Introductory Botany 2005

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Plant Anatomy and Physiology

This is a brief overview of some of the basic characteristics of plant cell and tissue structure. I will also briefly discuss some mechanisms plants use to move water and nutrients, and respond to environmental changes.

One of the first divisions of the great Kingdom of plants is between the *vascular* and the *non-vascular* plants. Vasculature is simply a term for a network of vessels plants use to transport water; most plants we work with are indeed *vascular*. But the first ones to begin colonizing the dry land were just extensions of algae and water-plants, and as such, possessed no internal vessels because they were used to just soaking up water from their environment. These simpler plants still exist: they are the mosses, liverworts and algae. Obviously, they need a moist environment to live, or their cells will die due to lack of water. They have no vasculature.

So *vasculature* evolved to allow plants to colonize areas that were far from direct water sources, allowing them to transport water up from the roots and into the leaf tissues. Water transport alone was only part of the problem, however: when removed from a moist environment, plants faced two other issues: how to prevent death by loss of moisture through their green parts, and how to spread pollen and reproduce without the aid of water.

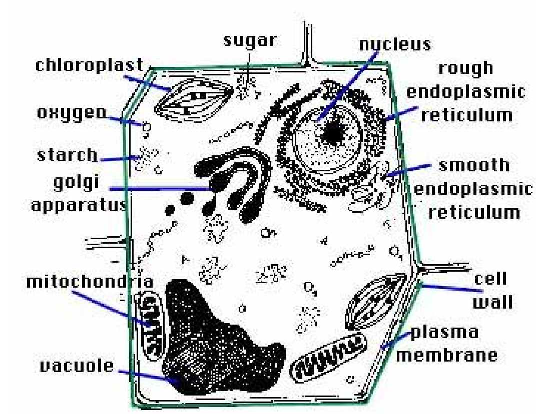
In the first case, water loss was prevented through the development of the *cuticle*, a waterproof protective coating on leaves and stems. This functions quite well – but the plant must also be able to breathe (both CO_2 and O_2), so the *stomata*, small holes in the cuticle, developed. The plants can open and close these stomata as needed, to conserve water during the heat of the day.

In the second case, seeds were developed. Most algae and mosses secrete their sperm, unprotected, into the moist environment. Here, it could survive quite well until fertilization. But in a dry environment, such unprotected pollen would quickly dry out and die: therefore, seeds and protected spores and pollen were developed, basically by surrounding the sperm and eggs in their own, extra-tough, cuticle and providing the plants with enzymes to break that cuticle down when the time was right.

So, in sum, plants developed **vasculature, cuticles and stomata,** and **protected reproductive cells** in order to cope with the dryness of life outside the oceans, lakes and streams.

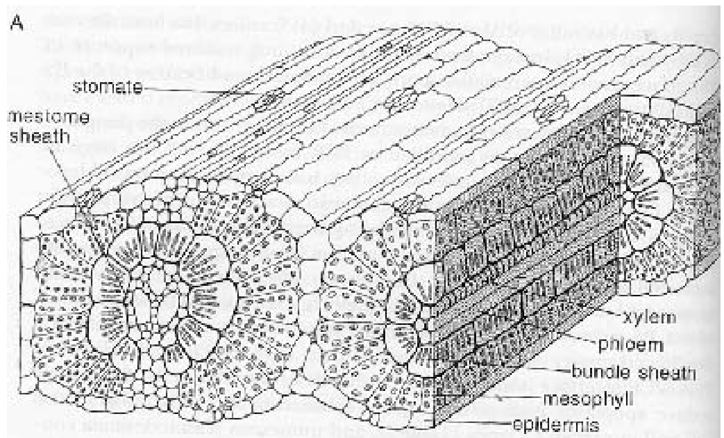
The next major division of vascular plants separated those whose reproductive cells, once fertilized, are left out in the open from those who encase them in an ovary and flower. The first plants are called *gymnosperms*, or ‘naked-seed’; the second are termed *angiosperms*, and comprise all of the flowering plants. For our purposes (since a great majority of the herbs we use are angiosperms), we will continue our discussion in relation to the flowering plants only.

