TEACHER BACKGROUND INFORMATION
PLANTS

CHAPTER'S BIG IDEAS:

- Plants have **common characteristics**:
    - All are autotrophic
    - All are eukaryotes
    - All are multicellular
    - All have cell walls with cellulose
    - Unique life (reproductive) cycles

- All plants have **needs required for survival** and have developed a variety of adaptations (structural and reproductive) that allow them to meet these needs in their own environment. The basic needs for individual and population survival of a plant species are:
    - Water
    - Sunlight (energy)
    - Carbon Dioxide
    - Minerals (these first four things are required to make food)
    - Protection from desiccation (drying out)
    - Stable internal conditions
    - Reproduction (*for population survival only*)

- **Structure** and **function** are generally correlated at all levels of biological organization, including plants. Plants have a variety of structures with specific functions, such as roots, leaves and stems.

CHARACTERISTICS OF PLANTS

Members of the plant kingdom (Domain Eukarya) share several characteristics:

- **Autotrophic** (self-feeding, make their own food). Nearly all plants, some are parasitic.
- **Eukaryotic** (true-nucleus)
- **Multicellular** (made up of more than one cell)
- **Cell walls** surrounding cell membranes
- Unique **reproductive cycles**

Nearly all plants are autotrophs meaning they are able to make their own food through the process of photosynthesis which converts water and carbon dioxide to sugar. Neither multicellularity nor the ability to photosynthesize is unique to plants, but the simultaneous appearance of both traits in a single organism outside of the plant kingdom is quite rare. Plants cells are eukaryotic; they have a true nucleus surrounded by a nuclear membrane. But unlike animal cells, plant cells are enclosed by a cell wall. The cell wall surrounds the plasma membrane and separates the cell from its environment. Plant cell walls contain cellulose, a material that makes the walls rigid and the cell box-like. Plant cells also contain many other structures (see Fig. 1.) Chloroplasts (chloro = green; plast =

substance) are the structures in which photosynthesis takes place. A vacuole is a large storage sac that can expand and contract like a balloon. The vacuole stores many substances, including water, wastes, and food. When a plant's vacuole does not contain enough water, the plant wilts.

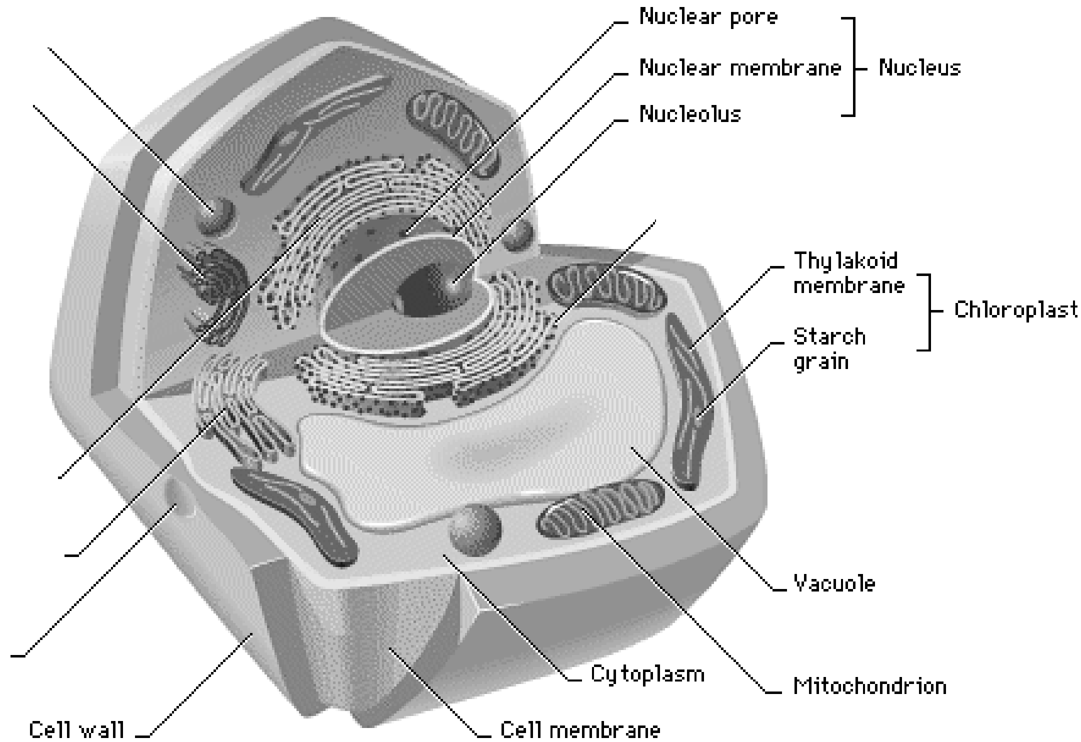

Figure 1 – Typical plant cell. Notice large vacuole and thick cell wall. (Diagram from http://images.encarta.msn.com)

The most distinctive feature of plants, however, is their reproductive cycle, characterized by the alternation of generations, in which generations of diploid (two sets of chromosomes) and haploid (one set of chromosomes) alternate with one another. This will be elaborated on in the section on plant reproduction and flowers.

All these characteristics have enabled plants to colonize almost every part of land on Earth.

