

Evolutionary History of Plants

Bio 6A/Sanhita Datta
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 **Reading:** Campbell, Ch. 29 & 30.

 **Web site:** See the Bio 6A web pages on microscopy and plants.

INTRODUCTION

Photosynthesis first evolved in the water, but modern plants are highly adapted to life on land. In this lab you'll see that the more recently evolved groups of plants are defined by characteristics that make them increasingly suited to surviving and reproducing out of the water.

There will be several labs on plants. This one is designed to acquaint you with the major evolutionary groups of plants and their distinguishing characteristics. In later labs, you'll take a closer look at some specific plant structures and how they work.

You don't need to turn anything in for today's lab. Go through this lab handout and look at the accompanying specimens.

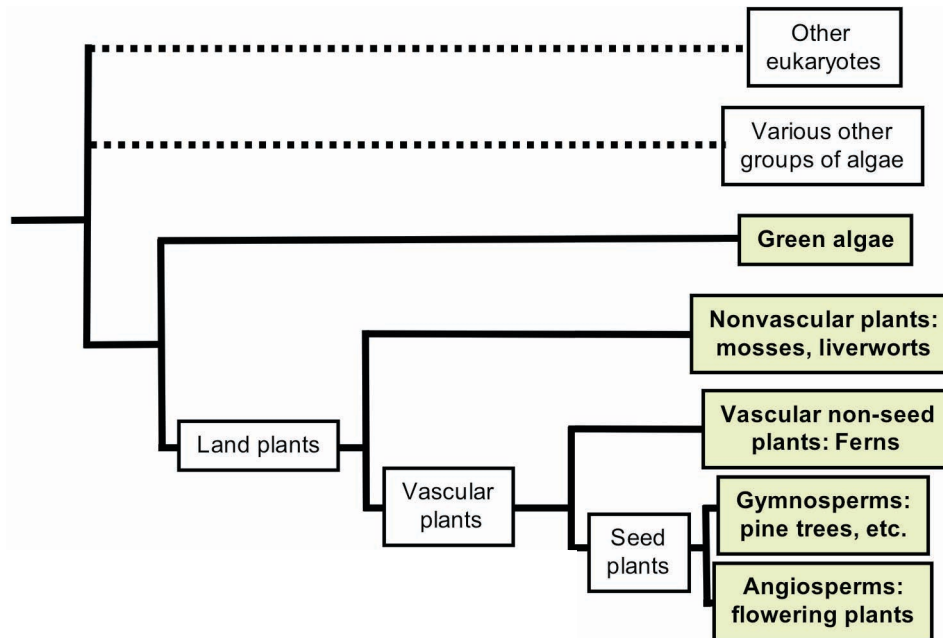
 **Observe the flagged items in the handout.** These indicate things you should look at in the lab.

Your goal should be to become familiar with the specimens so you can recognize them and understand their significance. At the end of the handout, you'll find some questions. Use these to test your knowledge. You don't need to turn in your answers, but you will see questions like these on a test.

WHAT IS A PLANT?

CELL FEATURES:	<ul style="list-style-type: none">• Eukaryotic: nucleus, mitochondria, and other membrane-bound organelles present.• Chloroplasts present.• Cell wall made of cellulose.• Cells often large (20-30 μm).• Contain chlorophylls a and b.• Synthesize and store starch in plastids.
BODY PLAN:	<ul style="list-style-type: none">• Land plants are multicellular, with significant differentiation. Green algae, which are closely related to land plants, may be unicellular or multicellular with very little differentiation.
MODE OF NUTRITION:	<ul style="list-style-type: none">• Photoautotrophs, with a few exceptions (parasitic heterotrophs).

It's clear that all plants share certain characteristics, as shown in the table above. However, not all biologists agree on exactly which organisms should be classified in the plant kingdom. Take a look at the cladogram below:



Here are some of the phyla belonging to the groups in the cladogram, along with their estimated numbers of species:

	# species
Green Algae	8,000
Phylum Chlorophyta	
Nonvascular plants ("bryophytes"; part of Embryophyta)	24,700
Phylum Bryophyta: true mosses	
Phylum Hepaticophyta: liverworts	
Phylum Anthocerotophyta: hornworts	
Vascular plants (part of Embryophyta)	263,044
Vascular seedless plants ("pteridophytes")	12,171
Phylum Pterophyta: ferns	11,000
Phylum Psilophyta: whisk ferns	6
Phylum Lycopphyta: club mosses	1,150
Phylum Arthropphyta: horsetails	15
Vascular seed plants	
Gymnosperms	873
Phylum Coniferophyta: pines, etc.	601
Phylum Cycadophyta: cycads	206
Phylum Gnetophyta: gnetophytes	65
Phylum Ginkgophyta: <i>Gingko</i>	1
Angiosperms	250,000
Phylum Anthophyta: flowering plants	250,000

Until recently, most biologists classified the land plants as belonging to the kingdom **Plantae**, and put the green algae in their own kingdom (**Chlorophyta**). However, it has become clear that the land plants and the green algae are closely related; some biologists now group them

together in the kingdom **Viridiplantae** ("green plants"). This lab briefly introduces the green algae, but includes much more detail on the land plants.

You should be aware that **not all organisms that do photosynthesis are plants**. For example, cyanobacteria are unicellular prokaryotes and they look nothing like plants, but they do photosynthesis just like plants do. In fact, the chloroplasts that perform photosynthesis inside the cells of plants are descended from cyanobacteria-like cells. Also, there are various types of eukaryotic algae, from diatoms to giant kelps, that contain chloroplasts and perform photosynthesis, but are not closely related to plants.

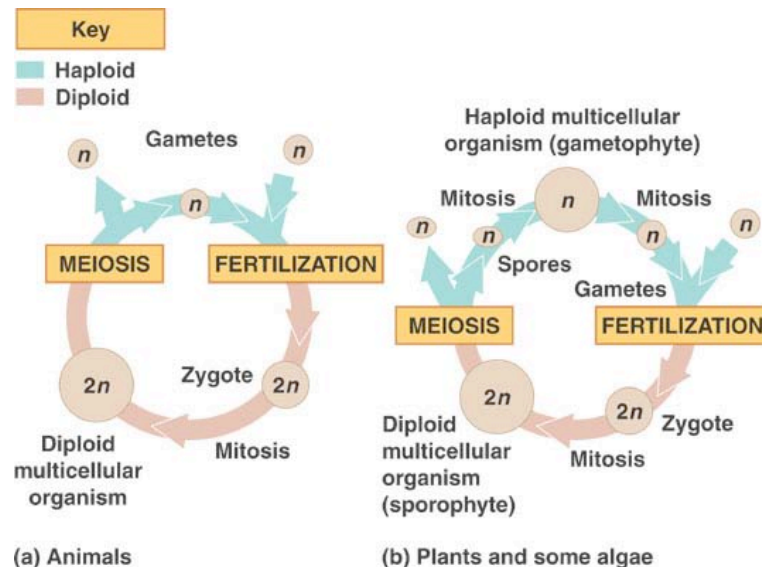
In this lab and the next several plant labs, you'll compare and contrast a wide range of plants, and to some extent reconstruct their evolutionary history. The land plants you see will be divided into three major groups: **nonvascular non-seed plants**, **vascular non-seed plants**, and **vascular seed plants**. By the end of this lab, it should become clear that plants are put into these groups not just for convenience, but because their defining characteristics tell the story of how plants have evolved.

EUKARYOTIC LIFE CYCLES

Many of the defining characteristics of plant taxa are related to reproduction and life cycles. This diagram (fig. 13.06 in Campbell) shows the basic idea of two kinds of eukaryotic life cycles. The most important idea is that all eukaryotic groups have sexual life cycles, which include these features:

- **Diploid:** cells having two copies of each chromosome, one from the mother and one from the father. Human diploid cells have 46 chromosomes.
- **Haploid:** cells having one copy of each chromosome. Eggs and sperm, for example. Human haploid cells have 23 chromosomes.
- **Meiosis:** the process of cutting the chromosome number in half to make haploid cells from diploid cells.
- **Mitosis:** On this diagram, the word "mitosis" is used to mean "mitotic cell proliferation." **Cell proliferation** simply means making more cells that are genetically identical to the original cell. **Mitosis** is a way of dividing up the chromosomes so the cell ends up with two sets of chromosomes identical to the original set. (Mitosis and Meiosis will be covered in detail in Bio 6B.) Mitotic cell proliferation is how a single cell like a zygote becomes a multicellular organism.
- **Gamete:** an egg or sperm cell; always haploid.
- **Fertilization:** joining two haploid cells (such as egg and sperm) to make a diploid. This is also often called **syngamy**. You'll see in a later lab that the word fertilization isn't used in fungi, but they achieve the same end result.

