**"And the Green Grass Grew All Around and Around, the Green Grass Grew All Around…"**
**Evolution of Plants**

## Adapting to Terrestrial Living

- Plants are complex multicellular organisms that are autotrophs
  - they feed themselves by photosynthesis
  - they occur almost exclusively on land
  - they are the dominant organisms on the surface of the earth
  - there are about 263,500 species of plants today

- The green algae that were probably the ancestors of today's plants are aquatic organisms that are not well adapted to living on land

- Before their descendants could live on land, they had to overcome many environmental challenges
  - how to absorb minerals?
  - how to conserve water?
  - how to reproduce on land?

- Plants require relatively large amounts of six inorganic minerals: N, K, Ca, P, Mg, and S
- Each of these minerals constitutes 1% or more of a plant's dry weight
- Plants must absorb these materials, along with water, through their **roots**
  - the first plants were symbiotically involved with **mycorrhizae**

- One of the key challenges to living on land is to avoid drying out
  - plants have a watertight outer covering called a **cuticle**, which has a waxy consistency
  - water enters plants only through the roots while the cuticle prevents water loss to the air
  - specialized pores called **stomata** (singular, **stoma**) allow passage for water through the cuticle
    - they are found in the leaves and, sometimes, the green portion of stem
    - they allow for the passage of $CO_2$ into the plant for photosynthesis and $H_2O$ vapor and $O_2$ to pass out

**A stoma**

- Reproducing sexually on land presented special challenges
  - as plants could not move, it was necessary for plants to pass gametes from one individual to another
    - the first plants needed a film of water for a sperm to swim to an egg and fertilize

it
- later, pollen evolved, providing a means of transferring gametes without drying out

- In early plants, meiosis was delayed and the cells of the zygote divided to produce a multicellular diploid structure

- This resulted in an **alternation of generations**, in which a diploid generation alternates with a haploid one
  - the diploid generation is called the **sporophyte**
  - the haploid generation is called the **gametophyte**

**Generalized plant life cycle**

**Two types of gametophytes**

**Plant Evolution**

- Four key evolutionary advances occurred in the evolution of the plant kingdom
  - alternation of generations
    - the sporophyte becomes the dominant generation in all but the earliest plants
  - vascular tissue
    - transports water and nutrients through the plant body and provides structural support
  - seeds
    - seeds provide nutrients and protection for the plant embryo until it encounters favorable growing conditions
  - flowers and fruits
    - improved the chances of successful mating in sedentary organisms and facilitated dispersal of their seeds

**Plant Phyla**

**Plant Phyla**

**Nonvascular Plants**

- The first successful land plants had no vascular system
  - as a result, the maximum size of the plant was greatly limited because all materials had to be transported by osmosis and diffusion
  - only two phyla of living plants completely lack a vascular system
    - **liverworts** (phylum Hepaticophyta)
    - **hornworts** (phylum Anthocerophyta)
  - a third phylum of plants has a simple conducting tissue system of soft strands
    - **mosses** (phylum Bryophyta)

**The life cycle of a moss**

## The Evolution of Vascular Tissue

- **vascular tissues** are specialized cylindrical or elongated cells that form a network throughout a plant
  - the earliest vascular plants grew by cell division at the tips of the stem and roots
    - this **primary growth** made plants longer or taller
  - later vascular plants developed a new pattern of growth in which a ring of cells could divide around the periphery of the plant
    - this **secondary growth** made it possible for a plant stem to increase in diameter
    - the product of secondary growth is **wood**

## The vascular system of a leaf

## Seedless Vascular Plants

- There are two phyla of living seedless vascular plants
  - **ferns** (phylum Pterophyta)
    - in ferns, the sporophyte generation is much larger and more complex than the gametophyte
    - the leaves are the sporophyte are called **fronds**
  - **club mosses** (phylum Lycophyta)

## Seedless vascular plants

## Fern life cycle

## Evolution of Seed Plants

- The seed is a crucial adaptation to life on land because it protects the embryonic plant when it is at its most vulnerable stage