PLANT NEEDS:

All plants have **needs required for survival** and have developed a variety of adaptations (structural and reproductive) that allow them to meet these needs in their own environment. The *basic* needs for plants to survive are **water**, **energy**, **carbon dioxide**, and **minerals**. Photosynthesis traps sunlight energy and stores it as chemical energy in *glucose* molecules. Glucose is just stored energy and in order to use this energy the plant must use oxygen to undergo cellular respiration to release the energy from the glucose. Furthermore, glucose is an immediate source of energy but it is not enough for a plant to survive and meet its needs. The plant must convert glucose into *carbohydrates* (e.g. starch) for storage, into *proteins* for cellular processes (e.g. enzymes) and into *nucleic acids* (e.g. DNA) for information. A glucose molecule contains *carbon* (C), *hydrogen* (H) and *oxygen* (O), which all are derived from the water (H_2O) and carbon dioxide (CO2) plants need. Proteins and nucleic acids are also made up of C, H and O, but they also contain *phosphorus* (P) and *nitrogen* (N). In order for a plant to make proteins or DNA, it must absorb these essential chemical elements (minerals) from the soil. Nitrogen and phosphorus are common ingredients of plant fertilizers. Overall, plants require nine macronutrients in fairly large amounts (carbon, oxygen, hydrogen, nitrogen, sulfur, phosphorus, potassium, calcium, magnesium) and eight micronutrients in much smaller amounts (chlorine, iron, boron, manganese, zinc, copper, molybdenum, nickel). Researchers have used a method known as hydroponic culture to determine which of the mineral elements essential nutrients for plants.

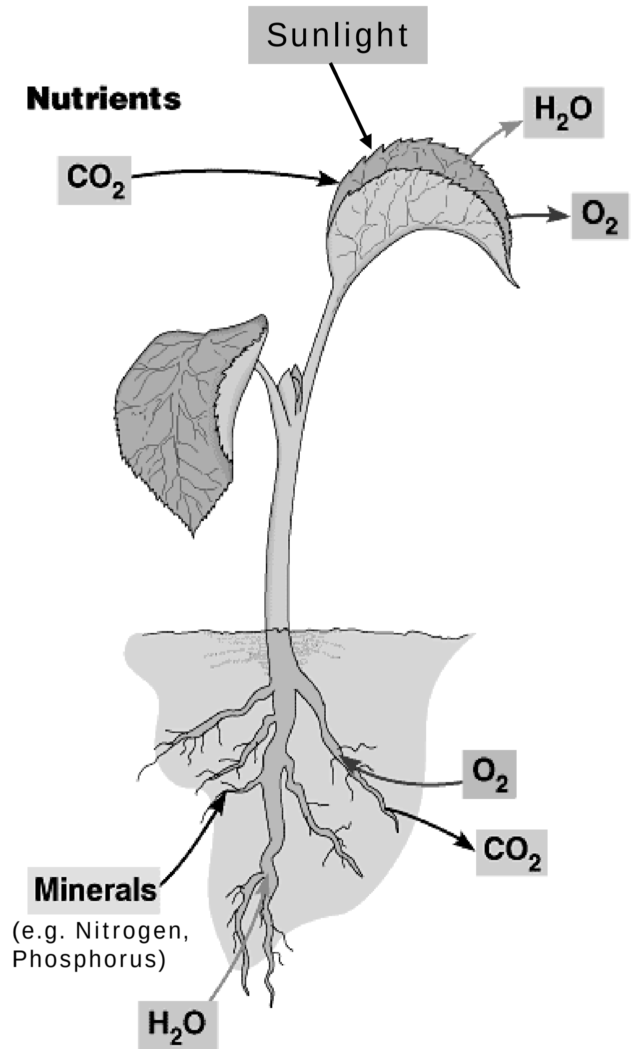

Figure 2 – Summary of plant inputs (H2O, CO2, O2, N and P) and outputs (CO2, H2O, O2 and nutrients). Diagram from www.campbellbiology.com

PLANT ANATOMY & PHYSIOLOGY (Form & Function):

Plants are composed of structures (e.g. roots, stems, and leaves; fig.3) that are modified to meet the needs of the plant.