Different groups of eukaryotes have different life cycles, which can be summarized like this:



- **All eukaryotes, including animals and plants:** Life cycle has both a haploid phase and a diploid phase. Two haploid cells (usually from two different parents) are joined together to make a new diploid cell called a **zygote**. Eventually, a diploid cell undergoes meiosis to create haploid cells.
- **Animals:** haploid cells are produced only to make gametes. The haploid stage is always unicellular. The diploid stage is multicellular.
- **Plants:** Like animals, have a multicellular diploid stage. Unlike animals, they also have a multicellular haploid stage. Having a multicellular haploid and a multicellular diploid is called **alternation of generations**. Only plants and some algae do this. Look at the life cycle diagram for plants, shown above. You'll see that the haploid cells produced by meiosis are called **spores**. Spores are defined as haploid cells that undergo cell proliferation to produce more haploid cells. Plants have spores; animals don't.
- **Prokaryotes:** none of these life cycle terms apply, because they don't do sexual reproduction and normally have only one copy of their chromosomes. They do cell proliferation, but they don't do meiosis or mitosis.

GREEN ALGAE (CHLOROPHYTA)

The term "algae" simply means photosynthetic organisms that aren't land plants. The algae are not a monophyletic group, but the green algae are apparently monophyletic.

Green algae are closely related to land plants. They have the same kind of chloroplasts and chlorophylls, and many biochemical similarities. However, their body structures are very simple; they lack the highly differentiated tissues of land plants. Many are unicellular, while some are multicellular but without specialized cell types other than reproductive cells. All the Chlorophyta live in the water (even if it's only a thin layer of water such as on wet tree bark).

Key point: since algae live in the water, all their cells have the opportunity to absorb water, nutrients, and sunlight directly from the environment. Plants that live on dry land are in a different situation, because they need roots underground to absorb water and nutrients and leaves above ground to absorb sunlight. Plants must have specialized tissues to live on land.

📖 **Observe the live specimens of green algae.** Put a tiny piece of tissue on a microscope slide and see if you can observe the simple tissue structure. Do you see evidence that these are eukaryotes?

📖 **Observe the prepared slides of green algae.** Again, note the simple tissue structure.

📖 **Study the *Chlamydomonas* green algae life cycle diagram in Campbell.** What features of this life cycle are also found in the human life cycle? What features are also found in plant life cycles?

NON-VASCULAR PLANTS: MOSSES

This group includes:

- Phylum Bryophyta: true mosses
- Phylum Hepaticophyta: liverworts
- Phylum Antherocerotophyta: hornworts

The term "bryophyte" refers to all three groups together. For this lab, we can just call them the non-vascular plants.

The evolutionary history of plants shows a great increase in tissue differentiation and adaptation to living on land. These two trends are linked, as you'll see in this lab. The specialized tissues of plants help them survive on land.

Some key characteristics that land plants have, but algae don't:

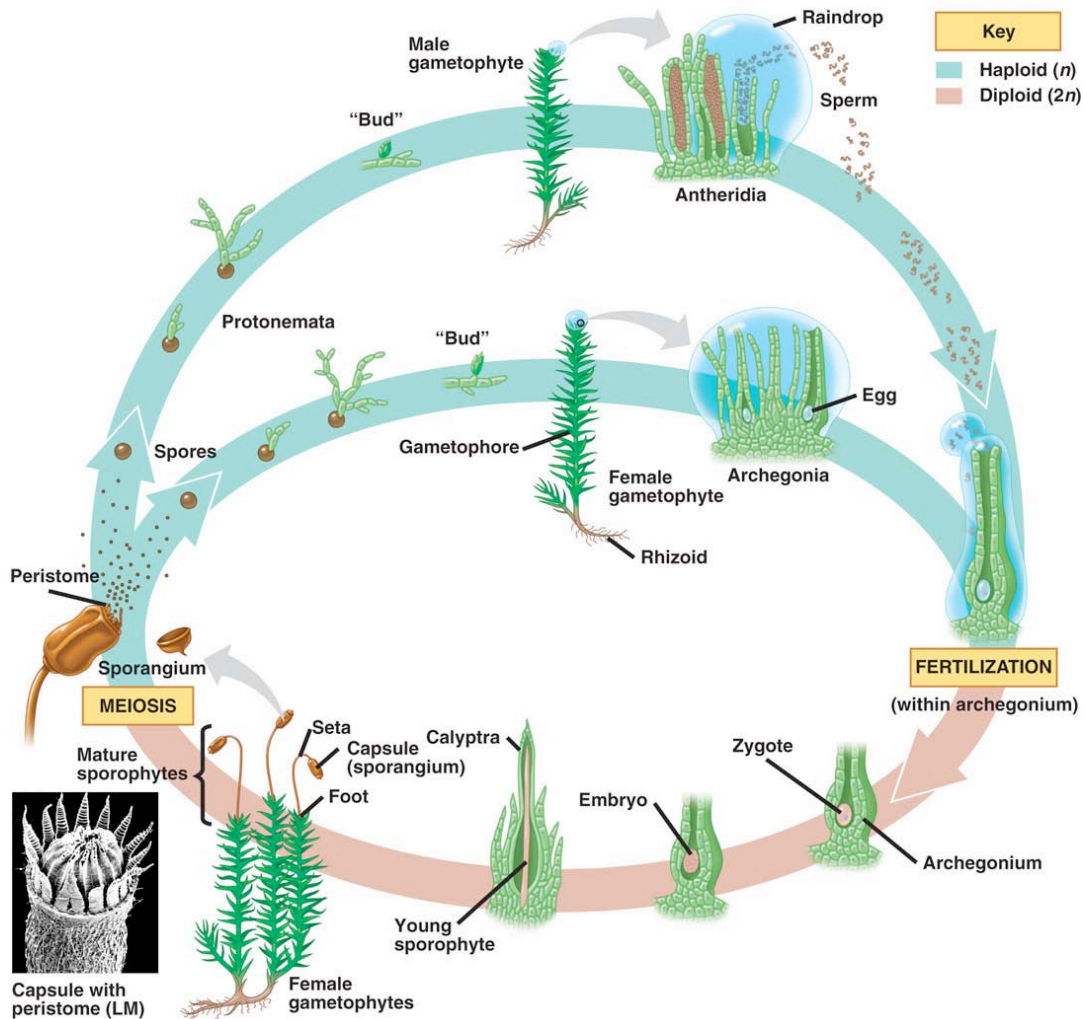
- **Tissue differentiation.** Unlike algae, land plants are differentiated into two main parts: a root, usually growing underground and absorbing nutrients, and a shoot, usually growing above ground and absorbing sunlight to perform photosynthesis. Most plants have a variety of specialized tissues within these two regions of the body. For example, a simple leaf involves several different kinds of cells, which you'll study in a later lab. Algae are simpler; when you look at them under a microscope, you generally see the same kind of cell throughout the whole body (except for specialized reproductive cells).
- **Growth at meristems.** Plant growth normally occurs at meristems, which are localized regions of cells specialized for cell proliferation. There is a meristem at the apex of the shoot and one at the apex of the root; there may be other meristem regions as well. Since plants are so highly differentiated, it makes sense that, for example, root cells should only be produced in the roots and not elsewhere. Algae are different; since the cells are less specialized, growth can occur anywhere.
- **Alternation of generations.** All eukaryotes have a haploid stage and a diploid stage. In plants, both the haploid and the diploid stage are multicellular. Some algae also have this feature, but the algal ancestors of plants probably did not.
- **Multicellular, dependent embryo.** In plants, fertilization (the fusion of egg and sperm) creates a zygote, which develops into a multicellular embryo. This occurs inside the parent plant. In green algae, the zygote is on its own. It floats free of the parent and is independent.

The characteristics listed above are common to all plants, including the simplest non-vascular plants. However, nonvascular plants lack many characteristics found in vascular plants. **Some key differences between mosses and vascular plants:**