Here, at right, is a diagram of a basic, generalized **plant cell**, the essential unit of all plants. Don’t concern yourself too much with the internal pieces, except from noting that plant cells possess a *cell wall*, which is hard and sturdy and helps give plants their rigidity; *chloroplasts* where photosynthesis takes place; and *sugar* and *starch*, foodstuff for the plant, which we will discuss in the context of nutrient

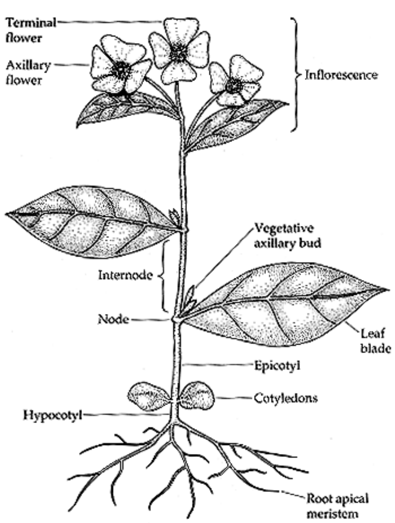


transport. The rest of the structures are mostly concerned with reading DNA and creating proteins for development and regulation of the plant's life.

To get a bit more specific, there are three basic sub-divisions of plant cells, depending on the general purpose they serve in the plant: 1) the 'worker' cells, called *parenchyma*, that contain an abundance of chloroplasts, sugars and starches, and both produce and store energy for the plant; 2) the 'structure' cells, called *collenchyma* and *sclerenchyma*, which die as soon as they are fully grown, but leave their solid cell walls to give structure to the plant; 3) the 'vascular' cells, called *vessel elements, tracheids,* and *sieve-tube elements*, which allow for the transport of water and nutrients through openings in their cell walls.



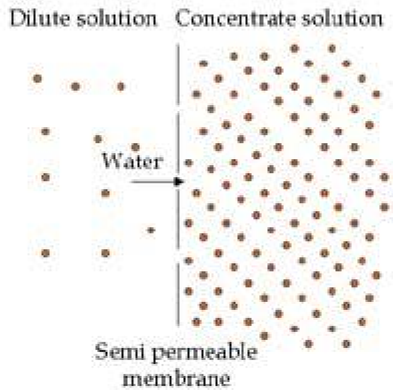
A simple plant **tissue** is diagrammed at right. It consists of three basic layers: the first is the *epidermis*, which is sheathed by the *cuticle*, and is the protective barrier for the plant, as well as containing the *stomata*, or pores; the second is the *mesophyll* or *ground tissue*, which can serve both as structure and as work tissue (in the leaves, for example, it will contain parenchyma loaded with chloroplasts); the third is the *vascular layer*, which consists of *xylem* (for water and mineral transport) and *phloem* (for sugar transport). In the diagram, you are looking at the cross-section of a leaf; however, this basic structure will exist at all levels of the plant, from root, to trunk or stem, and into leaves and flowers.



The basic **parts** of a plant, which determine its structure and shape, are the *roots* (comprised of main root, side roots, and rootlets), the *shoot* (the central stem or trunk, as well as any branching side-stems), the *petioles* (small stems that the leaves and flowers are attached to), and *leaves* and *flowers.* The places where petioles attach to the shoot are known as *nodes*. The first leaves, which are not true leaves, of a seedling are termed the *cotyledons.* The plant grows from a seed, upward and downward, as well as outward (it widens) during the course of its life. Such growth occurs at the *meristems*, which are of two different types: the tips of the shoot and or the root are termed *apical meristems*, and they determine the vertical growth of the plant. The inner tissue of the shoot and roots, called the *cambium* (also known as the *secondary meristem*), also grows, but outward rather than upward. Growth in most plants is *indeterminate*, meaning the plant can expand in a variety of different ways depending on growing conditions and environmental factors. Witness, for example, the difference in trees grown in the open (wide, branching) versus those that grow in a crowded forest (slender and tall).

Plant physiology is incredibly complex, but for our purposes we will discuss three basic processes that occur: the movement of water and ionic solutes, the movement of sugar and other nutrients, and the sensory / hormonal adaptation processes. But before we can enter into plant physiology, we will need to quickly discuss the concept of *osmosis*.

Osmosis is a simple physical phenomenon that involves water and ions or molecules (collectively called solutes) that are dissolved in the water. Imagine you had a container with two sides that were separated by a membrane, or barrier, that wasn't quite waterproof but could still effectively block dissolved substances (a *semi-permeable* membrane). On the right of the container you has water with a high concentration of solutes; on the left, water that had much fewer solutes. Osmosis tells us that the water will attempt to equalize the concentrations on each side: therefore, it will tend to move from the left to the right, diluting the concentrated solution until the two sides are equal. The law of osmosis is summed up this way: **water tends to move *against* the concentration gradient**, from low concentration to high concentration, until equilibrium or balance is reached. It will even work against gravity to do this! And this is where water transport in plants comes in.



