scars left behind on a stem where the terminal bud scales have fallen off after the new tissue emerges. The distance between terminal bud scale scars indicates one year of growth (in a temperate climate).

Tertiary consumer - see "Consumer"

Tetrasporangium - a structure that produces tetraspores

Tetraspore - a haploid spore produced by meiosis in the red algae life cycle. Tetraspores develop into either male or female gametophytes.

Tetrasporophyte - the multicellular diploid that undergoes meiosis in the red algae life cycle

Thallus - a body composed of undifferentiated tissues

Thalloid - having a thallus for a body plan

Thigmotropism - movement or growth in response to touch

Thin layer chromatography - a process used to separate substances by polarity

Thorn - a stem modified as a sharp armament for protection

Thylakoid - a high surface area structure in chloroplasts with chlorophyll molecules in the membrane. This is where the electron transport chain of photosynthesis occurs.

Thylakoid space - the internal area of a thylakoid

Tissue - a collection of cells working toward the same function

Tonicity - the amount of dissolved solutes in the solution relative to another solution on the other side of a membrane. This can also be thought of as osmotic potential.

Tonoplast - the membrane that encloses the central vacuole in plant cells.

troph- feeding

Tracheid - a long, narrow sclerenchyma cell in the xylem with tapered ends and bordered pits. These cells conduct water in the xylem tissue.

Tracheophytes - plants that have lignified vascular tissue. This group includes seedless vascular plants, gymnosperms, and angiosperms.

Transfusion tissue - tissue that surrounds the vascular bundles in some xerophytic leaves, located within the endodermis

Transpiration - the evaporation of water from plant tissues

Trap - a leaf that has been modified to capture organisms, most often insects, to digest for nutrients missing from the plant's environment

Treatment group - a group in your experiment where you have made some modification to the independent variable

trich- hair

Trichogyne - a slender tube that the spermatium travels through to get to the egg in the red algal life cycle

Trichome - a parenchyma cell that projects outward as a hair from the epidermis

Trumpet hyphae - sugar-conducting cells present in some brown algae

Tube cell - the cell in pollen grains that grows the pollen tube to the ovule for the sperm to travel down

Tuber - an underground stem modified for storage that can produce new shoots from nodes called "eyes"

Turgid - the state of being filled to swollen, such as with plant cells

U

Umbel - an inflorescence where pedicels converge on a single point where they attach to the peduncle

uni- singular, one

Unicellular - an organism composed of a single cell. Unicellular organisms can be prokaryotic or eukaryotic.

Universal veil - some mushrooms start out covered by a material called a universal veil. As they grow, they break through this veil, often leaving remnants in areas of the mushroom.

Universal veil scales (warts) - remnants of the universal veil on the cap of a mushroom

V

Vascular cambium - the secondary meristem that makes the secondary xylem to the inside and secondary phloem to the outside

Vascular cylinder - when the vascular tissue forms a ring that divides the ground tissue into two distinct regions. This is present in monocot roots and eudicot stems.

Vascular tissue - composed of xylem tissue that conducts water and dissolved nutrients, and phloem tissue that conducts photosynthates

Vegetative - a cell, organ, or life stage of an organism that is not actively involved in reproduction. When referring to cyanobacteria, the vegetative cells are the individuals that are performing photosynthesis for the colony. For *Spirogyra*, the vegetative cells are those that are not undergoing sexual reproduction to form a zygote. In plants, vegetative parts (you might call them vegetables) are anything that is not a fruit or flower.

Vessel element - a wide sclerenchyma cell in the xylem with perforation plates at each end. These cells conduct water in the xylem tissue of angiosperms and gnetophytes.

Volva - remnants of the universal veil at the base of a mushroom

W

Whorled (leaf arrangement) - three or more leaves emerge at a node

X

xanth- yellow

xero/xeric- dry

Xerophyte - a plant adapted to dry environmental conditions

Xerophytic leaf - a leaf that has specifically adapted to dry conditions

Xylem - the lignified, water conducting tissue in a plant

Xylem rays - sheets of parenchyma cells that traverse the secondary xylem

Y

Yeast - a unicellular fungus

Z

Zone of division - a region in the growing root tip where the RAM and primary meristems are located. Generally, this zone ends around where the root cap stops.

Zone of elongation - a region in the growing root tip where cells exit the cell cycle and begin to get larger

Zone of maturation - a region in the growing root tip where cells differentiate into specialized cells or tissues

zoo- animal

Zoosporangium - a structure that produces zoospores

Zoospore - swimming spore (has at least one flagellum)

zygo- can mean yoke-shaped, paired, or joined

Zygomorphic - see “bilateral symmetry”

Zygosporangium - a large, ornamented structure where both fertilization and meiosis occur in some lineages of early fungi (formerly classified as the Zygomycota)

Zygote - the first diploid cell in an organism’s life cycle

Contributors and Attributions

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GLOSSARY

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Evolutionary Profile - Photosynthetic Groups

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Dichotomous Key to Common Fruits

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INDEX

A

amyloplasts
3.8: Cell Structures and Organelles
angiosperms
19.3: Major Evolutionary Lineages
Anthocerotophyta
20.4: Anthocerotophyta - Hornworts

B

bark
11.2: Introduction
basal meristem
20.4: Anthocerotophyta - Hornworts
branching sporophytes
21.2: Introduction to Seedless Vascular Plants
brown algae
17.5: Phaeophyta - The Brown Algae
bryophyta
20.6: Bryophyta - Mosses
bryophytes
19.3: Major Evolutionary Lineages
20: Bryophytes

C

carposporophyte
18.3: Phylum Rhodophyta - The Red Algae
central vacuole
3.8: Cell Structures and Organelles
chloroplast
3.7: Primary Endosymbiosis
closed vascular bundles
8.4: Monocots
coevolution
2.7: Coevolution and Natural Selection
collenchyma cells
4.2: Introduction
community
2.6: Community Interactions
companion cells
4.3: Identifying Cell Types and Tissues
cone
22.2: Introduction to Gymnosperms
conifer
22.5: Gnetophytes and Conifers
cortex
4.3: Identifying Cell Types and Tissues
Cuticle
19.3: Major Evolutionary Lineages
cycads
22.4: Cycads and Ginkgos

D

dendrochronology
11.6: Dendrochronology
dichotomous key
22.6: Using a Dichotomous Key
dicots
8.4: Monocots

E

ectomycorrhizal
16.4: Fungal Ecology
embryophytes
19.2: Introduction to the Evolution of the Embryophyta
endosymbiosis
3.7: Primary Endosymbiosis
epidermis
4.3: Identifying Cell Types and Tissues
epidermis (plants)
9.3: Leaf Anatomy
eudicots
8.4: Monocots

F

fermentation
13.3: Cellular Respiration
ferns
21.4: Ferns (Class Polypodiopsida)
Floridean starch
18.3: Phylum Rhodophyta - The Red Algae

G

ginkgos
22.4: Cycads and Ginkgos
glycolysis
13.3: Cellular Respiration
gnetophytes
22.5: Gnetophytes and Conifers
gymnosperms
19.3: Major Evolutionary Lineages

H

hornworts
20.4: Anthocerotophyta - Hornworts

L

lignin
21.2: Introduction to Seedless Vascular Plants
liverworts
20.5: Marchantiophyta - The Liverworts
lycophytes
21.3: Lycophytes (Class Lycopodiopsida)

M

mesophyll cells
4.3: Identifying Cell Types and Tissues
mesophyte
9.3: Leaf Anatomy
monocots
8.4: Monocots
monoplastidic
20.4: Anthocerotophyta - Hornworts
mosses
20.6: Bryophyta - Mosses
multicellular gametangia
19.2: Introduction to the Evolution of the Embryophyta
mutualism
2.5: Mycorrhizal Networks
mycelium
16.4: Fungal Ecology
mycorrhizal networks
2.5: Mycorrhizal Networks
mycorrhizal relationship
2.5: Mycorrhizal Networks

O

oomycota
17.3: Oomycota -- The Water Molds

P

palisade mesophyll
9.3: Leaf Anatomy
parasites
2.5: Mycorrhizal Networks
parenchyma cells
4.2: Introduction
perforation plates
4.3: Identifying Cell Types and Tissues
phaeophyta
17.5: Phaeophyta - The Brown Algae
phagocytosis
3.7: Primary Endosymbiosis
phloem
4.3: Identifying Cell Types and Tissues
phloem fibers
8.4: Monocots
pit connections
18.3: Phylum Rhodophyta - The Red Algae
pith
4.3: Identifying Cell Types and Tissues
pits
4.3: Identifying Cell Types and Tissues
plasmodesmata
3.8: Cell Structures and Organelles
pollination
2.6: Community Interactions
polypodiopsida
21.4: Ferns (Class Polypodiopsida)
population
2.6: Community Interactions

R

red algae
18.3: Phylum Rhodophyta - The Red Algae
Rhodophyta
18.3: Phylum Rhodophyta - The Red Algae

S

sclerenchyma cells
4.2: Introduction
4.3: Identifying Cell Types and Tissues

secondary wall
4.2: Introduction
sieve tube elements
4.3: Identifying Cell Types and Tissues
sporopollenin
19.2: Introduction to the Evolution of the Embryophyta
stoma
9.3: Leaf Anatomy
symbiosis
2.5: Mycorrhizal Networks
3.7: Primary Endosymbiosis

T

tonoplast
3.8: Cell Structures and Organelles
tracheids
4.3: Identifying Cell Types and Tissues
tracheophytes
19.3: Major Evolutionary Lineages
transpiration
2.4: Nutrient Cycling in Ecosystems
tuber
3.8: Cell Structures and Organelles

V

vessel elements
4.3: Identifying Cell Types and Tissues

W

water molds
17.3: Oomycota -- The Water Molds

X

xerophytic leaves
22.2: Introduction to Gymnosperms
xylem
4.3: Identifying Cell Types and Tissues

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GLOSSARY

A

Abiotic | nonliving

Abscission | the natural detachment of plant parts, such as with leaves in the winter

Accessory fruit | a fruit where the fleshy material is not derived from the ovary. Ex. A strawberry or rose hip

Achene | a dry fruit with a single seed surrounded by a pericarp that can be peeled away. Layers of the pericarp are not distinguishable with the naked eye. Ex. A sunflower seed.