- **Mosses don't have much of a cuticle** to protect them from drying out, so they must grow in wet places. The cuticle is a waxy layer found on most plants, including some nonvascular plants; you'll observe it later. Lacking a cuticle, mosses can absorb water easily through all their tissues and lose water easily. Vascular plants usually only absorb water through their roots.
- **Mosses have less tissue differentiation than vascular plants.** Aside from lacking vascular tissues, they also lack roots and leaves. Though they look pretty leafy, their green parts aren't considered true leaves because they are so different structurally from vascular plant leaves. In particular, mosses lack the heavily fortified (lignified) vascular tissues present in vascular plants. They may, however, have some cells that are specialized for water transport.
- **Mosses don't have seeds.** Seeds help most plants reproduce in dry environments; mosses can only reproduce in wet environments.
- **Mosses don't have their sperm enclosed in pollen grains;** they have naked, swimming sperm just like people do. Like animals, all plants have sperm and eggs. In mosses, the sperm can't get to the egg unless they have water to swim through. Unlike mosses, vascular seed plants have pollen grains to protect their sperm. Pollen will be discussed later in this lab.
- **In mosses, the gametophyte (haploid) is big and the sporophyte (diploid) is small** and contained within the gametophyte. In other plant groups, it's the other way around.

The significance of these features makes the most sense when contrasted with vascular plants, so for now just notice these things and plan to come back to them later. Overall, you could summarize mosses by saying that they can live on land, but they still require a watery environment for at least part of their life cycle. In this sense, they're similar to amphibians such as toads or salamanders.

- 📖 **Observe the live mosses.** Compare the specimens to the pictures in your books, including the life cycle diagrams. Note which parts are haploid, which parts are diploid, and where meiosis and fertilization occur. Note that when you're looking at moss, you're looking primarily at the **gametophyte** – the haploid phase. The **sporophyte** is smaller and contained within the gametophyte; often you can see it as a brown stalk sticking up from the leafy green gametophyte. Observe the structure of the "leaves" (technically not true leaves) for comparison with the leaves of seed plants.
- 📖 **Observe the prepared slide of moss (*Mnium*) life history.** Compare what you see on this slide to the life cycle diagrams in Campbell. Be ready to say which parts are haploid (gametophyte) and which parts are diploid (sporophyte).
- 📖 **Study the *Polytrichum* (moss) life cycle diagram from Campbell.** Compare and contrast this life cycle with those of green algae and humans.



When you look at a moss, the main green part is the gametophyte – in other words, it's haploid. The diploid sporophytes are much smaller; they look like little brown stalks sticking out of the green gametophyte. (This is the opposite of what you see in vascular plants, which have a large sporophyte and a tiny gametophyte.) You should remember some key points about this life cycle:

Gametophytes produce gametes. Gametophytes are haploid, and they produce haploid gametes. Sperm must swim through water (even a small amount such as a raindrop). Fertilization occurs inside the female gametophyte, forming a zygote.

Sporophytes produce spores. The diploid zygote grows inside the haploid gametophyte, eventually becoming a sporophyte. Cells in the sporophyte undergo meiosis, producing haploid spores. These spores eventually grow into new, independent gametophytes.

VASCULAR NON-SEED PLANTS (PTERIDOPHYTES)

This group includes:

Phylum Pterophyta: ferns	11,000 species
Phylum Psilophyta: whisk ferns	6
Phylum Lycophyta: club mosses	1,150
Phylum Arthrophyta: horsetails	15

Nonvascular plants such as mosses aren't very tall. In contrast, some ferns (vascular non-seed plants) can grow as tall as trees. Being tall is only possible for plants with a highly developed vascular system for transporting materials between the roots and the shoot, which is the part of the plant above the ground. Mosses lack these structures.

In evolutionary history, the advent of vascular plants changed the way the world looked. Prior to the spread of vascular plants, the land had only plants that were no more than a few centimeters tall; the origin of the vascular system made it possible for plants to be much taller. As it became possible for plants to grow taller, it also became necessary – otherwise, they would get shaded by their taller neighbors. With the advent of vascular plants, the competition for light became intense, and forests started to cover the earth. (A forest is simply a crowd of plants competing for light.) The earliest forests were composed of vascular non-seed plants, though modern forests are dominated by seed plants.

Some key differences between ferns and mosses:

- **Ferns generally have a more highly developed cuticle** and can live in drier places.
- **Ferns have a highly developed vascular system** with vessels that are reinforced with lignin (a woody material).
- **In ferns, the sporophyte is much bigger** and longer-lived than the gametophyte. When you're looking at a fern, you're usually looking at a sporophyte (the diploid phase). The gametophyte lives and grows independently of the sporophyte, but it is small and seldom seen.
- **Ferns can grow tall:** tree ferns can be several meters tall, while most mosses are limited to a few centimeters.