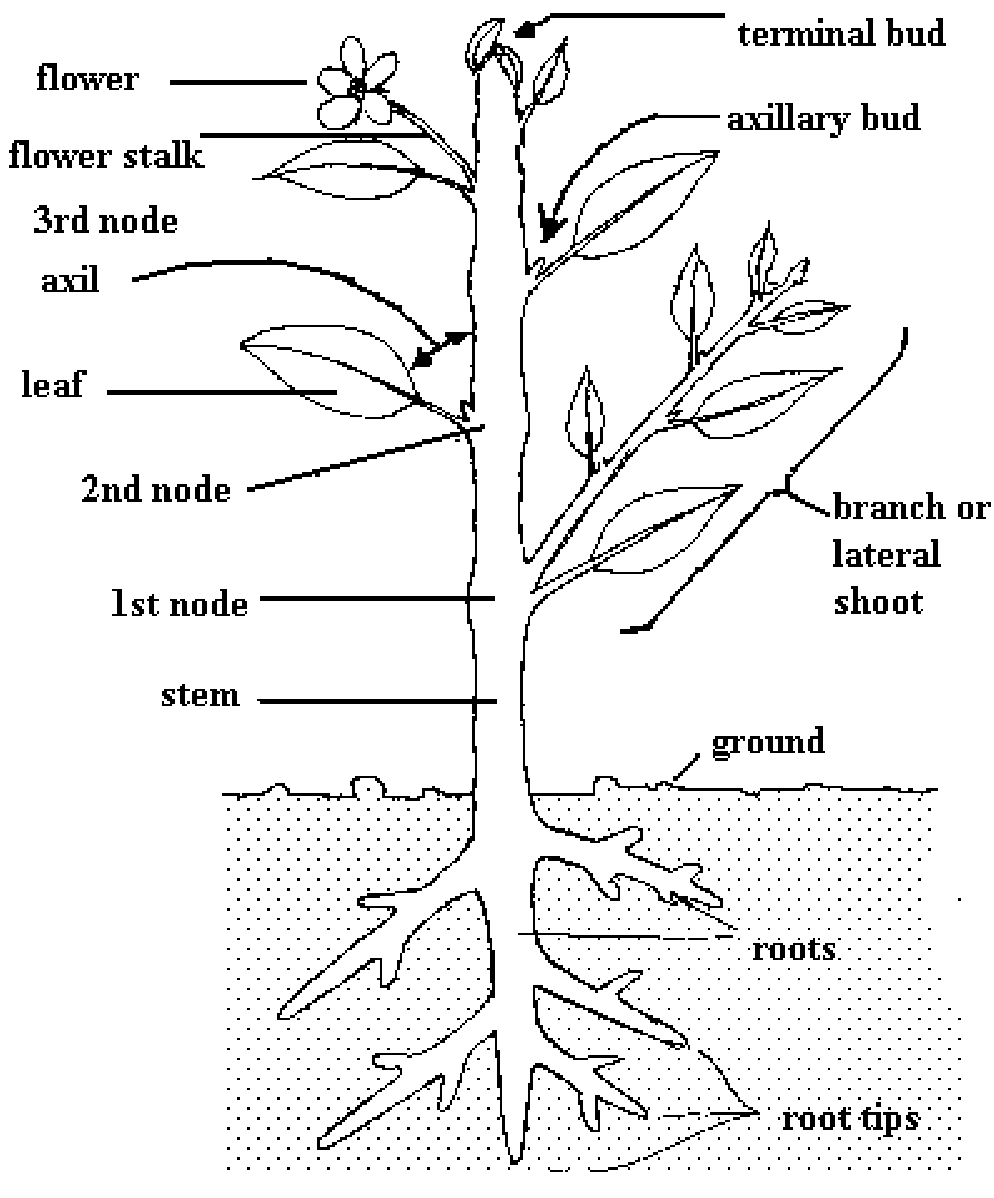

Figure 3 – Parts of a flowering plant (Diagram from http://www.naturegrid.org.uk)

Most plants live on land but have evolved from marine green algae. Living on land is different from living in water because sea water provides algae with support (buoyancy), water, carbon dioxide, essential nutrients, and allows for the transfer of gametes (eggs and sperm). On land, plants have made adaptations that help them meet their needs without having water all around them. For plants to survive on land they must have ways to obtain water and other nutrients from their surroundings, retain water (not dehydrate), transport materials in their bodies, support their bodies and reproduce.

- **Roots**: All living organisms require food (energy) and water to survive. To live on land, plants have adapted roots to ***take nutrients and water from the soil***. Although the first plants had no roots, fossils show that fungi lived on or within the underground parts of many early plants. Fungi, known as mycorrhizae help plants get nutrients. As a matter of fact, 80% of all plant species on Earth today depend on mycorrhizae for nutrient absorption. Roots are structures that *anchor* plants, but also *absorb* *water* and mineral *nutrients*. In many plants, roots also function in the *storage* of organic nutrients, such as starch. All plants cells need *oxygen* to undergo cellular respiration, the break down of molecules and release of energy that is required for cellular function. In general, plants get their oxygen from photosynthesis, but roots do not photosynthesize so they must get their oxygen from their surroundings. This is why houseplants that are over-watered for extended periods of time die – their roots literally suffocate or drown for lack of oxygen. Trees that live in swamps, such as mangroves and cypress, have roots that emerge above the water (pneumatophores) that obtain oxygen from the air – thus avoiding drowning.

- **Stems**: A plant needs to ***transport water, minerals, food, and other materials*** from one part of its body to another. In general, water and minerals are taken up by the bottom part of the plant, while food is made in the top part. But all of the plant's cells need water, minerals, and food. In small plants (*nonvascular plants*), materials can simply move from one cell to the next. But larger plants (*vascular plants*) need a more efficient way to transport materials a longer distance from one part of the plant to another. These plants have transporting tissue called vascular tissue. **Vascular tissue** is a system of tube-like structures inside a plant through which water, minerals, and food move. Stems *transport* substances between roots and leaves. They also ***provide support*** for plants. A plant on land must support its own body. Support is not an issue for small plants that grow low to the ground. But for larger plants to survive, the plant's food-making parts must be exposed to as much sunlight as possible. Rigid cell walls (with lignin) and vascular tissue strengthen and support the large bodies of these plants. Many plants have stems that are specialized for other functions, e.g. cacti stems store water.

Stems are either *non-woody* or *woody*. Plants with non-woody stems are known as *herbaceous* plants. Their stems are flexible and usually green. Examples of herbaceous plants include grasses, violets, and clovers. Herbaceous stems are covered by an epidermis (epi = top; dermis = skin) with stomata (pores in the leaf) scattered in it to allow gas exchanges.

Plants with woody stems include trees and shrubs such as pines, oaks, roses and hollies. Woody stems are stiff and not green. They are surrounded by cork, which protects them from physical damage and helps prevent water loss.