Actinomorphic | See “Radial symmetry”

Adhesion | attraction between dissimilar molecules or substances (such as tape to paper)

Adventitious root | a root that emerges from stem tissue

Aerenchyma | parenchyma tissue with large air pockets for flotation

Aggregate fruit | a fruit derived from a flower with multiple free carpels. Ex. A blackberry.

Akinete | a form some cyanobacteria can take. Larger, thick-walled cells that tend to be more granular in appearance. Akinetes store large amounts of lipids and carbohydrates so that they have enough energy to begin a new colony if conditions become too cold or too dry for survival. Formation of akinetes can be triggered by dry or cold conditions.

Alcohol fermentation | a form of fermentation performed by yeasts that converts pyruvate into ethanol and CO2 to replenish NAD+

Alternate (leaf arrangement) | one leaf emerges at a node

Alternation of generations | See “Haplodiplontic”

amylo | starch (amylose)

Amyloplast | a type of plastid that produces and stores starch. An amyloplast is a type of leucoplast, which are plastids that do not contain pigment.

Anaphase | the stage of mitosis where spindle fibers pull sister chromatids to either side of the cell, splitting them into two separate chromosomes

Anaphase I | the stage of meiosis I where spindle fibers pull homologous chromosomes to either side of the cell

Anaphase II | the stage of meiosis II where spindle fibers pull sister chromatids to either side of the cell, splitting them into two separate chromosomes

andro | male, man

Androecium | the floral whorl composed of stamens

angio/angium | vessel

Annual growth ring | a light and dark region of secondary xylem that forms in response to environmental conditions. The light portion of the ring is composed of larger cells, formed when water is abundant (also called early wood). The dark portion of the ring is composed of smaller diameter, densely packed cells, formed when water becomes more scarce (also called late wood).

Annulus | a ring-like structure. In fungi, this refers to the partial veil remnants left around the stipe. In ferns, it refers to the ring of inflated cells around the sporangium that dries and pulls the sporangium open, releasing the spores.

anth | flower

Anther | pollen sacs in flowering plants

Antheridiophore | a structure that bears antheridia

Antheridium | a multicellular structure on the gametophyte that produce sperm by mitosis

Antipodals | three haploid cells in the embryo sac located on the opposite end of the micropyle

Apical growth | growth extending from the tips (such as the tips of roots or shoots in plants)

Apothecium | a (usually) cup-shaped fruiting body produced by some ascomycetes

Arbuscule | a highly branched structure formed by endomycorrhizal fungi on the plasma membrane of plant root cells. The increased surface area increases the ability to exchange materials.

Archegoniophore | a structure that bears archegonia

Archegonium | a multicellular structure on the gametophyte that produce an egg by mitosis

Ascocarp | a fruiting body (sexually reproducing structure) produced in the fungal phylum Ascomycota

Ascospore | a haploid spore produced by meiosis, then mitosis, within the ascus of an ascomycete

Ascus | a sac-like structure where meiosis occurs to produce spores in ascomycetes. Asci, plural.

Asexual reproduction | a form of reproduction that produces identical copies of the parent cell (e.g. mitosis, binary fission, and budding)

Astrosclereid | a sclereid cell that transverses the leaves of *Nymphaea* and forms star-like shapes

ATP | (adenosine triphosphate) a high energy molecule with three negatively charged phosphate groups. ATP can "donate" a phosphate group to a reaction, breaking a high energy bond and releasing energy. This process is called phosphorylation. Most work done in cells is powered by ATP.

ATP Synthase | an enzyme that uses the flow of H+ ions back down their concentration gradient (secondary active transport) to phosphorylate ADP into ATP.

auto | self

Autotroph | an organism that forms organic molecules from inorganic molecules. This can also be thought of as an organism that makes its own food (self-feeding).

Auxospore | an enlarged spore produced by diatoms during sexual reproduction (and apparently sometimes through asexual reproduction)

Axillary bud | a structure located in the axil of the leaf that produces a branch, flower, or inflorescence

B

Bark | layers of periderm (phelloderm, cork cambium, and cork) form the outer bark, while the secondary phloem forms the inner bark.

Basal meristem | meristematic tissue located at the base of a structure. Most plants grow from apical meristems, producing new tissue at and elongating from the tips. Basal meristems produce tissue where the tips are the oldest parts.

Basidiocarp | a fruiting body (sexually reproducing structure) produced by some basidiomycetes

Basidiospore | a haploid spore produced by meiosis within the basidium

Basidium | a (usually) club-shaped structure that produces spores in the basidiomycetes

Benthic | at the bottom of a body of water

Berry | a fleshy fruit with a thin exocarp, fleshy mesocarp, and one to many seeds not enclosed within an endocarp derived from the ovary wall

bi | two

Bilateral symmetry | having one line of symmetry

Binary fission | a form of asexual reproduction used by prokaryotic cells where the original cell expands as internal contents are replicated, then a new cell wall forms in the middle, dividing into two new, identical cells

bio | life

Bioavailable | a form that can be absorbed by and assimilated into an organism.

Biotic | living

Blade | the (usually) flat, photosynthetic portion of the leaf located at the end of the petiole. In brown algae, this is the leaf-like structure (or structures) on the thallus.

Bud primordium | the early developmental stage of the axillary bud

Bud scar | the scar left behind on a stem where the axillary bud has fallen off via abscission

Budding | a form of asexual reproduction used by yeast where a smaller cell is made from the original cell, leaving a bud scar. The smaller cell grows to normal size after separation from the parent cell.

Bulb | a rosette of fleshy leaves modified for storage, surrounding a short stem

Bulliform cells | enlarged cells in the epidermis that respond to water loss by collapsing, causing the leaf to roll or fold and reducing sun exposure

Bundle scars | scars left behind inside a leaf scar where the vascular bundles of the leaf travelled into the stem

Bundle sheath | the ring of cells that surround a vascular bundle. This could be in the stems of monocots or in the leaves of either group.

C

C3 | the "standard" and most energy efficient form of photosynthesis

C4 | a form of photosynthesis performed by plants adapted to hot weather. RuBisCO is located in the bundle sheath cells, where CO2 is actively transported in the form of an acid to keep concentrations high. This occurs when stomata close to prevent water loss, limiting CO2 intake.

Calvin cycle | the light independent phase of photosynthesis where RuBisCO fixes CO2 and the end product is glucose. This process occurs in

the stroma of the chloroplast.

Calyptra | tissue from the female gametophyte that is carried on top of the developing sporophyte in the bryophytes

Calyx | the floral whorl composed of sepals

CAM | Crassulacean acid metabolism. This is a form of photosynthesis performed by plants adapted to dry weather. Stomata close during the day to prevent transpiration and open at night to let in CO2. The CO2 is actively transported into the central vacuole and converted into an acid. During the day, it is converted back into CO2 so photosynthesis can occur.

Cap (pileus) | the top of a mushroom. The spore producing surface is on the underside of the cap (usually).

Capillary action | the tendency of a liquid to rise or fall as a result of surface tension

Capsule | a dry fruit with multiple fused carpels that open at maturity. Ex. Cotton. Note: this term is also often used to describe the structure that encases the sporangia in mosses.

Carotenoids | red, orange, and yellow pigments found in plants, green algae, and photosynthetic heterokonts. These are often used to protect from sun damage or to signal ripening in fruits, as well as absorb some of the green parts of the spectrum of light.

carp | of the fruit or fruiting body

Carpogonium | a structure produced on the red algae female gametophyte. It consists of the egg and the trichogyne and may also be called the carpogonial branch.

Carposporangium | a structure that produces carpospores

Carpospore | a diploid spore that is identical to the zygote in the red algae life cycle. Carpospores grow by mitosis into a tetrasporophyte.

Carposporophyte | a multicellular diploid phase in the red algal life cycle that produces clones of the zygote called carpospores

Caryopsis | a dry fruit similar to an achene, but the pericarp is fused to the seed. This fruit type is produced by members of the Poaceae (grass family). Ex. A corn kernel.

Casparian strip | a layer of suberin that coats the endodermis in roots. This layer forms in patches, leaving passage cells at the xylem poles.

Cell wall | a rigid structure that encloses the plasma membrane. The presence and composition of the cell wall are useful features in classifying and identifying organisms.

Cellulose | a polysaccharide found in plant cell walls. Cellulose is also found in the cell walls of oomycetes and red, green, and brown algae.

Central cell | a cell in the embryo sac containing two polar nuclei

Central vacuole | a (generally) large, fluid-filled organelle enclosed by a membrane (the tonoplast). The central vacuole often takes up the majority of a plant cell and is responsible for storage of compounds (ex. toxins, anthocyanins, and salts) and turgidity of the plant cell, which contributes to rigidity of the entire plant.

Centric | (a diatom) with radial symmetry

Centromere | the central region of a chromosome where sister chromatids are attached (in replicated chromosomes)

Chemical energy | energy stored in the bonds between atoms within molecules

Chemiosmosis | the movement of ions from areas of high concentration to low concentration across a semipermeable membrane. This happens with H+ flow through ATP synthase in both cellular respiration and photosynthesis.

Chemosynthesis | a cellular process that uses chemical energy derived from oxidizing (stealing electrons from) inorganic compounds to build organic molecules. In this process, the inorganic compound is the electron donor. The waste product will depend on what the initial inorganic compound is (for example, if hydrogen sulfide is used, sulfur and water could be produced as waste products).

Chitin | polysaccharide (carbohydrate) found in fungal cell walls and arthropod exoskeletons

Chlorenchyma | parenchyma cells with chloroplasts for photosynthesis

Chlorophyll | a photosynthetic pigment that reflects light in the green portion of the spectrum. These molecules can harvest energy from the blue and, to a lesser extent, red part of the spectrum of light by emitting an electron after absorbing a photon. All photosynthetic organisms covered in this class contain chlorophyll a, which is the primary molecule involved in the light-harvesting portion of photosynthesis.