How do plants and trees move water sometimes hundreds of feet up their stems and trunks? We already know that they use their *vascular tissue*, specifically the *xylem*, to do this. But how exactly does it work? The sort answer is, by a combination of osmosis and hydrogen bonding. Remember the stomata in the leaves? Just like pores in humans, plants use the stomata to *transpire* water, allowing it to evaporate from their leaves. When that water evaporates, it leaves a little 'gap' inside the leaf where water used to be, and it also makes the water that remains in the leaves a bit more concentrated with solutes. The gap creates what's known as a *meniscus*, a bowl-shaped structure created by the surface tension in the water. Surface tension is there thanks to *hydrogen bonding*, the peculiar quality of water that helps it 'stick together' (remember this from inorganic chemistry?). As water transpires and the meniscus gets stronger, it sets up a *negative pressure* (basically, a gentle vacuum) inside the leaf. The water in the leaf's veins gets sucked up a little bit to fill that gap, and also to dilute the remaining liquid which has become more concentrated due to transpiration. And basically, if water is moving inside the leaf's little veins, it's moving inside the bigger veins, and all the way down the xylem into the roots, where it gets sucked out of the soil to balance out the whole system. So, in essence, **transpiration sets up a pressure and osmotic gradient inside the plant that causes water to move up the stem to replace water that's been lost**. If there's not enough moisture in the soil, the water will come out of the plant's cells, at it will wilt or dry out. If this isn't remedied quickly, the cells will begin to die.

There is an interesting observation related to the osmotic gradient necessary for water absorption. If plants are to function correctly, they need to have more solutes inside them than in the soil – otherwise water will want to move out of the roots, not in! Well, conventional agri-business with its industrial farming techniques has run into this very problem: if you keep adding chemical fertilizers that are predominantly ionic to the soil, and couple this with irrigation using water that is rich in solutes, the soil will become saturated and get to the point where water can no longer flow up the plant's stem to nourish its growth. The soil has lost all its fertility. This is happening in farmland all across our country, and the world. You'd think that science could teach itself a little lesson on this one!

The transport of sugar and other nutrients occurs in the *phloem*, the other type of *vascular tissue* in plants. Simply put, sugars move from sources to 'sinks', or destinations. In the summer, the leaves are sources, producing large amounts of sugar from photosynthesis. The phloem moves these sugars down into the roots, where they are stored for later use, and the remaining are used up by the plant to grow, develop flowers and seeds, and perform other metabolic activities. In the spring, the roots send out their stored sugars to the apical meristems, where they are used to open buds and turn them into leaves for the summer season. The basic difference between sugar movement and water movement in plants is that sugars require energy to be moved, while water just flows almost automatically. Plants accomplish this energy expenditure through the use of special cells, the *sieve-tube elements*, that have membranes on them capable of directing sugar movement in response to energy expenditure, like miniature pumps.

Some plants cannot produce sugars and nutrients in enough quantity on their own. These plants need to latch on to another, more self-reliant species, and take nutrients from it. In this case, we are obviously dealing with plant *parasites*. Other times, certain species will rely on trapping insects and decaying matter from the environment and processing it for their nutrition; these are the *carnivorous* plants.

Through a complex dance of hormones and other chemicals, plants are able to sense and adapt to their environments. They can respond to light, gravity, and touch quite dramatically, and also interact symbiotically with mushrooms (to form *mycorrhizae* in the roots for aid in nutrient absorption) or bacteria (famously, the nitrogen-fixing *Rhyzobium* species that interact with members of the Pea family).

Blue light is mostly responsible for direct plant growth. If you expose a plant to a light source, it will tend to bend towards the light as its apical meristem grows less on the light side, and more on the dark side, causing it to turn. But if you remove blue light from the spectrum, no such bending occurs. Near-red light is responsible for germination in those species whose seeds are light-dependent. Infrared light, which is predominant in the shade, causes light-loving plants to grown longer and leggier, as their apical meristems go into overdrive.

Gravity has a direct effect on meristem tissue, causing roots to bend towards the force and shoots to bend away. There are many theories as to why this is; one interesting one postulates that special compounds known as *amyloplasts*, which are pretty dense, sink to the bottom of cells and, in roots, inhibit cell growth, while in shoots they stimulate it. This causes the tissues to bend in the appropriate direction.

Plants possess an electrical field, like any other living being. This is a scientifically documented fact, and is used to explain how plants can move quickly (like the sunflower following the sun), or change their growth habits in response to touch or wind, becoming stockier and more compact the more contact they receive. It is almost as if the electrical field functioned as a 'buffer', needing to become stronger and more compact to protect the plant from external stimuli. This in turn affects the density of cells and the rate of node / leaf production.