- **Leaves**: The first plants lived near water, so drying out was not a problem. Land plants must have ways of holding on to the water they obtain in order to prevent them from drying out due to evaporation. When there is more water in plant cells than in the air, the water leaves the plant and enters the air. One adaptation that helps a plant ***reduce water loss*** is a waxy, waterproof layer called the **cuticle** that covers the leaves of most plants. This adaptation allowed plants to inhabit drier areas. The problem with the waxy cuticle is that it does not let oxygen or carbon dioxide pass through it, so another adaptation emerged that allows the passage of gases: pores known as **stomata**. Stomata open and close as the guard cells that surround them change shape (Fig.4)

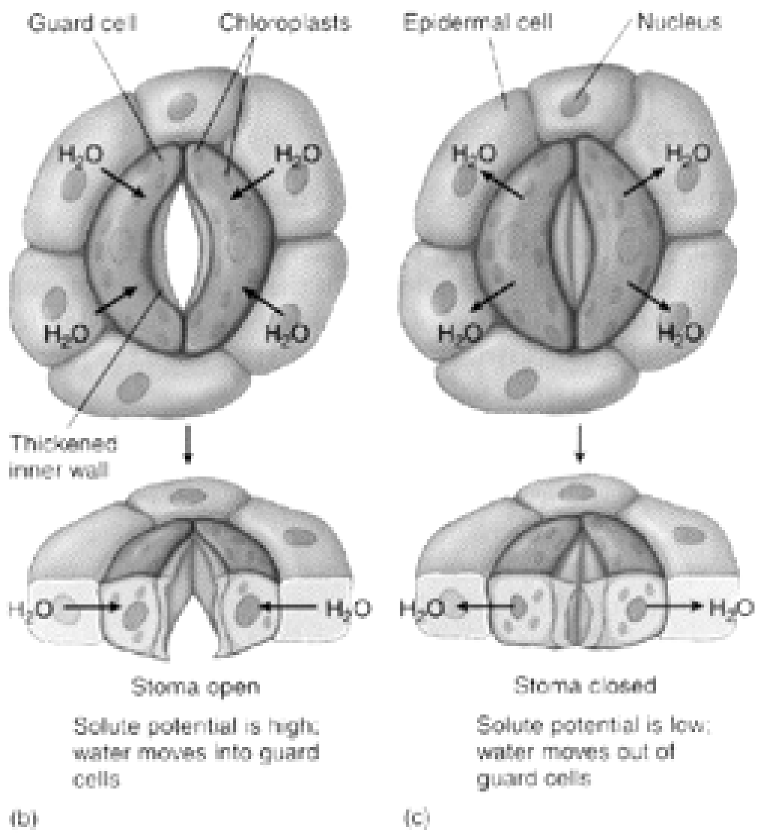

Figure 4– Plant stomata, open on left and closed on right.
Diagram from http://www.cbu.edu

Leaves are the ***primary photosynthetic organs*** of plants. Most leaves have flattened portions called the blade which maximizes the surface area exposed to the sun. The blade is often attached to the stem by a stalk called the petiole. Many plants have highly modified leaves that are specialized for particular functions. For example, the spines of a cactus and the tendrils of a garden pea are modified leaves. Cactus spines are specialized for protection and water conservation, while garden-pea tendrils are specialized for climbing.

- **Transport in plants**: Vascular plants have tissues specialized in the transport of water and nutrients. These tissues, known as vascular tissues, are made up of *xylem* and *phloem*. Xylem tissue is made up of thick-walled cells that conduct water and minerals from a plant's roots to its leaves. Phloem tissue is made up of cells that conduct sugars and other nutrients throughout a plant's body.

You can see the vascular tissues accomplishing their task when you place a celery stalk in colored water and watch as the dye travels up the xylem. This "sucking up water" works through a combination of capillary action and turgor pressure. Capillary action alone moves an insignificant amount of water upwards, especially in tall trees. The secret lies in the loss of water through a plant's leaves – transpiration – and the resulting pressure differential (lower water pressure in the leaf, higher water pressure in the roots) created by this loss of water.

Transpiration subjects water in the xylem to tension, reaching from leaves to stems to roots. Water molecules are pulled upward to replace the ones that have evaporated in the leaves. Water molecules are pulled upward, like links in a chain, partly due to capillary action and the cohesive attraction between the molecules. Water is also pushed upwards by turgor pressure. As water molecules escape from the cells at the leaf surface, those cells loose their internal water pressure – turgor pressure. Since materials move from areas of high pressure to areas of low pressure, water in lower cells moves in to replace the water that was lost at the leaf surface through the stomata. With this process, water can move at a rate of about 60 centimeters per minute in most plants. Of the water that moves through the leaf, 90 percent is lost by transpiration; only about 2 percent is used during photosynthesis.

- **Photosynthesis**: Photosynthesis requires raw materials including *carbon dioxide* and *water*. The products of photosynthesis are *glucose* and *oxygen*. Photosynthesis requires energy in the form of light to proceed. Plants absorb most of the wavelengths of sunlight, but reflect wavelengths in the green part of the spectrum, making plants look green. Light moves in tiny packets of electromagnetic energy called *photons*. When a photon strikes and is absorbed by the green pigment, *chlorophyll,* in a plant's cell, the energy excites an electron in the chlorophyll molecule. The electron initially moves from a lower-energy state to one of higher energy. When the electron returns to its original state, it releases energy that initiates a chemical change. The electron is given potential energy when it is moved to a higher level and releases that potential energy when returning to its original state. This is somewhat similar to lifting a book, giving it potential energy, and when the book is dropped the energy is converted to kinetic energy, which can be felt if the book is dropped on a foot!

The chemical energy released from the electron's change of position is then stored, usually in the form of carbohydrates (sugars), in the plant's cells. Once the complex molecules, such as carbohydrates, are made, the energy must be extracted from the molecules to run cell processes. Inside each cell, the glucose produced by photosynthesis and oxygen created as a by-product of photosynthesis undergoes a reaction, releasing chemical energy.