Chloroplast | a double-membrane bound organelle derived from bacterial endosymbiosis that contains chlorophyll and is responsible for photosynthesis. Chloroplasts can be converted into chromoplasts or leucoplasts, when needed.

Chromatin | DNA wound around histone proteins

chromo/chroma | color

Chromoplast | a double-membrane bound organelle derived from bacterial endosymbiosis that contains pigments other than chlorophyll, such as carotenoids. Often found in ripening fruits to attract animals with the red hues.

Chromosome | chromatin that has been tightly packaged in preparation for cell division

Chytrid | an aquatic fungus with swimming spores (zoospores)

Circinate vernation | the process by which fern fiddleheads unfurl in the spring

Citric acid cycle | a process that takes place in the matrix of a mitochondrion during cellular respiration. ATP, NADH, and FADH2 (as well as some CO2) are produced.

Cladode | a stem that has been modified for photosynthesis, often green with increased surface area

Clamp connection | a rounded structure that forms on the side of a basidiomycete hypha as nuclei divide

Classification | a system of categorizing organisms into like groups

Cleistothecium | an enclosed, microscopic fruiting body produced by some ascomycetes

Coenocytic | this can refer to fungal hyphae with no septations (cross walls) or, more generally, to any cell with many nuclei

Coevolution | the linked evolution of two interacting species

Cohesion | attraction between like molecules (for example the attraction of a partial positive charge on the hydrogen atom of one water molecule to the partial negative charge on the oxygen atom of another water molecule)

Collenchyma | cells with unevenly thickened primary walls, often involved in flexible support in young growing tissues

Community | multiple interacting populations living in the same area at the same time

Companion cell | a cell with a nucleus paired with a sieve tube element. The companion cell acts as the command center for that sieve tube element.

Complete (flower) | a flower containing all four floral whorls

Complex septation | also called a dolipore septum. The walls around the pore in the septum are swollen and two structures that look like parentheses (aptly called parenthesomes) flank the pore.

Conceptacle | a chamber inside the Fucus receptacle that houses the gametangia

Cone | see “strobilus”

Conidiophore | a structure that bears conidia

Conidium | a spore produced by mitosis (asexual reproduction) in molds

Conjugation tube | a structure produced in Spirogyra that allows mating to occur between compatible colonies. Cell contents are transferred through the conjugation tube.

Consumer | an organism that eats other organisms as an energy source. A primary consumer eats producers, a secondary consumer eats primary consumers (though it may also eat producers), and a tertiary consumer eats secondary consumers (though it may also eat both primary consumers and producers, as well).

Cork | suberized cells that are dead at functional maturity produced in the periderm during secondary growth. Cork cells form the outermost layer of stems and roots in secondary growth.

Cork cambium | the secondary meristem that produces cork to the outside and phelloderm to the inside

Corm | a stem that has been modified for storage. Nodes on the corm produce papery leaves.

Corolla | the floral whorl composed of petals

Cortex | tissue produced by the ground meristem, located between the vascular tissue and the epidermis

Costa | the central “vein” in a moss leaf. Note: mosses do not have true vascular tissue, particularly not in the gametophyte.

Cotyledon | the first leaf or leaves to appear as a seed germinates

Crossing over | during prophase I of meiosis, homologous chromosomes align and can swap regions of DNA, resulting in increased genetic variety within an organism’s gametes.

Crustose | a lichen that is completely appressed (stuck up against) what it is growing on. Cannot be (easily) removed from this substrate.

Cuticle | a waxy layer made of the lipid cutin that coats the epidermis in plants

cyan | blue

cyst | a sac or bladder containing fluid

Cystocarp | a structure produced on the female gametophyte of red algae. The carpogonium enlarges and the zygote develops inside, growing by mitosis into the carposporophyte. Female gametophyte tissue (the pericarp) surrounds the carposporophyte. These two components together comprise the cystocarp.

cyto | cell, cellular

Cytokinesis | division of the cytoplasm through the formation of a new cell wall during mitosis and meiosis, which happens concurrently with telophase.

Cytoplasm | everything inside the plasma membrane, excluding the nucleus. This term is often confused with the term cytosol, which refers to

the jelly-like matrix that fills the cell and surrounds the organelles, if present.

Cytoplasmic streaming | movement of the cytoplasm around the cell to transport nutrients, organelles, or other materials

D

Decomposer | an organism that breaks down dead organic matter, transforming the molecules trapped within those organisms into forms that are released into the environment and their respective nutrient cycles. This term is synonymous with the terms saprobe and saprophyte.

Dehiscent | a dry fruit that opens on its own at maturity, usually to disperse the seeds

Dendrochronology | a process used to determine the order and timing (chronology) of events using information in tree rings

Dependent variable | the variable(s) in a scientific experiment that you record data on during and/or after your experiment

di | two; double

Diffusion | the tendency of particles to move from areas of high concentration to areas of lower concentration due to random movements and entropy

Dikaryon | a dikaryotic fungal thallus

Dikaryotic | having two unfused, haploid nuclei per cell (n+n)

Dioecious | male and female reproductive structures are produced on different plants

Diploid | having two sets of chromosomes (2n)

Diplontic | a life cycle where the multicellular stage is diploid

Dispersal agent | in angiosperms, the organism or phenomenon that aids in dispersal of the seeds

Double fertilization | the fertilization of both the egg (producing a zygote) and the polar nuclei (producing the endosperm) in the angiosperm life cycle. A form of double fertilization also occurs in gnetophytes, but the result is two fertilized eggs.

Drupe | a (typically) fleshy fruit with a thin exocarp, fleshy mesocarp, stony endocarp, and (typically) a single seed. Ex. A peach.

E

Ecosystem | the biotic and abiotic components of an environment and the interactions between these components

Ectomycorrhizal | a mycorrhizal association formed by some Ascomycota and Basidiomycota (and at least one zygomycete) around the cells of plant roots, forming a fungal sheath around the roots and a hartig net within the roots. See “mycorrhizal” for more information.

Egg | the haploid cell produced by the megagametophyte that must fuse with a sperm to produce a zygote

Elaters | elongate structures that promote spore dispersal by interacting with moisture in the air (hygroscopic movement). Found on the spores of Equisetum and in the sporangia of bryophtyes.

Electromagnetic energy | energy that travels as a wave and does not require a medium. For example, light is a form of electromagnetic energy because it can travel as a wave through the vacuum of space. Sound, even though it travels as a wave, is not a form of electromagnetic energy because it requires a medium, such as air or water, to transmit it. Sound does not travel in space! So, laser gun battle in space = totally silent.

Electron transport chain | a series of protein complexes that transfer electrons between each other. The energy from the electrons allows some of these protein complexes to pump H+ across the membrane.

Embryo | a zygote that is retained and nourished by the female gametophyte.

Embryo sac | the mature megagametophyte of an angiosperm, containing 7 cells and 8 nuclei

endo | inside, internal, inner

Endocarp | the innermost layer of the pericarp in a fruit. In a peach, the endocarp is the stony pit enclosing the seed.

Endodermis | the innermost layer of the cortex in the root (also present surrounding the transfusion tissue in a pine needle)

Endogenous | formed from within

Endomycorrhizal | fungi that penetrate between the cell wall and plasma membrane of plant roots, establishing a mutualistic exchange of materials. This is a trait shared by all of Glomeromycota.

Endosperm | the result of a sperm fertilizing the polar nuclei (central cell) in the embryo sac. This triploid tissue is consumed by the growing zygote in an angiosperm seed.

epi | on top of

Epidermis | the outermost layer of the plant, composed of a single cell layer. These cells are parenchyma and often include specialized cells, such as trichomes or guard cells.

Epiphyte | growing on a plant

eryth | red

eu | true

Eudicot | (alternatively called dicot) flowering plants that produce two cotyledons

Eukaryote | an organism that can be unicellular or multicellular, but each cell with contain a nucleus (though this may be lost in some plant cells). Eukaryotes have linear DNA that is stored inside the nucleus and their cells contain membrane-bound organelles like mitochondria and the endoplasmic reticula.

exo | outer

Exocarp | the outer layer of the pericarp in a fruit. In a peach, the exocarp is the fuzzy skin.

Exogenous | formed on the exterior

F

Fascicular cambium | residual procambium within vascular bundles that joins with the interfascicular cambium to form the vascular cambium in eudicots

Fermentation | a process that occurs after glycolysis to restore NAD+, such as the production of lactate or ethanol

Fiber | an elongated sclerenchyma cell with tapered ends whose function is structural support

Fiddlehead | a frond that has yet to unfurl via circinate vernation

Filament | (in flowers) the stem-like structure that holds the anthers aloft

Flagellum | a long projection that can be present on both prokaryotic and eukaryotic cells that is used for movement

Floret | a flower in an inflorescence

Floridean starch | the form of starch used by red algae as a storage carbohydrate

Flower | a set of modified leaves that promote fertilization (pollination)

Foliose | leaf-like. In lichens, a flattened thallus with two distinct sides (can be removed from substrate).

Follicle | a dry fruit composed of a single carpel that splits open along a single seam at maturity

Food | compounds your body can break down to get energy, usually carbohydrates

Food web | an interconnected network of organisms participating in the flow of energy through an ecosystem. A food web involves primary producers, consumers, and decomposers. At each transition in a food web from one organism to another, about 90% of the available energy is lost as heat.