Some key differences between ferns and seed plants:

- **Ferns don't have seeds.** The new sporophyte grows directly out of the gametophyte, and is not packaged with its own nutritive and protective layers.

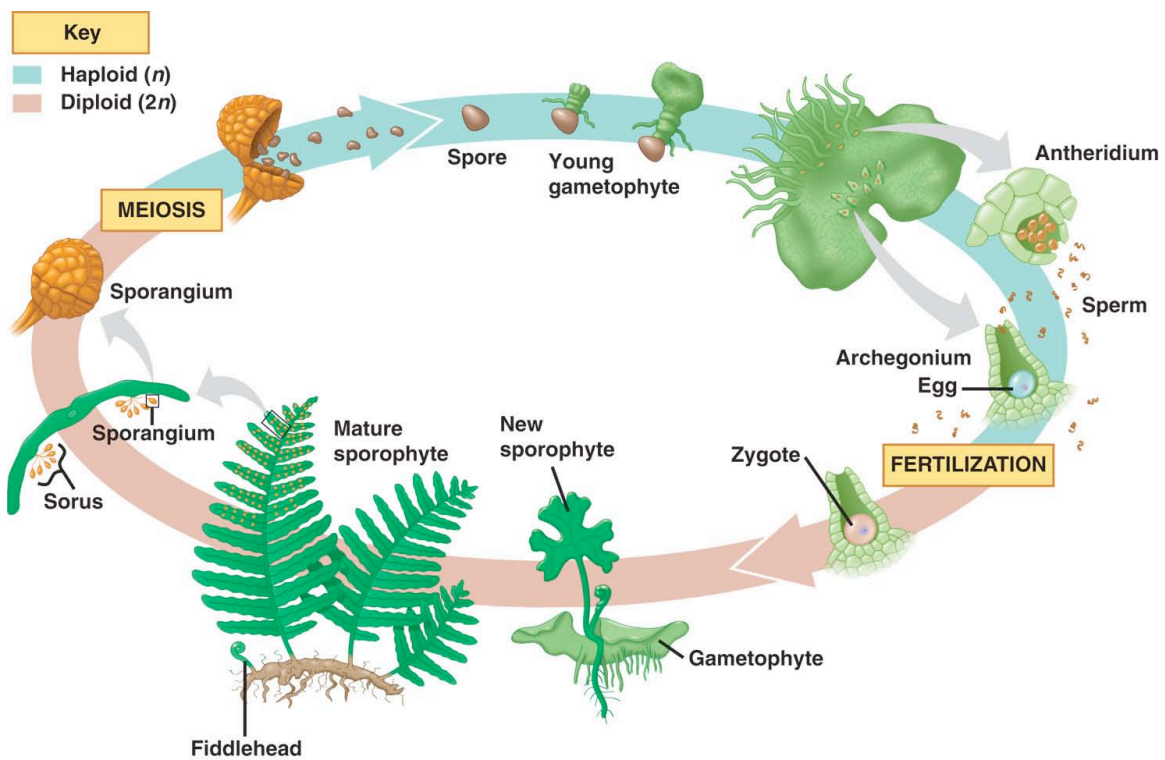
- **Ferns don't have pollen** to protect their sperm. Fern sperm are naked; they need water to swim to the egg. (This doesn't mean that the fern must be under water; it just means that it must be very wet.)
- **Ferns are usually homosporous:** they make only one kind of spore, which develops into a single gametophyte that makes both male and female gametes. As you'll soon see, in seed plants the male and female gametophytes are different.

To see how these characteristics relate to a fern's appearance, look at both the live specimen and the microscope slides.

📖 **Observe the fern fronds (sporophylls) with sori.** Compare to fig. 29.23 in Campbell. Make note of which parts are haploid, which parts are diploid, and where meiosis would occur. What comes out of the sori?

📖 **Observe the prepared slide of fern gametophyte (prothallium).** What does the gametophyte produce?

📖 **Study the fern life cycle diagram in Campbell.** Compare and contrast this with the other life cycle diagrams. Remember these terms about the life cycle diagram: fertilization, mitosis, meiosis, haploid, diploid, gametophyte, sporophyte, spore, sperm, egg.