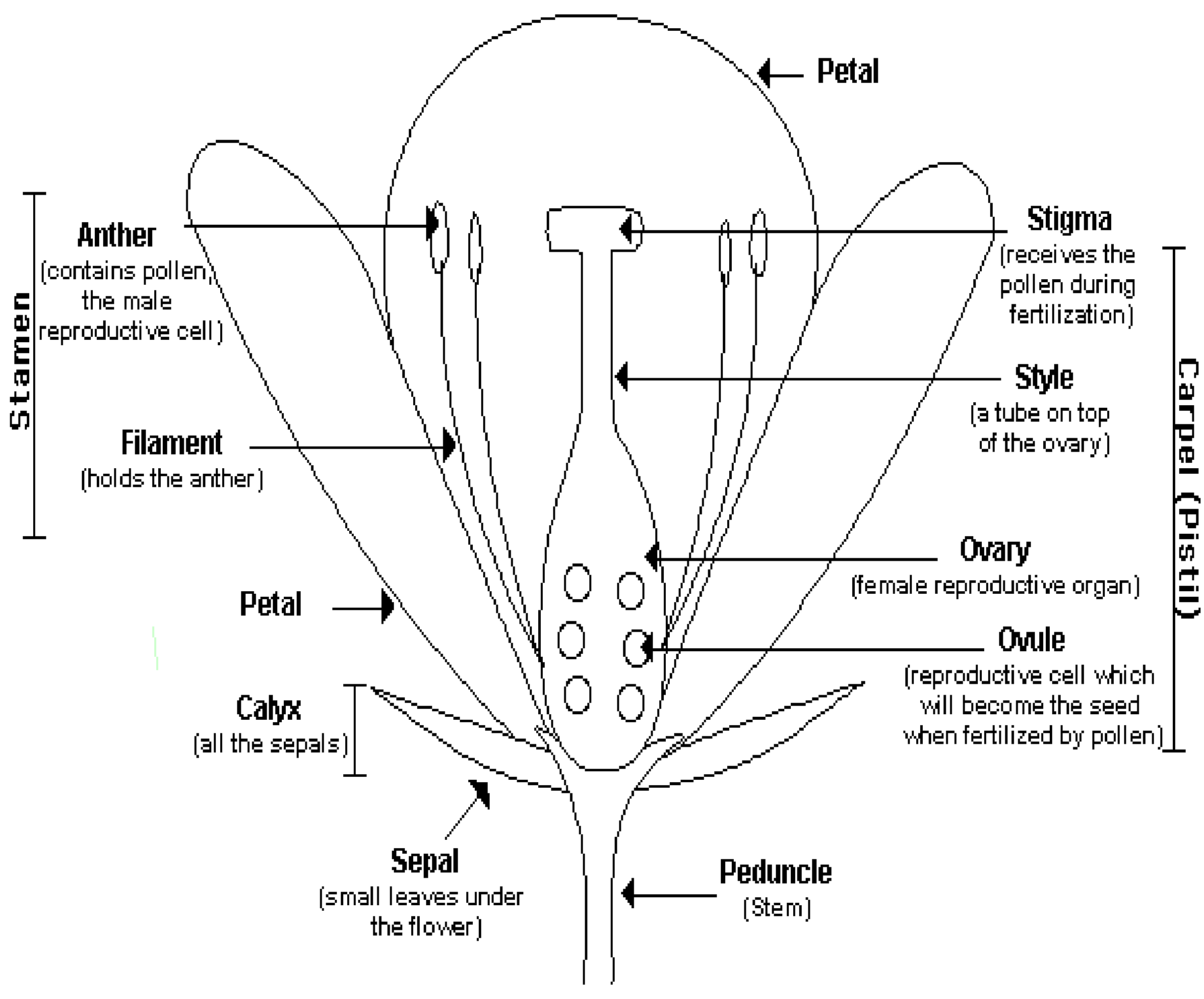
Additionally, plant cells are constantly photosynthesizing (obtaining energy from sunlight) in a process that involves and generates electrical fields and oscillations. The chloroplast, which is contained in the plant cell and carries out photosynthesis using specialized biochemical subunits called cytochromes, generates energy through the conversion of photons (light energy) into electrons (electricity). Reception and conversion of photons occur in a pulsing rhythm and are highly variable – setting up oscillations in every green plant tissue, another electric field phenomenon. Fascinating stuff – I can hardly believe that is all this electrical field can do! Perhaps if it can sense and oscillate (modulate), it can also –dare I say- communicate?!?