Foot | the base of the sporophyte seta, where it attaches to the gametophyte

Frond | the megaphyll of plants in subclass polypodiidae in the Ferns

Fruit | the swollen ovary and enclosed seeds produced by angiosperms

Frustule | the silica cell wall of diatoms, composed of two valves

Fruticose | a lichen that is three dimensional, but without two distinct sides. Often called “busy” or “shrubby”

Fucoxanthin | a carotenoid found in photosynthetic heterokonts

Funiculus | transitional tissue between the angiosperm ovary and the developing ovule, much like an umbilical cord

G

G0 | the stage of the cell cycle when a cell ceases to divide and specializes

G1 | the stage of the cell cycle when cytoplasmic contents are duplicated

G2 | the final stage of the cell cycle, where a cell is verified to be ready for division

Galactans | sulfated polysaccharides present in the cell walls of red algae

Gametangium | a structure that produces gametes

Gamete | a haploid cell that must fuse with another haploid cell to form a zygote

Gametophyte | a haploid, multicellular generation that produces gametes by mitosis

Gametophyte dominant | a life cycle where the gametophyte is larger, longer-lived, and nutritionally responsible for the sporophyte

gamy | union, marriage

Gas bladder | a pocket in the thallus of brown algae that traps gases to act as a float

Gemma | an asexual clone of plant tissues, such as in thalloid liverwort gametophytes (gemmae, plural)

Gemmae cup | a cup-like structure where gemmae are produced

Generative cell | the haploid cell in pollen grains that divides to produce sperm

Gills (lamellae) | structures in some mushrooms where the spore producing basidia are located

glyco | relating to sugar (often glucose)

Glycogen | a polysaccharide (carbohydrate) used to store sugars in fungi, animals, and other heterotrophs

Glycolysis | the first stage in cellular respiration or fermentation, where glucose is broken down into two molecules of pyruvate. This occurs in the cytoplasm.

Granum | a stack of thylakoids in a chloroplast (grana, plural)

Gravitropism | movement or growth with respect to the pull of gravity (toward or away from)

Ground meristem | the primary meristem that produces ground tissue, cortex, and pith. In the root, it also produces the endodermis (the innermost layer of the cortex).

Ground tissue | tissue produced by the ground meristem with no particular organizational structure, such as in the stems of monocots.

Guard cell | a parentheses-shaped parenchyma cell in the epidermis of a plant that regulates the opening and closing of a stoma, depending on water availability

gyn | female, woman

Gynoecium | the floral whorl composed of carpels

H

H+ | a hydrogen atom that is missing an electron. A hydrogen ion. A proton.

Haplodiplontic | a life cycle where there is a multicellular haploid phase and a multicellular diploid phase (also called alternation of generations or, occasionally, sporic meiosis)

Haploid | having one set of chromosomes (n)

Haplontic | a life cycle where the multicellular phase is haploid

Head (flower) | an inflorescence where florets are directly attached to the receptacle. There can be ray florets and/or disc florets present. Also called a capitulum.

Heartwood | secondary xylem that is no longer conducting water. Often darker in color and is located in the center of the stem.

Heliotropism | movement or growth with respect to the sun

Hesperidium | a modified berry with a leathery rind. Locules are filled with juicy trichomes. Ex. An orange.

hetero | other

Heterocyst | a form some cyanobacteria can take. Heterocysts are larger, round, thick-walled cells that can appear yellow and have two polar bodies, one on each end where they attach to other cells in the colony. These individuals are involved in nitrogen fixation and so cannot perform photosynthesis.

Heterosporous | producing two different spore types: microspores and megaspores

Heterotroph | an organism that consumes other organisms, living or dead, as a carbon source.

Holdfast | a structure at the base of brown algal thalli that attaches the thallus to a surface

homo | same

Homologous chromosomes | chromosomes from different parental origin that contain the same genes in the same order. For example, you have homologous copies of chromosome 1, one from each parent.

Homosporous | producing a single spore type that grows into a bisexual gametophyte

hydro | water

Hydrophyte | a plant adapted to aquatic environments (or high water levels)

hyper | over, above

Hypertonic | a solution with a higher ratio of dissolved solutes to water than the solution on the other side of a semipermeable membrane

Hypha | a walled, thread-like cellular structure that fungal body plans are composed of

hypo | under, below

Hypodermis | a layer or multiple layers of cells just under the epidermis

Hypothesis | a proposed explanation for a phenomenon that is both testable and falsifiable

Hypotonic | a solution with a lower ratio of dissolved solutes to water than the solution on the other side of a semipermeable membrane

I

Imperfect (flower) | a flower containing either an androecium or gynoecium, but not both

Incomplete (flower) | a flower missing at least one floral whorl

Indehiscent | a dry fruit that does not open on its own at maturity

Independent assortment | an event in meiosis that results in increased genetic diversity. During metaphase I, homologous chromosomes line up randomly on either side of the metaphase plate, resulting in different combinations of chromosomes in each meiotic event.

Independent variable | the variable in a scientific experiment that you change between treatment groups

Indusium | an umbrella-like structure in a fern sorus that protects the developing sporangia

Inflorescence | a compound flower composed of multiple florets

Inner bark | secondary phloem

Integument | the protective layer surrounding a developing ovule in seed plants. After fertilization, it becomes the seed coat.

Interfascicular cambium | cells in the pith rays that join with the fascicular cambium to form the vascular cambium in eudicots

Intermembrane space | the area between two membranes, such as between the inner and outer membranes in a mitochondrion

Internode | the region of the plant stem between nodes

Interphase | cells spend most of their time in this part of the cell cycle. It is broken into three distinct phases that prepare a cell for division.

iso | same

Isomorphic | sharing the same overall form

Isotonic | two solutions on either side of a semipermeable membrane that have the same ratio of dissolved solutes to water

K

karyo | seed (in biology, this term refers to the nucleus)

Karyogamy | fusion of two nuclei

Kinetochore | a region on the centromere of a chromosome where spindle fibers attach during cell division

Krebs cycle | see “citric acid cycle”

L

Lactic acid fermentation | a form of fermentation performed by animal cells and bacteria that converts pyruvate into lactate to replenish NAD+. H+ are produced as a byproduct, hence the name lactic acid.

Latex | a compound produced by some groups of plants that often serves a protective function. It can contain toxic compounds and/or gum up the mouthparts of insects

Leaf | a plant organ with lignified vascular tissue that emerges from a node in the position of the leaf, below the axillary bud (away from the growing tip of the branch)

Leaf axil | the area formed in the angle between the petiole of the leaf and the stem

Leaf primordium | the early developmental stage of a leaf

Leaf scar | the scar left behind on a stem where the leaf has fallen off or was removed

Legume | a dry fruit composed of a single carpel that splits open along two seams at maturity. This is the fruit of plants in the Fabaceae (bean family). Ex. A lupine pod or a peanut.

Lenticel | a tear in the periderm of woody plants that allows for the exchange of gases with the exterior environment

leuco | white or colorless

Leucoplast | a double-membraned organelle derived from bacterial endosymbiosis that does not contain pigment. Leucoplasts synthesize and store lipids or starch, such as in amyloplasts.

Lichen | a symbiotic relationship between a fungus and an alga and/or a cyanobacterium

Life cycle | a summary of the major events in a species’ development, including fertilization, growth, and reproduction

Lignin | a tough, complex polymer in the secondary walls of sclerenchyma cells. A primary component of wood, along with cellulose.

Link reaction | the transportation of pyruvate from the cytoplasm of the cell into the matrix of the mitochondrion. In the process, pyruvate is converted to acetyl-CoA.

Locule | a compartment of an angiosperm ovary representing one carpel

lyse | to break apart

M

Mannitol | a type of carbohydrate produced by fungi involved in lichen symbiosis

Matrix (mitochondrion) | the fluid-filled area enclosed by the inner membrane in a mitochondrion

Megagametophyte | a haploid, multicellular stage in heterosporous alternation of generations that produces eggs by mitosis

Megaphyll | a leaf with branching vascular tissue

Megaspore | a haploid cell produced via meiosis of the megasporocyte. This cell grows by mitosis into a megagametophyte.

Megasporocyte | a diploid cell produced by the sporophyte that will divide by meiosis to produce the megaspore(s) that grow into megagametophyte(s)

Megastrobilus | a structure on the sporophyte that produces the megagametophytes

Meiosis | a type of cell division that halves the number of chromosomes and results in 4 genetically distinct daughter cells. For example, one diploid cell could go through meiosis to produce 4 haploid cells. This type of division is used for sexual reproduction.

Meristem | a region of cells that divides by mitosis to produce new tissues

meso | middle

Mesocarp | the middle layer of the pericarp in a fruit. In a peach, the mesocarp is fleshy.

Mesophyll | the tissue in a leaf between the upper and lower epidermis that is not the vascular tissue

Mesophyte | a plant adapted to moderate environmental conditions

Metaphase | the stage in mitosis where chromosomes align in the center of the cell

Metaphase I | the stage in meiosis I where homologous chromosomes align across from each other in the center of the cell. The alignment is random, so each time meiosis occurs, there can be a different arrangement of chromosomes on either side. See “independent assortment”.

Metaphase II | the stage in meiosis II where chromosomes align in the center of the cell

Metaphase plate | a region in the center of a dividing cell, equidistant from the poles, where chromosomes line up

Microgametophyte | a haploid, multicellular stage in heterosporous alternation of generations that produces sperm by mitosis

Microphyll | a leaf with a single, unbranched vein of vascular tissue

Micropyle | a gap in the integument where the pollen drop is secreted and pollen grains (or tubes) can access the ovule

Microspore | a haploid cell produced via meiosis of the microsporocyte. This cell grows by mitosis into a microgametophyte.

Microsporocyte | a diploid cell produced by the sporophyte that will divide by meiosis to produce the microspore(s) that grow into microgametophyte(s)

Microstrobilus | a structure on the sporophyte that produces the microgametophytes

Middle lamella | a pectin-rich layer between plant cell walls

Middle lamella | a pectin-rich region between adjacent cells

Mitosis | a type of cell division that results in two identical daughter cells, both identical to each other and to the parent cell. This type of division is used for growth, repair, and asexual reproduction. Mitosis refers strictly to the division of the nucleus, while cytokinesis is the division of the rest of the cell contents.

Mitosporangium | a structure that produces spores by mitosis, such as in asexually reproducing *Rhizopus*

Mold | asexually reproducing mycelial fungus

mono | one, singular

Monocot | flowering plants that produce a single cotyledon

Monoecious | male and female reproductive structures are produced on the same plant

Monomer | a molecule that can bind to other molecules of the same type and form a polymer. A repeating subunit of a larger molecule.