- Seed plants produce two kinds of gametophytes, male and female, which develop completely within the sporophyte
  - male gametophytes are called **pollen grains**
    - they arise from **microspores**
  - a female gametophyte contains the egg within an **ovule**
    - it develops from a **megaspore**

- There is no need for free water in the fertilization process
  - **pollination** by insects, wind, or other agents transfers pollen to an ovule
  - the pollen grain then cracks open and sprouts as a **pollen tube**, bringing sperm cells directly to the egg

- All seed plants are derived from a single common ancestor
  - **gymnosperms**
    - in these seed plants, the ovules are not completely enclosed by sporophyte tissue at the time of pollination

- **angiosperms**
  - in these seed plants, the most recently evolved of all plant phyla, the ovules are completely enclosed in sporophyte tissue called the **carpel** at the time of pollination

- A seed has three visible parts
  1. a sporophyte embryo
  2. endosperm, a source for food for the developing embryo
     - in some seeds, the endosperm is used up by the embryo and stored as food in structures called cotyledons
  3. a drought-resistant protective cover

**Basic structure of seeds**

- Seeds improved the adaptation of plants to living in land in the following respects
  - **dispersal**
    - facilitates the migration and dispersal into new habitats
  - **dormancy**
    - permits plants to postpone development until conditions are favorable
  - **germination**
    - controls when the plant develops so that it can be synchronized with critical aspects of the plant's habitat
  - **nourishment**
    - provisions the seed during the critical period just after germination

**Seeds allow plants to bypass the dry season**

**Gymnosperms**

- Four phyla constitute the gymnosperms
  - **conifers** (phylum Coniferophyta)
    - trees that produce their seeds in cones and most have needle-like leaves
  - **cycads** (phylum Cycadophyta)
    - have short stems and palmlike leaves
  - **gnetophytes** (phylum Gnetophyta)
    - contains only three kinds of very unusual plants
  - **ginkgo** (Ginkgophyta)
    - only one living species, the maidenhair tree, which has fan-shaped leaves

**Gymnosperms**

- The life cycle of conifers is typical of gymnosperms
  - conifers form two types of cones
    - **seed cones** contain the female gametophytes
    - **pollen cones** contain the pollen grains (male gametophytes)
  - conifer pollen grains are dispersed by wind to the seed cones
  - the fertilized seed cones produce seeds, which are also wind-dispersed

- the germinated seed will grow into a new sporophyte plant

**Life cycle of a conifer**

**Rise of the Angiosperms**

- Ninety percent of all living plant species are angiosperms
  - virtually all of our food is derived, directly or indirectly, from angiosperms
  - angiosperms use flowers to use insects and other animals to carry pollen for them
    - fertilization is assured in a direct pollination from one individual of a species to another

- The basic structure of a flower consists of four concentric circles, or **whorls**, connected to a base called a **receptacle**
  - the **sepals** form the outermost whorl and typically protect the flower from physical damage
  - the **petals** are the second whorl and serve to attract pollinators
  - the third whorl is called the **stamens** and contains the "male" parts that produce pollen
    - a swollen **anther** occurs at the tip of an anther and contains pollen
  - the innermost whorl is the **carpel** of the flower and contains the "female" parts that produce the egg
    - the ovules occur in the bulging base of the carpel, called the **ovary**
    - a stalk called the **style** rises from the ovary and ends with a sticky tip called a **stigma**
      - the stigma receives pollen

**An angiosperm flower**

**Why Are There Different Kinds of Flowers?**

- Insects and plants have coevolved so that certain insects specialize in visiting particular kinds of flowers
  - as a result, a particular insect carries pollen from one individual flower to another *of the same species*
  - bees are the most numerous insect pollinator
- Birds also pollinate some flowers, especially red ones
- Grasses and some other angiosperms have reverted to wind pollination

**How a bee sees a flower**

**Red flowers are pollinated by hummingbirds**

**Improving Seeds: Double Fertilization**

- Angiosperms produce a special, highly nutritious tissue called **endosperm** within their seeds
  - the pollen grain contains two haploid sperm

        - the first sperm fuses with the egg at the base of the ovary
        - the second sperm fuses with polar nuclei to form a triploid endosperm cell, which divides faster than the zygote and gives rise to the endosperm tissue
    - the process of fertilization to produce both a zygote and endosperm is called **double fertilization**