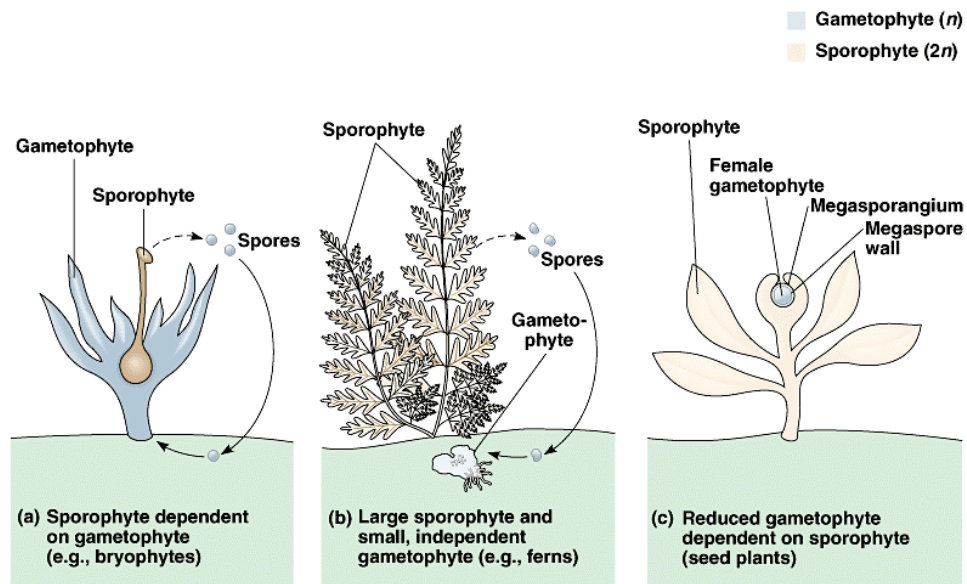
This fern life cycle has most of the key features seen in the moss life cycle. Again, sporophytes are diploid and produce spores via meiosis, while gametophytes are haploid and produce gametes. Fertilization occurs inside the gametophyte, and the sporophyte begins to grow inside the gametophyte. However, the fern sporophyte is much larger and longer-lived than the gametophyte.

VASCULAR SEED PLANTS: GYMNASPERMS & ANGIOSPERMS

Ferns can survive in fairly dry places, but they still need wet conditions for reproduction. The vascular seed plants are even better adapted to life on dry land; they have some extra tricks that facilitate reproduction even in dry conditions. The most important of these tricks are seeds and pollen.

Some key differences between seed plants (including both gymnosperms and angiosperms) and ferns:

- **Seed plants have seeds.** Seeds contain a diploid sporophyte embryo with a food supply and a protective outer seed coat. Seeds can survive harsh environments by remaining dormant, and when conditions improve they can germinate and allow the embryo to grow rapidly using its stored energy. In ferns, the sporophyte embryo grows directly out of the gametophyte. Ferns do have spores, which are thick-walled haploid cells that can grow into haploid gametophytes. However, the spores don't have the same kind of protective coat and food supply found in seeds.
- **Seed plants have pollen.** Pollen grains are tiny male gametophytes, consisting of just a few cells. They have a tough outer coating, so they can survive being carried by wind or animals to land on a female gametophyte some distance away. The male gametophyte then grows out of the pollen grain and produces sperm to fertilize an egg. In ferns, the only way sperm can get to eggs is by swimming; this means they can't get far and must reproduce when it's wet.
- **The gametophyte is even smaller in seed plants.** In ferns, the gametophyte is small and short-lived, but it is separate from the sporophyte. In seed plants, the gametophyte consists of a very small number of cells and grows completely within the sporophyte.



This diagram summarizes the sporophyte-gametophyte relationships of nonvascular plants (bryophytes), vascular non-seed plants (ferns), and seed plants (including both gymnosperms and angiosperms).

GYMNOSPERMS: PINE TREES

Conifers such as pine trees are the most familiar examples of gymnosperms.