The process that releases energy from nutrients is known as **cellular respiration** (Fig.5) and occurs in most organisms including plants and animals. Cellular respiration is actually the "opposite" of photosynthesis. The energy released by respiration can then be converted into kinetic and thermal energy which allows organisms to move and run cellular processes.

Photosynthesis: $CO_2 + H_2O \xrightarrow{\text{Sunlight}} \text{Glucose} + O_2$

Cellular Respiration: $O_2 + \text{Glucose} \xrightarrow{\text{ATP (Energy)}} CO_2 + \text{H2O}$

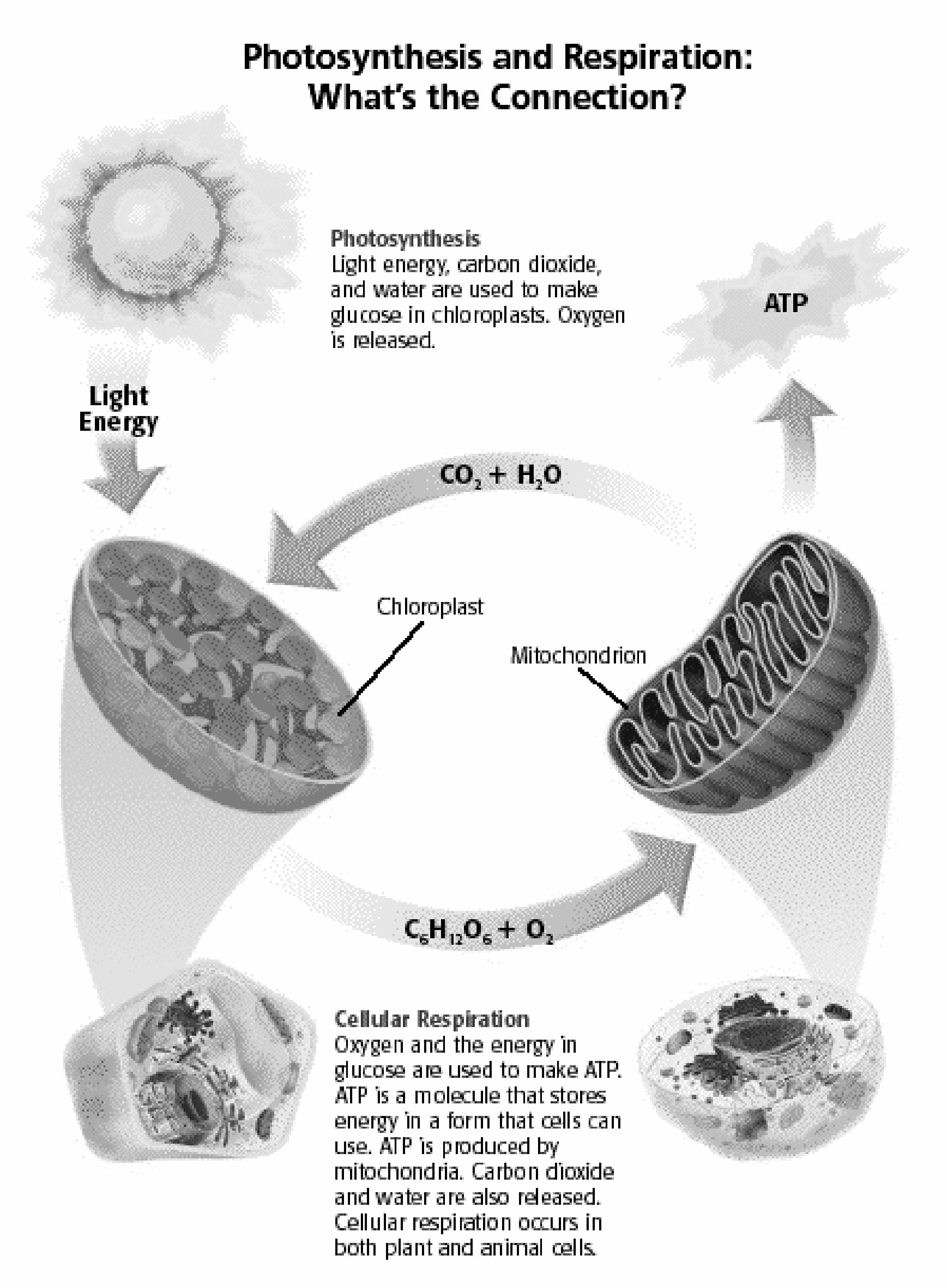

Figure 5 – Summary diagram of photosynthesis and respiration in plants. (Diagram from http://marshallteachers.sandi.net)

- **Reproduction**: All plants undergo sexual reproduction that involves fertilization. **Fertilization** occurs when a sperm cell unites with an egg cell. The fertilized egg is called a zygote. For algae and bryophytes (such as mosses), fertilization can only occur if there is water in the environment. This is because the sperm cells of the plants swim through the water to the egg cells. Other plants, however, have an adaptation that makes it possible for fertilization to occur in dry environments. This adaptation is **pollen**. Pollen permits the sperm of most plants to be carried from plant to plant by wind, insects or other animals rather than by water.

Note: Some plants reproduce asexually (no fertilization) by forming runners, bulbs or rhizomes (all are modified stems) to colonize new areas.

- **Flowers**: Flowers are found in plants known as angiosperms (angio = enclosed; Seed is enclosed in ovary). Flowers come in all sorts of shapes, sizes, and colors. But despite their differences, all flowers have the same function – ***reproduction***. A flower is the reproductive structure of an angiosperm. Figure 6 shows the parts of a typical flower. Parts of flowers vary from plant species to plant species. For example, some plants have flowers with only male reproductive parts, and some plants have flowers that lack petals.