**Life cycle of an angiosperm**

- In some angiosperms, the endosperm is fully used up by the time the seed is mature
    - food reserves are stored by the embryo in swollen, fleshly leaves called cotyledons, or seed leaves
        - **dicots** have two cotyledons
        - **monocots** have one cotyledon

**Dicots and monocots**

**Improving Seed Dispersal: Fruits**

- A mature ovary that surrounds the ovule becomes all or part of the **fruit**
    - a fruit is mature ripened ovary containing fertilized seeds
    - angiosperms use fruits to have animals aid in the dispersal of seeds
        - although eaten by animals, the seeds within the fruit are resistant to chewing and digestion
        - they pass out of the animal with the feces, ready to germinate at a new location far from the plant
    - some fruits are dispersed by water or wind

**Organization of a Vascular Plant**

- A vascular plant is organized along a vertical axis
    - the part below ground is called the **root**
        - the root penetrates the soil and absorbs water and ions
        - it also anchors the plant
    - the part above ground is called the **shoot**
        - the shoot consists of the **stem** and **leaves**
            - the stem serves as a framework for positioning the leaves
            - the leaves are where most photosynthesis takes place

- There are several specialized epidermal cells that make up dermal tissue
    - **guard cells** are paired cells that flank an opening called a **stoma**
        - the guard cells regulate the passage of oxygen, carbon dioxide, and water vapor across the epidermis
    - **trichomes** are outgrowths of the epidermis that occur on the shoot and give it a "fuzzy" appearance
        - they play an insulating role and affect heat and water balance
    - **root hairs** are extensions of the epidermis below ground and keep the root in intimate contact with soil particles
        - root hairs increase the surface area of the root

## Guard cells and trichomes

- There are two types of vascular tissues
  - **xylem** is the plant's principal water-conducting tissue
    - it forms a continuous system that runs throughout the plant body
    - water (and dissolved minerals) pass from the roots to the shoots
      - when water reaches the leaves, most exits through the stomata
  - **phloem** is the principal food-conducting tissue

## Roots

- Roots have a central column of xylem with radiating arms
  - alternating within the radiating arms of xylem are strands of primary phloem
  - surrounding the central column, and forming its boundary, is a cylinder of cells called the **pericycle**
    - branch, or lateral, roots are formed from cells of the pericycle

## A root cross section

## Stems

- Stems often experience both primary and secondary growth
  - stems are the source of an economically important product—wood
- In the primary growth of a shoot, leaves first appear as leaf **primordia**
  - these are rudimentary leaves that cluster around the apical meristem
  - they unfold and grow as the stem elongates
- Within soft, young stems, the vascular tissue strands are arranged differently in dicots versus monocots
  - in dicots, vascular bundles (containing primary xylem and primary phloem) are arranged around the outside of the stem
  - in monocots, vascular bundles are scattered throughout the stem

## A comparison of dicot and monocot stems

## Leaves

- Leaves are usually the most prominent shoot organ and are structurally diverse
  - growth occurs by means of **marginal meristems**
    - the marginal meristems grow outward and ultimately form the **blade** (the flattened portion) of the leaf
    - once a leaf is fully expanded, its marginal meristems cease to grow

## Dicot and monocot leaves

## Water Movement

- Several factors are at work to move water up the height of a plant
  - the initial movement of water into the roots of a plant involves osmosis

    - water moves into the cells of the root because the fluid in the xylem contains more solutes than the surroundings
        - this osmotic force is called **root pressure** but, by itself, is not sufficient to "push" water up a plant's stem

- In addition to root pressure, capillary action adds "pull" to the movement of water up a plant stem
    - **capillary action** results from the tiny electrical attractions of polar water molecules to surfaces that carry electrical charge
        - this attraction is called **adhesion**
    - but capillary action, by itself, is not strong enough to "pull" water up the plant stem