- 📖 **Observe the male and female pine cones.** Note how different they are in size. Why is this? What does the male gametophyte look like? What does the female gametophyte look like? Where does fertilization occur?
- 📖 **Observe the prepared slide of the male cone** ("staminate cone"). Are you looking at gametophyte or sporophyte? Would there be spores in this slide? Sperm?
- 📖 **Observe the prepared slide of the pollen grain.** Are you looking at haploid cells or diploid cells?
- 📖 **Observe the prepared slide of the "young ovulate cone"** (female). Are you looking at haploid cells or diploid cells? Where is the female gametophyte? Where would meiosis occur? Where would fertilization occur? Would there be spores in this slide? Sperm? Eggs?
- 📖 **Observe the prepared slide of the pine needle.** Notice how structured this is compared to the moss. The pine needle has a thick cuticle, protecting it from water loss. In order to absorb carbon dioxide from the air, the pine needle has openings, called stomata. You'll see this in more detail in a later lab. (Also remember that a pine needle is part of the sporophyte, unlike the green "leaves" of the moss you saw earlier.)
- 📖 **Study the pine life cycle diagram in Campbell.** Compare and contrast this with the other life cycle diagrams. Remember these terms about the life cycle diagram: fertilization, mitosis, meiosis, haploid, diploid, gametophyte, sporophyte, spore, sperm, egg. We'll come back to this diagram in a later lab.

ANGIOSPERMS: FLOWERING PLANTS

Most plants are angiosperms. This group includes such obviously flowering plants as lilies, along with less-obvious ones such as grasses. You may have noticed already in this handout that reproductive mechanisms can have an enormous impact on where and how various groups of plants live (that's why we don't live in a world dominated by ferns). Flowering plants show an amazing variety in terms of two key reproductive events: getting sperm and egg together (pollination) and dispersing seeds with dispersal mechanisms connected with fruit. These reproductive tricks help explain why, out of about 300,000 known species of plants on earth, 250,000 of them are angiosperms.

Key differences between angiosperms and gymnosperms:

- **Angiosperms have flowers.** Flowers help ensure that sperm and egg get together. In gymnosperms, pollen grains are carried on the wind, but the angiosperms display an extremely wide range of tricks for getting animals such as bees to carry pollen from one flower to another. Some angiosperms, such as grasses, are wind-pollinated.
- **Angiosperms have fruits.** Fruits help ensure that seeds get carried to new locations and have a decent chance at survival. As with flowers, many fruits have features that result in animals carrying the seeds around.

Some of the specific reproductive tricks found in angiosperms will be covered in a later lab. For today, the main point is the things that separate angiosperms from the other groups.

- 📖 **Observe the prepared slide of the *Lilium* ovaries and anthers.** Ovaries make the eggs, and anthers make the pollen. Which parts are haploid, and which parts are diploid?

Where would meiosis occur? Where would fertilization occur? Relate the features of the slides to the life cycle diagram.

📖 **Observe the whole angiosperm leaves and the prepared slides of angiosperm leaves.** Like the pine needle, this is a complex structure compared to the “leaves” of a moss.

📖 **Observe the prepared slides of root tips (*Coleus* or *Allium*).** The area with a lot of small cells is the root apical meristem, a zone of rapid cell proliferation.

📖 **Study the angiosperm life cycle diagram in Campbell.** Compare and contrast this with the other life cycle diagrams. Remember these terms about the life cycle diagram: fertilization, mitosis, meiosis, haploid, diploid, gametophyte, sporophyte, spore, sperm, egg. We'll come back to this diagram in a later lab.

KEY VOCABULARY FOR THIS LAB

You should be familiar with these terms; be able to recognize the structures and say which groups have them.

alternation of generations
angiosperm
chlorophyta
chloroplast
cuticle
diploid
embryo
gamete
gametophyte
green algae
gymnosperm
haploid

lignified vascular tissue
meiosis
meristem
mitosis
pollen
seed
spore
sporophyte
syngamy
vascular tissue
viridiplantae
zygote

QUESTIONS FOR PLANT LAB I

You don't need to turn in answers to these questions now. However, you'll see questions like these on the lab exam.

1. How is a moss “leaf” (not considered a true leaf) similar to a flowering plant’s leaf? How is it different?
2. How is a moss rhizoid similar to a flowering plant’s root? How is it different?
3. Mosses are particularly susceptible to damage by air pollution – more so than most plants. Why do you think this is the case?
4. How does water get from the ground to the upper part of a moss?
5. When you're looking at a moss, what's haploid? What's diploid?
6. Which life cycle stage is bigger and longer-lived in mosses – sporophyte or gametophyte? Is this stage haploid or diploid?
7. Is water necessary for fertilization in mosses? Why or why not?
8. Is water necessary for fertilization in ferns? Why or why not?
9. Is water necessary for fertilization in gymnosperms? Why or why not?