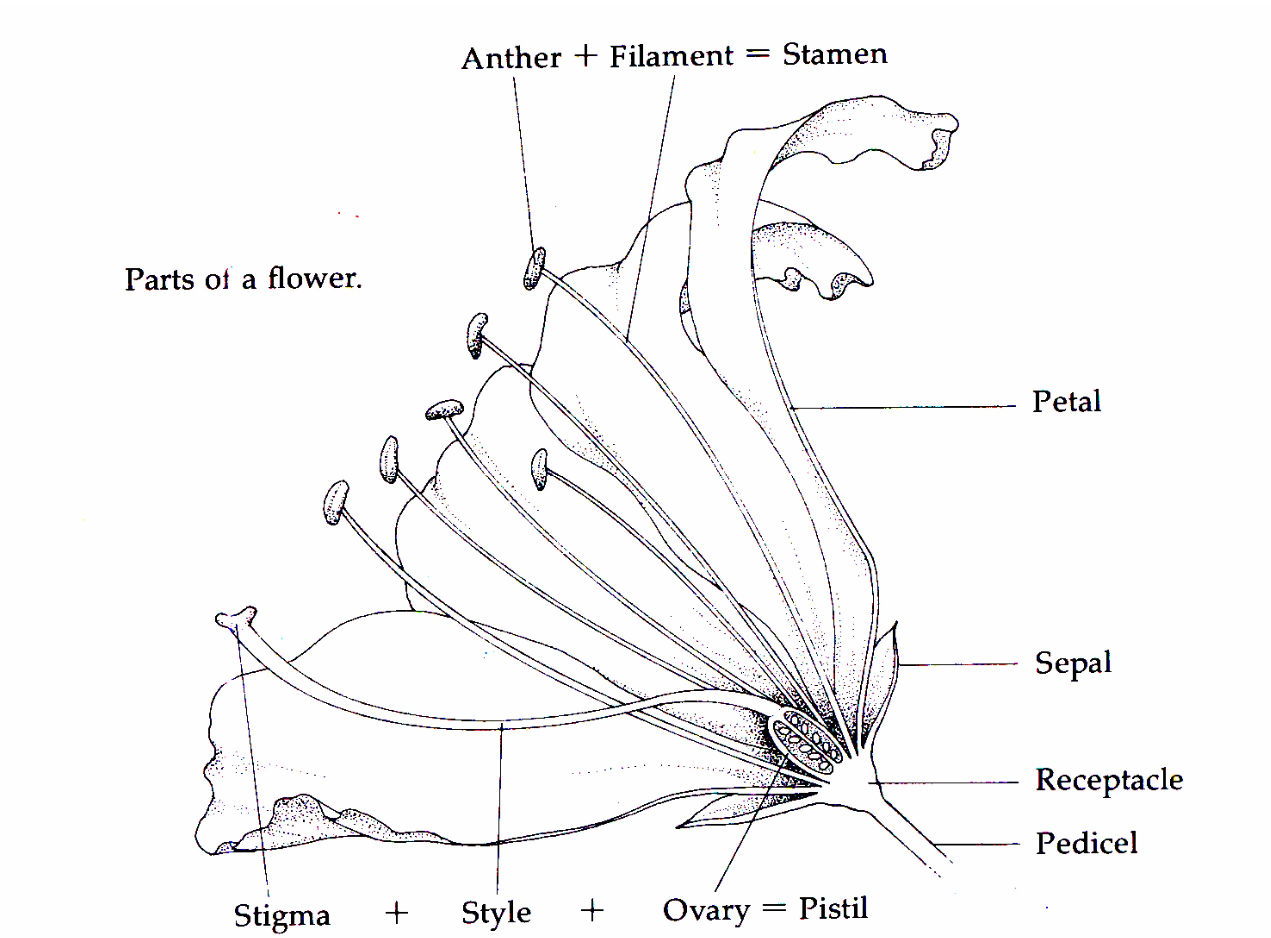

Figure 6 – Parts of a typical flower.

Each part of the flower has a specific function. When a flower is still in a bud, it is enclosed and protected by leaflike structures called **sepals**. When a flower opens, the sepals fold back and reveal the flower's colorful leaflike **petals**, which function in attracting pollinators and serving as landing platforms. Within the petals are the flower's male and female reproductive parts. The **stamens** are the male reproductive parts. They are made up of **anthers**, which produce **pollen**, sitting on top of **filaments**. The female parts, or **pistils**, are found in the center of most flowers. Some flowers have two or more pistils; others only have one. The sticky tip of the pistil is called the **stigma** which receives the pollen. A slender tube, called the **style**, connects the stigma to a hollow structure at the base of the flower called the **ovary**. The colors, shapes, and scents produced by most flowers attract insects and other animals. These organisms ensure that pollination occurs.

- **Seeds**: Seeds are found in seed plants and these plants share two important characteristics: they have vascular tissue and they use pollen and seeds to reproduce. Seed plants are able to live in a variety of dry environments as they do not require water for the transfer of sperm cells. Instead, seed plants produce pollen, tiny structures that contain the cells that will later become sperm cells.

Note: Do not associate pollen with flowers only. Pollen is also produced in cones by cone-bearing plants (gymnosperms: gymno = naked; naked seed or not enclosed in ovary) such as pine trees.

Pollen delivers the sperm cells directly near the eggs. After sperm cells fertilize the eggs, seeds develop. A seed is a structure that contains a young plant inside a protective covering. ***Seeds protect the young plant from drying out***. If a seed lands in an area where conditions are favorable, the plant sprouts out of the seed and begins to grow.