Monoplastidic (cell) | a cell having only a single plastid, such as the single large chloroplast in the cells of Anthocerophyta

morph | form

Multicellular | an organism composed of multiple interacting cells

Multiple fruit | a single fruit that is composed of many florets from the same inflorescence. Ex. A pineapple.

Mutualism | a type of symbiosis in which both partners get a net benefit from the interaction.

Mycelium | the fungal body, composed of hyphal filaments

myco | fungus

Mycobiont | the fungal partner in a lichen

Mycorrhizal | a type of mutualistic relationship between plants and fungi. The fungus enters the plant through the roots and takes sugars from the plant. In exchange, the plant takes water and dissolved nutrients (particularly nitrogen and phosphorus) from the fungus.

N

NADH | a molecule that carries two high energy electrons from glycolysis or the citric acid cycle to the electron transport chain in cellular respiration

NADP+ reductase | reduces (adds electrons to) a molecule of NADP+ to create high-energy NADPH. The H+ is added to balance the negative charge from one of the added electrons.

NADPH | a molecule that carries two high energy electrons from the electron transport chain to the Calvin cycle in photosynthesis

Negative control | a group in your experiment that should show no change from initial conditions. If change occurs in the negative control, your experiment could have false positives.

Netted root system | a root system where there is no central, larger root. Most roots are relatively the same diameter.

Nitrogen fixation | the process of converting atmospheric nitrogen (N2) into bioavailable forms, such as ammonia (NH3). This process is carried out by certain bacteria using the enzyme nitrogenase and by the action of lighting ripping through the atmosphere, splitting molecules apart.

Node | the region on a stem where a leaf and axillary bud emerge. The axillary bud emerges on the side of the node closest to the growing tip of the stem.

Nonpolar | a type of covalent bond that is equally shared, resulting in no residual charges on the atoms. Nonpolar compounds “like” to interact with other nonpolar compounds.

Nucellus | the nutritive tissue provided by the megasporangium to the growing embryo in seed plants

Nuclear envelope | a double-membraned structure composed of phospholipids that encloses the genetic material of the cell

Nucleoid | a region in prokaryotes that contains all or most of the genetic material. A nucleoid is not surrounded by a membrane.

Nucleolus | a dense region within the nucleus that often appears as a dark dot. A single nucleus can contain several nucleoli. This region is where ribosomes are synthesized and contains a large amount of RNA.

Nucleus | a double-membrane bound organelle in eukaryotes that contains the organism’s genetic material. The nucleus is often referred to as the command center of the cell, both DNA replication and transcription occur within this organelle. In multicellular organisms, some eukaryotic cells may lack a nucleus at maturity, such as sclerenchyma.

Null hypothesis | an “anti-hypothesis” that predicts no relationship between the dependent and independent variables

Nut | a dry fruit with a stony pericarp encasing a single, large seed. Ex. An acorn.

O

Oogonium | a structure in heterokonts where the eggs are produced

Oospore | a thick-walled zygote produced in the oogonium of oomycetes

Operculum | a cap-like structure that covers the opening of the moss capsule until the spores are ready to be dispersed

Opposite (leaf arrangement) | two leaves emerge at a node

Organ | a collection of tissues working toward the same function, such as a leaf, stem or root

Osmosis | the diffusion of water across a semipermeable membrane

Ostiole | a small opening, such as at the top of a *Fucus* conceptacle

Outer bark | periderm or layers of periderm

ova | egg

Ovary | a structure that encloses the ovules in angiosperms and will develop into the pericarp when fertilized

Ovule | a structure in seed plants that contains the megagametophyte and will develop into a seed when fertilized

Ovuliferous scale | a cone scale in the megastrobilus of conifers where seeds develop

P

Palisade mesophyll | tissue in eudicot leaves that is composed of elongated cells that look like columns, full of chloroplasts photosynthesizing

Panicle | a branched raceme inflorescence

Parasitism | a type of symbiosis in which one partner gets a net benefit, while the other gets a net negative impact.

Parenchyma | cells with an even, thin primary wall and no secondary wall that are alive at functional maturity.

Passage cells | cells where the xylem is closest to the endodermis in the root where the Casparian strip forms last. This allows water to be transported into the xylem from root hairs.

Pedicel | the stem that attaches to a floret

Peduncle | the stem that attaches to a flower at the receptacle

Pennate | (a diatom) with bilateral symmetry

Pepo | a modified berry with a tough, rind-like exocarp. Ex. A pumpkin.

Peptidoglycan | a substance found in bacterial cell walls that consists of interlinked carbohydrates and polypeptides. Antibacterials like penicillin work by inhibiting the formation of peptidoglycan.

Perfect (flower) | a flower containing both an androecium and a gynoecium

Perforation plate | an opening at the end of a vessel element that allows for the passage of water and dissolved nutrients from cell to cell.

peri | around

Perianth | the outer whorls of a flower, composed of the calyx and corolla

Pericarp (fruits) | tissue that develops from the ovary wall in angiosperms and encloses the developing seeds. The pericarp is composed of the exocarp, mesocarp, and endocarp.

Pericarp (Rhodophyta) | the female gametophyte tissue that surrounds the carposporophyte in the cystocarp

Pericycle | a layer of meristematic tissue in the root, just inside the endodermis, that produces lateral roots and secondary meristems

Periderm | an exterior layer produced during secondary growth composed of phelloderm, cork cambium, and cork. Also called outer bark.

Peristome teeth | sheets of cells that look like papery teeth that interact with moisture in the air (hygroscopic movement) to help spores disperse from the capsule in some mosses

Perithecium | a microscopic, flask-shaped fruiting body produced by some ascomycetes

Petiole | the structure that attaches the leaf blade to the stem. Some plants lack petioles and these leaves are called sessile.

phaeo | dusky (often refers to organisms with golden brown hues)

Phagocytosis | to consume by engulfing. The process of engulfing creates a compartment called a phagosome, where acids or other digestive fluids can be secreted for breakdown of the engulfed material.

Phelloderm | large storage cells produced to the inside of the cork cambium in secondary growth

Phloem | the conducting tissue in plants that transports sugars produced during photosynthesis.

Phloem fibers | clusters of fibers located in the phloem that provide structural support (other phloem cells lack a secondary wall).

Phloem rays | parenchyma cells that connect the secondary phloem to the secondary xylem

phore | bearer of

photo | light

Photobiont | the photosynthetic partner in a lichen, such as green algae or cyanobacteria

Photon | a particle of light

Photorespiration | a process that occurs when RuBisCO binds to oxygen instead of CO_2; no glucose is made and energy is wasted in the process. This occurs when concentrations of CO_2 are low.

Photosynthesis | a cellular process that uses electromagnetic energy (sunlight) to assemble molecules of glucose from carbon dioxide. Water is used as an electron donor and oxygen is produced as a waste product (in oxygenic photosynthesis). Chemical formula: $6CO_2 + 6H_2O$ --(in the presence of sunlight)--> $C_6H_{12}O_6 + 6O_2$

Photosystems I & II | complexes containing chlorophyll, located in the thylakoid membrane, that absorb photons during photosynthesis.

Phototropism | movement or growth with respect to a light source

Phycobilins | polar pigments found in red algae and cyanobacteria

Phycocyanin | a blue phycobilin, more prominent in cyanobacteria

Phycoerythrin | a red phycobilin, more prominent in red algae

phyll | leaf

Phyllode | a modified petiole that is flattened to function like a leaf

Phylogeny | a hypothesis on the evolutionary relationships between organisms depicted as a branching tree diagram

phyte/phyto | plant

Phytoplankton | microscopic, photosynthesizing organisms in aquatic environments

Pilus | a projection from a prokaryotic cell that is used to interact with other cells. Pili, plural.

Pinnae | leaflets on a pinnately compound leaf (pinna, singular), such as a fern frond

Pit connection | a connection of the cytoplasm between adjacent cells formed due to incomplete cytokinesis. Found in Rhodophyta.

Pith | tissue produced by the ground meristem that is enclosed by vascular tissue

Placenta | a region of tissue in the ovary wall that supplies nutrition to the developing ovule and then seed through the funiculus

Planktonic | free-floating; wandering

plasm | living substance, tissue

Plasma membrane | a semi-permeable membrane composed of a phospholipid bilayer and a fluid mosaic of proteins, lipids, and associated carbohydrates that encloses the cytoplasm. In general, plasma membrane controls what enters and exits the cell. Nonpolar molecules like oxygen and carbon dioxide, and small molecules like water, can freely diffuse across. Molecules that are too large or too polar (charged) must be transported across.

Plasmid | a small loop of DNA that can be transmitted between organisms. Antibiotic resistance genes are often carried on plasmids.

Plasmodesma | a tube of plasma membrane that traverses the cell wall and middle lamella, connecting the cytoplasm of adjacent cells (plasmodesmata, plural).

Plasmogamy | fusion of the cytoplasm of two cellular structures

Ploidy | the number of sets of chromosomes an organism has

Pneumatophore | a root that has been modified to grow above ground and access oxygen for plants that live in flooded environments, e.g. mangroves

Polar | a type of covalent bond that is unequally shared, resulting in partial charges on the atoms. Polar compounds are partially charged and "like" to interact with other polar or ionic (charged) compounds.

Pollen | the microgametophyte of gymnosperms and angiosperms. Pollen grains deliver the sperm to the egg.

Pollen cone | see "microstrobilus"

Pollination | the successful transfer of pollen from one plant to another. This process is often mediated by insects, wind, or other vectors.

Pollination syndrome | a set of floral characteristics that have evolved in response to a particular pollinator

Pome | a fleshy fruit encased in a swollen hypanthium, the papery endocarp forms a "core". Ex. An apple.

Population | individuals of the same species living in the same environment at the same time

Positive control | a group in your experiment that should show normal/expected results. If no change occurs in the positive control, your experiment could have false negatives.

Prickle | a modified region of the epidermis that functions as a sharp armament for protection

Primary consumer | an organism that eats primary producers, often called herbivores.