**Capillary action**

- A final "pull" to the process of moving water up a plant shoot is provided by **transpiration**
    - water evaporating from the top (leaf) of the tube pulls the column of water from the bottom (root)
    - the column of water does not collapse because water molecules are attracted to each other
        - this process is called **cohesion**
            - the narrower the diameter of the tube, the more **tensile strength**, or resistance to separation, of the water column
- The combination of gravity, tensile strength, and cohesion affects water movement
    - the whole process is explained by the **cohesion-adhesion-tension theory**
- **Transpiration** is the process by which water leaves a plant
    - more than 90% of the water taken in by a plant is lost to the atmosphere, mostly through the leaves
    - water first passes into the pockets of air in the spongy mesophyll and then evaporates through the stomata
    - high humidity and low temperatures increase transpiration rates

**How transpiration works**

- The only way that plants can control water loss on a short-term basis is to close their stomata
    - but plants need to balance closing their stomata with keeping them open for providing access to carbon dioxide
    - the stomata open and close because of changes in the water pressure of their guard cells
- When the guard cells are plump and swollen with water, they are said to be **turgid** and the stoma is open
- When the guard cells lose water, the stoma closes
- Root hairs greatly increase the surface area of roots

- root hairs are turgid because they contain a higher concentration of dissolved solutes than the soil
- minerals also enter the root hairs because they contain a variety of ion transport channels that transport specific ions
  - this may involve active transport
  - the minerals are transported by the xylem while dissolved in water

**Root hairs**

**The flow of materials into, out of, and within a plant**

**Carbohydrate Transport**

- **Translocation** is the process by which most of the carbohydrates manufactured in plants are moved through the phloem
  - the movement is a passive process
    - the **mass flow** of materials transported occurs because of water pressure generated by osmosis
      - an area where sucrose is made is called a **source** and an area where sucrose is delivered from the sieve tubes is called a **sink**
    - sucrose moves from a source to a sink by a process described by the **pressure-flow hypothesis**

**How translocation works**

**Essential Plant Nutrients**

- Minerals are involved in plant metabolism in many ways
  - **nitrogen (N)** is an essential part of proteins and nucleic acids
  - **potassium (K)** ions are used to regulate **turgor pressure** in guard cells
  - **calcium (Ca)** is an essential part of cell walls
  - **magnesium (Mg)** is a part of the chlorophyll molecule
  - **phosphorous (P)** is a part of ATP and nucleic acids
  - **sulfur (S)** is a key component of the amino acid, cysteine

- Other essential minerals for plant health include chlorine (Cl), iron (Fe), boron (B), manganese (Mn), zinc (Zn), copper (Cu), and molybdenum (Mb)
- Most plants acquire minerals from the soil, although some **carnivorous** plants are able to use other organisms directly as sources of nitrogen, just as animals do

**A carnivorous plant**

**Angiosperm Reproduction**

- Reproduction in flowering plants, the angiosperms, can be asexual or sexual
  - asexual reproduction is common in stable environments
    - this **vegetative reproduction** results when new individuals are simply cloned from parts of the parent
    - asexual reproduction allows individuals to reproduce with lower investment of

energy than sexual reproduction

- Sexual reproduction in plants involves an alternation of generations
  - diploid sporophyte generation gives rise to a haploid gametophyte generation
    - the male gametophytes are **pollen grains** that come from **microspores**
    - the female gametophyte is the **embryo sac**, which develops from a **megaspore**
    - these gametophytes are produced in separate, specialized structures of the angiosperm flower
      - but both usually occur together in the same flower
      - they are produced seasonally

- Most flowers contain male and female parts
  - the male parts are called **stamens**
  - the female part is called the **carpel**

- Flowers that contain only male or only female parts are known as **imperfect**
  - plants that contain imperfect flowers that produce only ovules or only pollen are known as **dioecious**
  - plants that contain imperfect flowers of both male and female on the same plant are called **monoecious**

## Fruit

- During seed formation, the flower ovary begins to develop into **fruit**
  - fruits form in many ways and exhibit a wide array of modes of specialization
  - fruits with fleshy covering are normally dispersed by bird and other vertebrates
    - the animals carry seeds from place to place before excreting them as solid waste
  - some fruits are dispersed by wind or by attaching themselves to the fur of mammals or the feathers of birds
  - some fruits are dispersed by water