A seed (Fig. 7) has three main parts – an embryo, stored food, and a seed coat. The embryo is formed from the zygote, (fertilized egg) and it already has the beginnings of roots, stems, and leaves. In the seeds of most plants, the embryo starts to grow using the stored food until it can make its own food by photosynthesis. In all seeds, the embryo has one (monocot) or two (dicot) seed leaves known as **cotyledons**.

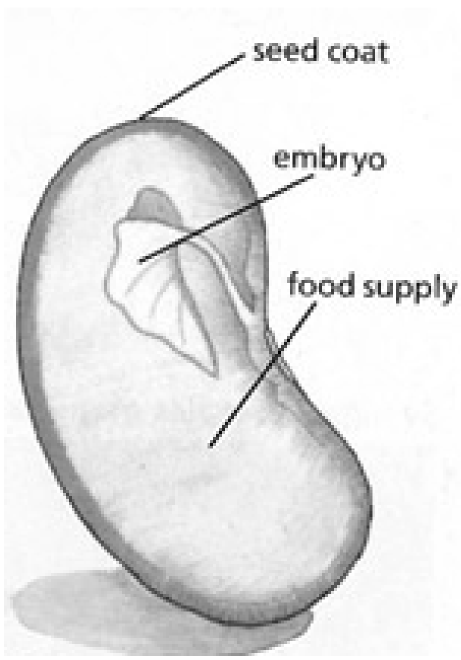

Figure 7 – Parts of a typical seed (Diagram from http://www.acsd.k12.pa.us)

Seeds are dispersed in many ways. One method involves other organisms such as animals eating fruit where the seeds pass through the digestive system and are deposited in new areas with lots of fertilizer (e.g.

cherries)! Other seeds hook onto an animal's fur and fall off in a new area (e.g. sand spurs). A second means of dispersal is water. Water can disperse seeds that fall into oceans and rivers (e.g. mangroves). A third dispersal method involves wind, spreading lightweight seeds with special wind-catching structures to far off places (e.g. dandelion). And finally, some plants eject their seeds just like a cannon ball. The force scatters the seeds in many directions (e.g. squirting cucumber)

- **Life Cycle of flowering plants (angiosperms):** All angiosperms share two important characteristics, they produce flowers and their seeds are enclosed in fruits. Figure 8 follows the life cycle of a typical angiosperm. The first step starts with pollination, when a grain of pollen falls on the stigma of a flower. Next the pollen grains produce a pollen tube that grows into the ovule. A sperm cell moves through the pollen tube and fertilizes the egg inside the ovule located in the ovary. The ovule then develops into a seed and the fertilized egg (zygote) becomes the seed's embryo. Other parts of the ovule develop into the seed coat and the seed's stored food. The ovary and other structures develop into a fruit that encloses the seeds. The fruit helps in seed dispersal. Finally, the seeds are dispersed and hopefully end up in a suitable habitat and grow into new plants.