Primary endosymbiosis | an evolutionary process by which, in this case, a photosynthetic cyanobacterium was engulfed by a heterotrophic ancestor of the red algae. The cyanobacterium was not digested and evolved into a double membrane chloroplast. This process also occurred with mitochondria.

Primary meristem | a region of cells produced by the apical meristem that divides to produce primary tissues

Primary phloem | phloem tissue produced by the procambium

Primary producer | an organism that uses some external, abiotic energy source, such as electromagnetic or chemical energy, to build organic molecules. Example: plants use energy derived from sunlight to molecules of glucose.

Primary tissue | a region of cells produced by a primary meristem that collaborate toward a shared function

Primary wall | a semi-rigid structure that surrounds the plasma membrane. All plant cells have a primary wall composed of cellulose.

Primary xylem | xylem tissue produced by the procambium

pro | before

Procambium | the primary meristem that produces the primary xylem and primary phloem. In the root, it also produces the pericycle.

Prokaryote | a unicellular organism that lacks a nucleus or membrane-bound organelles. The DNA in a prokaryote occurs as a single, circular chromosome. Prokaryotic cells are surrounded by a cell wall, though the composition can vary depending on whether it is a bacterium or an archaean.

Prop root | an adventitious root used to provide stability or to attach onto other organisms

Prophase | the first stage of mitosis, where the nuclear envelope and nucleoli break down, spindle fibers form, and chromatin condenses into chromosomes

Prophase I | the first stage of meiosis I, where the nuclear envelope and nucleoli break down, spindle fibers form, and chromatin condenses into chromosomes. Homologous chromosomes pair and crossing over occurs.

Prophase II | the first stage of meiosis II, similar to prophase of mitosis. In meiosis of a diploid cell, cells are haploid when prophase II begins.

Protoderm | the primary meristem that produces the epidermis

Pyrenoid | a dense region where carbon fixation happens within chloroplasts of many groups of algae and hornworts

Pyruvate | a three carbon compound formed from the breakdown of glucose during glycolysis

R

Raceme | an inflorescence where florets are attached to a central axis by pedicels

Rachis | the central stem in a pinnately compound leaf, where the leaflets attach

Radial symmetry | multiple lines of symmetry can be drawn

Random fertilization | reproductive propagules (such as eggs and sperm) are not individually selected by the parents for the production of offspring, but are paired on chance

Raphide | a needle-like crystal of calcium oxalate that forms in the tissues of certain plants

Receptacle | in flowers, the point where all of the whorls attach to the peduncle. In *Fucus*, the swollen ends of the thallus.

Residual procambium | procambial tissue (the primary meristem that forms the vascular tissue) remaining between the xylem and phloem of eudicot vascular bundles in primary growth

Resin | a sticky substance produced in some gymnosperms and angiosperms that works to seal wound damage and prevent infection and herbivory

Resin canal | a channel that runs through the tissues of some gymnosperms and angiosperms to secrete and transport resin

rhiz | root

Rhizoid | a root-like structure that lacks vascular tissue and has the function of anchorage

Rhizome | a modified stem that travels horizontally below ground, producing new shoots and adventitious roots at nodes, resulting in asexual reproduction of the shoot

Ribosomes | complexes of proteins and RNA that function as an enzyme. This enzyme reads RNA to build proteins during a process called translation. The ribosome forms a peptide bond between amino acids, releasing a water molecule in the process. This is why proteins are called polypeptides.

Root | a plant organ whose function is anchorage and water absorption. Roots have a specific sequence of development and organization of tissues that is different from stems and leaves.

Root apical meristem (RAM) | the meristem responsible for producing the primary meristems in the root. All cells in the root ultimately derive from this meristem.

Root cap | cells that are produced by the RAM to the outside of the root and sloughed off continually. These cells protect the growing tip, lubricate its journey through the soil, and interact with microbes in the vacinity of the root.

Root hair | a single epidermal cell that elongates to maximize surface area. Root hairs are only produced at the growing tips of the root system.

RuBisCO | Ribulose-1,5-bisphosphate carboxylase/oxygenase. This enzyme fixes CO2 during the Calvin cycle of photosynthesis. If CO2 concentrations are low, it may bind to oxygen instead, causing photorespiration.

S

S | phase - the stage of interphase where DNA is replicated

Samara | a winged achene. Ex. A maple helicopter is both a samara and a schizocarp.

sapro | death, decay

Saprobe | see “Decomposer”

Saprophyte | see “Decomposer”

Sapwood | secondary xylem that is still actively conducting water. Often lighter in color than the heartwood

Schizocarp | a fruit that breaks into multiple pieces (separate carpels) when mature

scler | hard, tough

Sclereid | a sclerenchyma cells that (generally) serves a protective function. In pears, these cells dominate unripened fruits, making them difficult to eat.

Sclerenchyma | a cell with a secondary wall that is dead at functional maturity

Secondary consumer | see “Consumer”

Secondary endosymbiosis | an evolutionary process by which, in this case, a red alga was engulfed by a heterotrophic oomycete. The red alga was not digested and evolved into a four membrane chloroplast. This type of endosymbiosis has occurred multiple times.

Secondary growth | the production of secondary tissues, resulting in lateral growth. Occurs in gymnosperms and some angiosperms

Secondary phloem | phloem tissue produced by the vascular cambium. Also called inner bark.

Secondary wall | a wall in plant cells that is formed within the primary wall. The secondary wall contains lignin, providing structural support, but its formation kills the cell eventually. This cell wall is present in sclerenchyma cells.

Secondary xylem | xylem tissue produced by the vascular cambium. Also called wood.

Seed | a structure produced by gymnosperms and angiosperms that houses the growing embryo and supplies nutrition via the nucellus and the megagametophyte.

Seed coat | the integument forms the seed coat after fertilization of the egg. This structure surrounds and protects the seed.

Seed cone | see “megastrobilus”

Septum | division; divider. For example, the cross walls between cells in hyphae.

Serpentine | a mineral that, when present in soils, results in low Ca:Mg ratios and often contains heavy metals

Seta | a stem-like structure that holds up the sporangium in the sporophytes of some bryophytes (setae, plural)

Sexual reproduction | production of offspring through the fusion of cells that were produced during meiosis

Shoot apical meristem (RAM) | the meristem responsible for producing the primary meristems in the shoot. All cells in the shoot ultimately derive from this meristem.

Sieve cell | a conducting cell in the xylem

Sieve tube element | a conducting cell in the xylem of angiosperms that lacks a nucleus

Simple pore | a hole in the epidermis that is not regulated by guard cells

Simple septation | in ascomycetes, the cross walls between cells have a hole in the center

Sister chromatid | one of two replicated, attached, identical chromosomes

som(e) | body

Sorus | a cluster of sporangia, such as on a fern frond (sori, plural)

Sperm | a gamete that fuses with an egg. Generally smaller than the egg and often with flagella.

Spermatangium | a structure that produces spermatia

Spermatium | the nonmotile male gametes of red algae. This term is also used to describe a stage in the life cycle of rust fungi.

Spike | an inflorescence where florets are sessile, attached directly to a central axis

Spindle | a network of microtubules that organizes and separates chromosomes during cell division

Spine | a leaf that has been modified into a sharp armament for protection

Splash cup | the head of a male gametophyte in mosses, where antheridia await raindrops to splash sperm out

Spongy mesophyll | tissue in eudicot leaves that is full of air pockets for gas exchange during photosynthesis, located below the palisade mesophyll

Sporangiophore | a structure that holds up sporangia (such as the T-shaped projections on Equisetum strobili)

Sporangium | a structure that produces spores

Spore | a propagule that grows by mitosis (it does not fuse with another propagule)

Sporophyll | a leaf where spores are produced

Sporophyte | the multicellular, diploid phase of the plant life cycle that produces spores by meiosis

Sporophyte dominant | a life cycle where the sporophyte is larger, longer-lived, and nutritionally independent from the gametophyte

Stamen | a floral structure composed of anthers and a filament

Standardized variables | variables in your experiment that are kept the same across all treatment groups and control groups

Stem | a plant organ with lignified vascular tissue that emerges from a node in the position of the axillary bud (toward the growing tip of the branch)

Sterigma | a projection from a basidium that the basidiospore sits atop in phylum Basidiomycota. Sterigmata, plural.

Stigma | the pollen receiving part of the carpel, located at the end of the style

Stipe | the stem-like structure in brown algae and fungi

Stipular spines | stipules modified as sharp armaments for a protective function

Stipules | paired appendages at the base of a leaf

Stolon | a stem that grows horizontally above ground, producing new shoots and adventitious roots at nodes, resulting in asexual reproduction of the shoot

Stoma | an opening in the epidermis of a plant that is flanked by two guard cells, allowing for regulated gas exchange with the exterior environment.

Stomatal crypt | a cavity in the lower epidermis of a leaf where stomata are located

Storage root | a root modified to store water or carbohydrates

Strobilus | a structure where gametophytes are produced in most SVPs and gymnosperms. The strobilus is composed of sporophylls (or similar structures) and sporangia.

Stroma | the fluid inside a chloroplast, much like the cytosol of a cell

Stromatolite | a formation created by the layering of photosynthetic bacteria, mucilage, and calcium carbonate. The first widely agreed upon evidence of life can be found in fossilized stromatolites.

Style | the structure that the pollen tube grows down to reach the ovary, located between the ovary and stigma

Suberin | a waxy lipid that forms the Casparian strip and is present in cork cells

Succulent | a plant or swollen tissue that stores water and can use this water for metabolic purposes during periods of drought

Sunken stoma | a stoma located in a depression in the epidermis to prevent water loss

Surface tension | a property caused by the attraction of partial charges between molecules in a liquid. This property minimizes surface area.

sym | shared

Symbiosis | when two or more organisms of different species live in close proximity to one another, sharing some aspect of their life cycle.

Synergids | two haploid cells that flank the egg in the embryo sac

synthesis | to form or put together

T

Taproot | a root system that has a larger central root with smaller lateral roots, such as a carrot or a turnip.

Telomere | the region at the end of a chromosomal arm

Telophase | the stage of mitosis where the chromosomes decondense into chromatin, the spindle breaks down, and the nuclear envelope and nucleoli reform. Cytokinesis happens during this stage of mitosis.

Telophase I | the stage of meiosis I where the chromosomes decondense into chromatin, the spindle breaks down, and the nuclear envelope and nucleoli reform. Cytokinesis happens during this stage of meiosis, resulting in two haploid cells.

Telophase II | the stage of meiosis II where the chromosomes decondense into chromatin, the spindle breaks down, and the nuclear envelope and nucleoli reform. Cytokinesis happens during this stage of meiosis, resulting in four haploid cells.

Tendril | a modified leaf or branch used for attachment and/or climbing

Terminal bud | the bud at the end of a stem where the next year's growth is formed

Terminal bud scale scars | scars left behind on a stem where the terminal bud scales have fallen off after the new tissue emerges. The distance between terminal bud scale scars indicates one year of growth (in a temperate climate).

Terminal bud scales | modified leaves (bracts) that cover and protect the developing terminal bud

Tertiary consumer | see "Consumer"

Tetrasporangium | a structure that produces tetraspores

Tetraspore | a haploid spore produced by meiosis in the red algae life cycle. Tetraspores develop into either male or female gametophytes.

Tetrasporophyte | the multicellular diploid that undergoes meiosis in the red algae life cycle

Thalloid | having a thallus for a body plan

Thallus | a body composed of undifferentiated tissues

Thigmotropism | movement or growth in response to touch

Thin layer chromatography | a process used to separate substances by polarity

Thorn | a stem modified as a sharp armament for protection

Thylakoid | a high surface area structure in chloroplasts with chlorophyll molecules in the membrane. This is where the electron transport chain of photosynthesis occurs.

Thylakoid space | the internal area of a thylakoid

Tissue | a collection of cells working toward the same function

Tonicity | the amount of dissolved solutes in the solution relative to another solution on the other side of a membrane. This can also be thought of as osmotic potential.

Tonoplast | the membrane that encloses the central vacuole in plant cells.

Tracheid | a long, narrow sclerenchyma cell in the xylem with tapered ends and bordered pits. These cells conduct water in the xylem tissue.

Tracheophytes | plants that have lignified vascular tissue. This group includes seedless vascular plants, gymnosperms, and angiosperms.

Transfusion tissue | tissue that surrounds the vascular bundles in some xerophytic leaves, located within the endodermis

Transpiration | the evaporation of water from plant tissues

Trap | a leaf that has been modified to capture organisms, most often insects, to digest for nutrients missing from the plant's environment

Treatment group | a group in your experiment where you have made some modification to the independent variable

trich | hair

Trichogyne | a slender tube that the spermatium travels through to get to the egg in the red algal life cycle

Trichome | a parenchyma cell that projects outward as a hair from the epidermis

troph | feeding

Trumpet hyphae | sugar-conducting cells present in some brown algae

Tube cell | the cell in pollen grains that grows the pollen tube to the ovule for the sperm to travel down

Tuber | an underground stem modified for storage that can produce new shoots from nodes called "eyes"

Turgid | the state of being filled to swollen, such as with plant cells

U

Umbel | an inflorescence where pedicels converge on a single point where they attach to the peduncle

uni | singular, one

Unicellular | an organism composed of a single cell. Unicellular organisms can be prokaryotic or eukaryotic.

Universal veil | some mushrooms start out covered by a material called a universal veil. As they grow, they break through this veil, often leaving remnants in areas of the mushroom.

Universal veil scales (warts) | remnants of the universal veil on the cap of a mushroom

V

Vascular cambium | the secondary meristem that makes the secondary xylem to the inside and secondary phloem to the outside

Vascular cylinder | when the vascular tissue forms a ring that divides the ground tissue into two distinct regions. This is present in monocot roots and eudicot stems.

Vascular tissue | composed of xylem tissue that conducts water and dissolved nutrients, and phloem tissue that conducts photosynthates

Vegetative | a cell, organ, or life stage of an organism that is not actively involved in reproduction. When referring to cyanobacteria, the vegetative cells are the individuals that are performing photosynthesis for the colony. For *Spirogyra*, the vegetative cells are those that are not undergoing sexual reproduction to form a zygote. In plants, vegetative parts (you might call them vegetables) are anything that is not a fruit or flower.

Vessel element | a wide sclerenchyma cell in the xylem with perforation plates at each end. These cells conduct water in the xylem tissue of angiosperms and gnetophytes.

Volva | remnants of the universal veil at the base of a mushroom

W

Whorled (leaf arrangement) | three or more leaves emerge at a node

X

xanth | yellow

xero/xeric | dry

Xerophyte | a plant adapted to dry environmental conditions

Xerophytic leaf | a leaf that has specifically adapted to dry conditions

Xylem | the lignified, water conducting tissue in a plant

Xylem rays | sheets of parenchyma cells that traverse the secondary xylem

Y

Yeast | a unicellular fungus

Z

Zone of division | a region in the growing root tip where the RAM and primary meristems are located. Generally, this zone ends around where the root cap stops.

Zone of elongation | a region in the growing root tip where cells exit the cell cycle and begin to get larger

Zone of maturation | a region in the growing root tip where cells differentiate into specialized cells or tissues

zoo | animal

Zoosporangium | a structure that produces zoospores

Zoospore | swimming spore (has at least one flagellum)

zygo | can mean yoke-shaped, paired, or joined

Zygomorphic | see “bilateral symmetry”

Zygosporangium | a large, ornamented structure where both fertilization and meiosis occur in some lineages of early fungi (formerly classified as the Zygomycota)

Zygote | the first diploid cell in an organism’s life cycle

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    - Preface - *CC BY-NC 4.0*
    - ProgramPage - *CC BY-NC 4.0*
  - 1: Long term Experiment - Nutrient Deficiency in Wisconsin Fast Plants (Brassica rapa) - *CC BY-NC 4.0*
    - 1.1: Introduction - *CC BY-NC 4.0*
    - 1.2: Preparing for the Experiment - *CC BY-NC 4.0*
    - 1.3: Before the experiment - *CC BY-NC 4.0*
    - 1.4: The Experiment - *CC BY-NC 4.0*
    - 1.5: Suggested Rubric - *CC BY-NC 4.0*
  - 2: Introduction to Ecology - *CC BY-NC 4.0*
    - 2.1: Formative Questions - *CC BY-NC 4.0*
    - 2.2: Introduction - *CC BY-NC 4.0*
    - 2.3: Modeling a Food Web - *CC BY-NC 4.0*
    - 2.4: Nutrient Cycling in Ecosystems - *CC BY-NC 4.0*
    - 2.5: Mycorrhizal Networks - *CC BY-NC 4.0*
    - 2.6: Community Interactions - *CC BY-NC 4.0*
    - 2.7: Coevolution and Natural Selection - *CC BY-NC 4.0*
    - 2.8: Summative Questions - *CC BY-NC 4.0*
  - 3: From Prokaryotes to Eukaryotes - *CC BY-NC 4.0*
    - 3.1: Formative Questions - *CC BY-NC 4.0*
    - 3.2: Introduction - *CC BY-NC 4.0*
    - 3.3: Using the Dissecting Microscope - *CC BY-NC 4.0*
    - 3.4: Prokaryotic Cells - *CC BY-NC 4.0*
    - 3.5: Using the Compound Microscope - *CC BY-NC 4.0*
    - 3.6: Eukaryotic Cells - *CC BY-NC 4.0*
    - 3.7: Primary Endosymbiosis - *CC BY-NC 4.0*
    - 3.8: Cell Structures and Organelles - *CC BY-NC 4.0*
    - 3.9: Summative Questions - *CC BY-NC 4.0*
  - 4: Plant Cell Types and Tissues - *CC BY-NC 4.0*
    - 4.1: Formative Questions - *CC BY-NC 4.0*
    - 4.2: Introduction - *CC BY-NC 4.0*
    - 4.3: Identifying Cell Types and Tissues - *CC BY-NC 4.0*
    - 4.4: Summative Questions - *CC BY-NC 4.0*
  - 5: Multicellularity and Asexual Reproduction - *CC BY-NC 4.0*
    - 5.1: Formative Questions - *CC BY-NC 4.0*
    - 5.2: Introduction - *CC BY-NC 4.0*
    - 5.3: Anatomy of a Chromosome - *CC BY-NC 4.0*
    - 5.4: Mitosis - *CC BY-NC 4.0*
    - 5.5: The Cell Cycle - *CC BY-NC 4.0*
    - 5.6: Meristems and Tissues in the Root - *CC BY-NC 4.0*
    - 5.7: Multicellularity and Clonal Reproduction - *CC BY-NC 4.0*
    - 5.8: Summative Questions - *CC BY-NC 4.0*
  - 6: Roots and the Movement of Water - How is water moved through a plant? - *CC BY-NC 4.0*
    - 6.1: Formative Questions - *CC BY-NC 4.0*
    - 6.2: Introduction - *CC BY-NC 4.0*
    - 6.3: The Behavior of Water - *CC BY-NC 4.0*
    - 6.4: Transpiration and Cohesion -Tension Theory - *CC BY-NC 4.0*
    - 6.5: Summative Questions - *CC BY-NC 4.0*
  - 7: Roots and the Movement of Water - Root structure and anatomy - *CC BY-NC 4.0*
    - 7.1: Formative Questions - *CC BY-NC 4.0*
    - 7.2: Introduction - *CC BY-NC 4.0*
    - 7.3: Root Structure and Anatomy - *CC BY-NC 4.0*
    - 7.4: Types of Root Systems - *CC BY-NC 4.0*
    - 7.5: Summative Questions - *CC BY-NC 4.0*
  - 8: Shoot Anatomy and Morphology - *CC BY-NC 4.0*

- 8.1: Formative Questions - *CC BY-NC 4.0*
- 8.2: Introduction - *CC BY-NC 4.0*
- 8.3: Shoot Development - *CC BY-NC 4.0*
- 8.4: Monocots - *CC BY-NC 4.0*
- 8.5: Eudicots - *CC BY-NC 4.0*
- 8.6: Shoot Morphology - *CC BY-NC 4.0*
- 8.7: Summative Questions - *CC BY-NC 4.0*