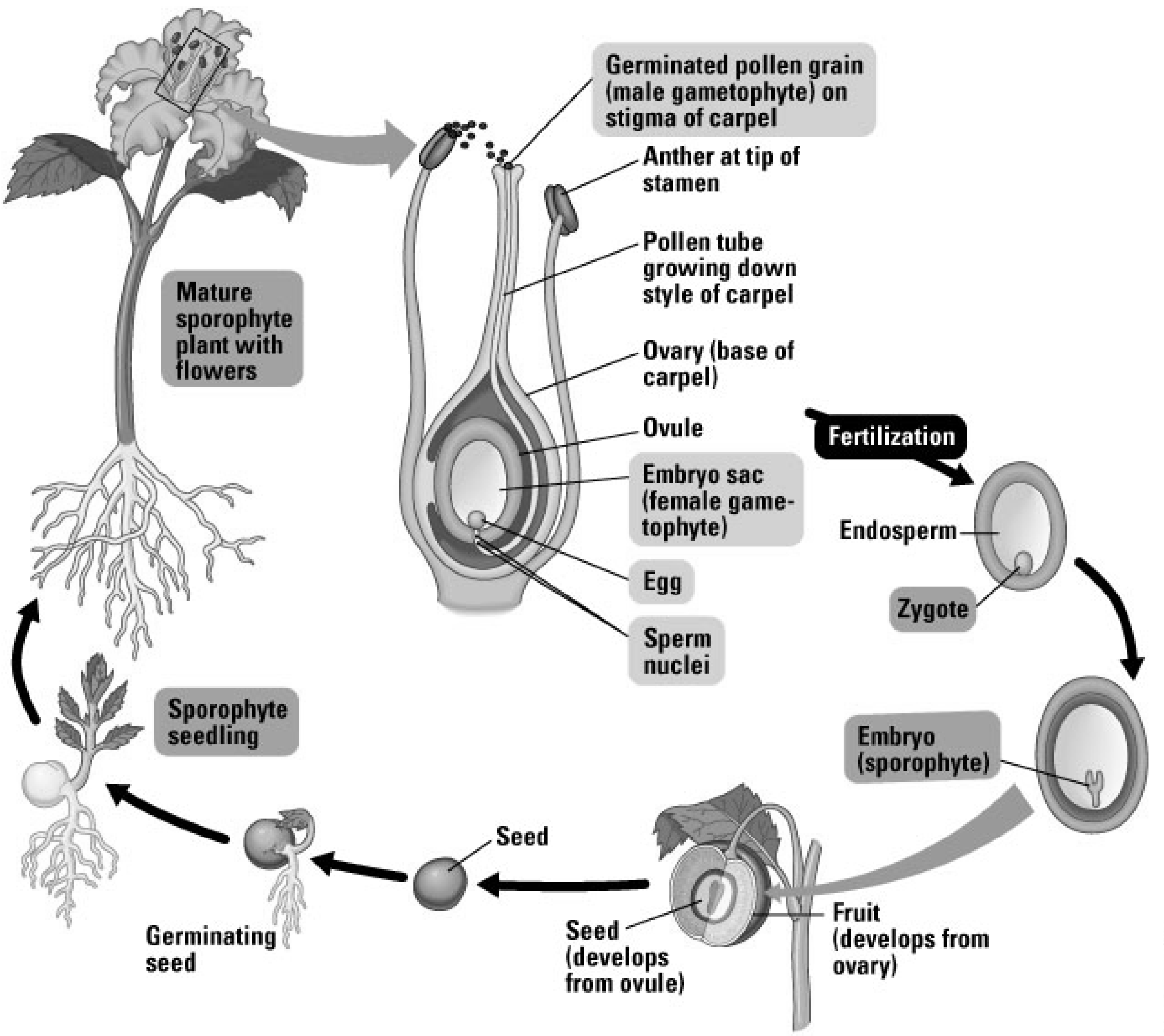

Figure 8 – Life cycle of a typical angiosperm (Diagram from www.campbellbiology.com)

CLASSIFICATION OF PLANTS:

Scientists informally group plants into two major groups – nonvascular and vascular plants.

- **Nonvascular Plants**: Plants that lack a well-developed system of tubes for transporting water and other materials are known as nonvascular plants. These plants are generally low-growing and do not have roots for absorbing water from the ground. Instead they obtain water and materials directly from their surroundings. The materials then simply pass from one cell to the next. This means that materials do not travel very far or very quickly. This slow method of transport helps explain why most nonvascular plants live in damp, shady places.

  Most nonvascular plants have only thin cell walls to provide support. This is one reason why these plants cannot grow more than a few centimeters tall. Bryophytes are nonvascular plants, which include mosses, liverworts, and hornworts. Note: some mosses do contain water-conducting tissues, though these tissues are not strong enough to provide efficient support or transport for the plant.

- **Vascular Plants**: Plants with true vascular tissue are called vascular plants. Vascular plants are better suited to live in dry areas than are nonvascular plants. Their well-developed vascular tissue solves the problem of transport, moving materials quickly and efficiently throughout the plant's body. Vascular tissue also provides strength, stability, and support to a plant. Thus, vascular plants are able to grow quite tall.

Vascular plants can be further classified by their method of reproduction.

- **Ferns (pteridophytes)** are seedless vascular plants that reproduce by making spores.
- **Gymnosperms**, which include all cone-bearing plants, are vascular plants that reproduce by seeds but do not form flowers or fruits.
- **Angiosperms** are vascular plants that flower and produce seeds that are surrounded by fruit. Angiosperms are also further divided into monocots and dicots (Fig. 9)

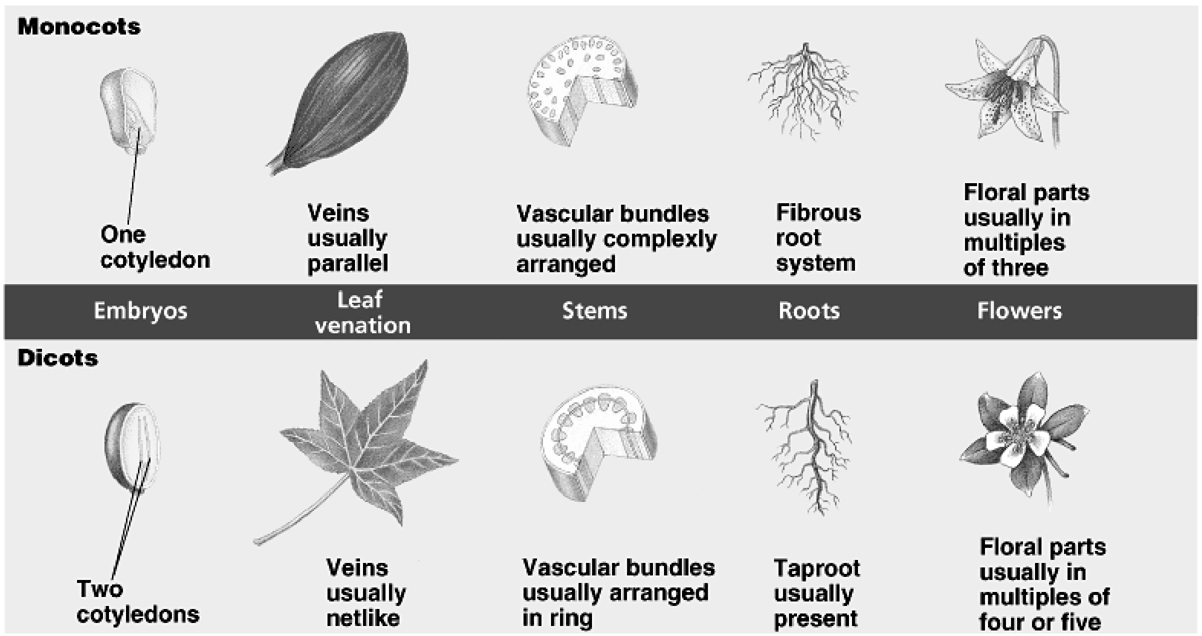

Figure 9 – Characteristics of monocots versus dicots (Diagram from www.campbellbiology.com)

There is great diversity within the plant kingdom. Plants play critical roles in the ecosystems in which they are found. They are primary producers and form the foundation of many food webs. Plants also release oxygen gas, a product of photosynthesis essential for other organisms.