◦ 9: Leaf Anatomy - *CC BY-NC 4.0*
- 9.1: Formative Questions - *CC BY-NC 4.0*
- 9.2: Introduction to Leaf Anatomy - *CC BY-NC 4.0*
- 9.3: Leaf Anatomy - *CC BY-NC 4.0*
- 9.4: Process of Science - Predicting Drought Tolerance in Leaves - *CC BY-NC 4.0*
- 9.5: Summative Questions - *CC BY-NC 4.0*

◦ 10: Plant Adaptations - *CC BY-NC 4.0*
- 10.1: Formative Questions - *CC BY-NC 4.0*
- 10.2: Introduction - *CC BY-NC 4.0*
- 10.3: Organ Modifications - *CC BY-NC 4.0*
- 10.4: Determining Plant Modifications and Function - *CC BY-NC 4.0*
- 10.5: Color-coded Organs - *CC BY-NC 4.0*
- 10.6: Summative questions - *CC BY-NC 4.0*

◦ 11: Secondary Growth - *CC BY-NC 4.0*
- 11.1: Formative Questions - *CC BY-NC 4.0*
- 11.2: Introduction - *CC BY-NC 4.0*
- 11.3: Secondary Tissues in the Root - *CC BY-NC 4.0*
- 11.4: Flowcharts of Development - *CC BY-NC 4.0*
- 11.5: Secondary Tissues in the Shoot - *CC BY-NC 4.0*
- 11.6: Dendrochronology - *CC BY-NC 4.0*
- 11.7: Summative Questions - *CC BY-NC 4.0*

◦ 12: Photosynthesis and Plant Pigments - *CC BY-NC 4.0*
- 12.1: Formative Questions - *CC BY-NC 4.0*
- 12.2: Introduction - *CC BY-NC 4.0*
- 12.3: Part 1 - Pigments - *CC BY-NC 4.0*
- 12.4: Pigments and Evolutionary Adaptations - *CC BY-NC 4.0*
- 12.5: Part 2 - Photosynthesis - *CC BY-NC 4.0*
- 12.6: C4 and CAM Photosynthesis - *CC BY-NC 4.0*
- 12.7: Summative Questions - *CC BY-NC 4.0*

◦ 13: Cellular Respiration and Fermentation - *CC BY-NC 4.0*
- 13.1: Formative Questions - *CC BY-NC 4.0*
- 13.2: Introduction - *CC BY-NC 4.0*
- 13.3: Cellular Respiration - *CC BY-NC 4.0*
- 13.4: Concept Mapping - Connecting Ideas Visually - *CC BY-NC 4.0*
- 13.5: Summative Questions - *CC BY-NC 4.0*

◦ 14: Meiosis, Fertilization, and Life Cycles - *CC BY-NC 4.0*
- 14.1: Formative Questions - *CC BY-NC 4.0*
- 14.2: Introduction - *CC BY-NC 4.0*
- 14.3: The Production of Genetic Diversity - *CC BY-NC 4.0*
- 14.4: Fertilization - *CC BY-NC 4.0*
- 14.5: Life Cycles - *CC BY-NC 4.0*
- 14.6: Life Cycle Diagram Fold Out - *CC BY-NC 4.0*
- 14.7: Summative Questions - *CC BY-NC 4.0*

◦ 15: Microfungi - Slimes, Molds, and Microscopic True Fungi - *CC BY-NC 4.0*
- 15.1: Formative Questions - *CC BY-NC 4.0*
- 15.2: Introduction - *CC BY-NC 4.0*
- 15.3: Fungus-Like Organisms - *CC BY-NC 4.0*
- 15.4: Kingdom Fungi - The True Fungi - *CC BY-NC 4.0*
- 15.5: General Morphology - *CC BY-NC 4.0*
- 15.6: The Fungal Phylogeny - *CC BY-NC 4.0*
- 15.7: Summative Questions - *CC BY-NC 4.0*

◦ 16: Macrofungi and Lichens - True Fungi and Fungal Mutualisms - *CC BY-NC 4.0*
- 16.1: Formative Questions - *CC BY-NC 4.0*
- 16.2: Introduction - *CC BY-NC 4.0*
- 16.3: Macrofungi - *CC BY-NC 4.0*
- 16.4: Fungal Ecology - *CC BY-NC 4.0*
- 16.5: Summative Questions - *CC BY-NC 4.0*

◦ 17: Heterokonts - *CC BY-NC 4.0*
- 17.1: Formative Questions - *CC BY-NC 4.0*
- 17.2: Introduction - *CC BY-NC 4.0*
- 17.3: Oomycota -- The Water Molds - *CC BY-NC 4.0*
- 17.4: Photosynthetic Heterokonts - Descendents of Secondary Endosymbiosis - *CC BY-NC 4.0*
- 17.5: Phaeophyta - The Brown Algae - *CC BY-NC 4.0*
- 17.6: Fucus Life Cycle - *CC BY-NC 4.0*
- 17.7: Bacillariophyta - The Diatoms - *CC BY-NC 4.0*
- 17.8: Summative Questions - *CC BY-NC 4.0*

◦ 18: Red and Green Algae - *CC BY-NC 4.0*
- 18.1: Formative Questions - *CC BY-NC 4.0*
- 18.2: Introduction to Red and Green Algae - *CC BY-NC 4.0*
- 18.3: Phylum Rhodophyta - The Red Algae - *CC BY-NC 4.0*
- 18.4: Phylum Chlorophyta and Phylum Streptophyta - *CC BY-NC 4.0*
- 18.5: Pond Ecosystem Relationships - *CC BY-NC 4.0*
- 18.6: Design an Experiment - *CC BY-NC 4.0*
- 18.7: Summative Questions - *CC BY-NC 4.0*

◦ 19: Evolution of the Embryophyta - *CC BY-NC 4.0*
- 19.1: Formative Questions - *CC BY-NC 4.0*
- 19.2: Introduction to the Evolution of the Embryophyta - *CC BY-NC 4.0*
- 19.3: Major Evolutionary Lineages - *CC BY-NC 4.0*
- 19.4: Summative Questions - *CC BY-NC 4.0*

◦ 20: Bryophytes - *CC BY-NC 4.0*
- 20.1: Formative Questions - *CC BY-NC 4.0*
- 20.2: Introduction to Bryophytes - *CC BY-NC*

4.0
- 20.3: Selection Pressures and Drivers - *CC BY-NC 4.0*
- 20.4: Anthocerotophyta - Hornworts - *CC BY-NC 4.0*
- 20.5: Marchantiophyta - The Liverworts - *CC BY-NC 4.0*
- 20.6: Bryophyta - Mosses - *CC BY-NC 4.0*
- 20.7: Summative Questions - *CC BY-NC 4.0*

◦ 21: Seedless Vascular Plants - *CC BY-NC 4.0*
- 21.1: Formative Questions - *CC BY-NC 4.0*
- 21.2: Introduction to Seedless Vascular Plants - *CC BY-NC 4.0*
- 21.3: Lycophytes (Class Lycopodiopsida) - *CC BY-NC 4.0*
- 21.4: Ferns (Class Polypodiopsida) - *CC BY-NC 4.0*
- 21.5: Summative Questions - *CC BY-NC 4.0*

◦ 22: Gymnosperms - *CC BY-NC 4.0*
- 22.1: Formative Questions - *CC BY-NC 4.0*
- 22.2: Introduction to Gymnosperms - *CC BY-NC 4.0*
- 22.3: Selection Pressures and Drivers - *CC BY-NC 4.0*
- 22.4: Cycads and Ginkgos - *CC BY-NC 4.0*
- 22.5: Gnetophytes and Conifers - *CC BY-NC 4.0*
- 22.6: Using a Dichotomous Key - *CC BY-NC 4.0*
- 22.7: Summative Questions - *CC BY-NC 4.0*

◦ 23: Angiosperms I - Flowers - *CC BY-NC 4.0*
- 23.1: Formative Questions - *CC BY-NC 4.0*
- 23.2: Introduction to Angiosperms - *CC BY-NC 4.0*
- 23.3: Selection Pressures and Drivers - *CC BY-NC 4.0*
- 23.4: Specialized Vascular Tissue - *CC BY-NC 4.0*
- 23.5: Anatomy of a Flower - *CC BY-NC 4.0*
- 23.6: Stimulating Pollen Tube Growth - *CC BY-NC 4.0*
- 23.7: Pollination Syndromes - *CC BY-NC 4.0*
- 23.8: Inflorescence Types - *CC BY-NC 4.0*
- 23.9: Summative Questions - *CC BY-NC 4.0*

◦ 24: Angiosperms II - Fruits - *CC BY-NC 4.0*
- 24.1: Formative Questions - *CC BY-NC 4.0*
- 24.2: Introduction - *CC BY-NC 4.0*
- 24.3: Selection Pressures and Drivers - *CC BY-NC 4.0*
- 24.4: Angiosperm Life Cycle - *CC BY-NC 4.0*
- 24.5: Fruits - *CC BY-NC 4.0*
- 24.6: Using a Dichotomous Key to Identify Fruit Type - *CC BY-NC 4.0*
- 24.7: Dispersal Syndromes - *CC BY-NC 4.0*
- 24.8: Summative Questions - *CC BY-NC 4.0*

◦ 25: Glossary - *CC BY-NC 4.0*
- 25.1: Key to Common Local Tree Genera (Written for Humboldt County, California) - *CC BY-NC 4.0*
- 25.2: Dichotomous Key to Common Fruits - *CC BY-NC 4.0*
- 25.3: Evolutionary Profile - Photosynthetic Groups - *CC BY-NC 4.0*
- 25.4: Glossary of Terms and Root Words - *CC BY-NC 4.0*

◦ Back Matter - *CC BY-NC 4.0*
- Glossary of Terms and Root Words - *CC BY-NC 4.0*
- Evolutionary Profile - Photosynthetic Groups - *CC BY-NC 4.0*
- Dichotomous Key to Common Fruits - *CC BY-NC 4.0*
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