Plant hormones are responsible for these changes in growth patterns; they are the ones that 'signal' cells whether to grow more or less, or whether to change into a leaf, flower, or root hair. Most are derivatives of a simple alkaloid structure, with and acid group attached. Some important ones are: *auxin*, which plays a role in differentiation of tissues and in initiating the sensory responses discussed above; *gibberellic acid*, which stimulates growth; *abscisic acid*, which inhibits growth; *kinin*, which promotes cell division; and *ethylene* (actually, just a simple gas) which stimulates the ripening of fruit.

The parts of an 'ideal' flower

'Ideal' just means 'most common', and serves to indicate what basic flower anatomy is, from a general point of view. Different plant families will have very different anatomies, but the basic parts will always remain: the *calyx*, which consists of the *sepals*; the *carpel* or *pistil*, consisting of *stigma, style* and *ovary*; and the *stamen,* consisting of *anther* and *filament.* The calyx grows as the basic flower bud opens; there are always sepals (which used to be the outer 'skin' of the flower bud), and there may or may not be petals (some flowers don't have them). The seed(s) are generated in the carpel (pistil), through fertilization by the pollen contained in the stamen(s).

Here's a cross-section diagram to help in placing the flower parts:



The "Key" system of plant identification
Refer to Newcomb's Wildflower guide

It is perhaps unfortunate, but any wildflower guide will assume you have an actual *flower* in front of you to look at. From that point, based on the shape and features of the flower and coupled with the leaf shape and its placement on the stem, you can easily find what plant family your specimen belongs to, and probably what the actual genus (and even species) may be.

There are three basic questions to ask when looking at a flower:

1. How many *parts* does the flower have?

This refers to the number of sepals and/or petals you will find on the flower. In the case of compound flowers, such as members of the Aster family, you will have to find the smallest piece to be able to count the parts of the flower. Some answers to this question include: *irregular* (like the two-lipped flowers of the mint family, or jewelweed, or orchids for example), a *number from 2 to 7* (indicative of the number of petals, sepals, and / or divisions of the ovary). In addition, many botanical texts will refer to the arrangement of the flowers on the plant, whether they be *whorled*, or tightly wrapped around the stem, like many of the Mint family; in an *umbrel*, with multiple flowers spreading from a central point connecting to the stem, like many of the Parsley family; in a *corymb*, where multiple flowers are spreading from different points at the top of the stem, as in Yarrow; in a *raceme*, or elongated, spiky cluster coming from the top of the stem, as in Black Cohosh; or in a *panicle,* which is basically a set of multiple racemes joined to the stem at different points, like with Scullcap.

2. How are the leaves arranged on the plant?

If you are dealing with a shrub, you have limited your choices and made identification a lot easier. If not, look at how the leaves are arranged along the plant's stem. Some possible ways are: *no leaves* – this one is fairly obvious, and includes some plants like Indian pipe and Ephedra; *basal leaves*, meaning that no leaves extend up the flower stem, like in Plantain; *alternate leaves,* meaning that leaves on either side of the stem are separated by a gap, like in second-year Mullein; *opposite leaves*, meaning that leaves on either side of the stem are at the same spot on the stem, like most Mints; or *whorled leaves*, similar to opposite but consisting of more than just a pair, and arranged radially around the stem, like Cleavers or Bedstraw (members of the Galium family).

3. What do the leaves look like?

This last question usually refines your identification to a single species. Look at each individual leaf, and examine its edges: it may be *divided,* meaning that the leaves are separated into multiple leaflets, like Valerian or Ginseng; *lobed*, meaning it has deep divisions that don't quite separate the leaf into smaller leaflets, like the Motherwort or the Opium poppy; *toothed*, meaning they have a serrated edge, like most members of the Mint family; or *entire*, meaning they have smooth edges, like a Milkweed.

Some common plant families that include useful medicinal herbs, and their general characteristics.

Fabaceae (Leguminosae)
This is the bean and pea family. Characteristic are the flowers, shaped like a small "boat" with sails and a keel, and the leaves, which are usually divided, compound leaves with entire leaflets.
This family is nourishing (to people and to soil) and often used for food, and many of its representatives contain steroidal analogues that can be used in strengthening immunity, adjusting endocrine function, and benignly altering illness. Remember that they are often very powerful due to their chemistry; in older times, much caution and care surrounded their harvest and use.
Licorice, Red Clover, Soy, Astragalus, Scotch Broom

Apiaceae (Umbelliferae)
This is the parsley family. The flowers are usually shaped in an umbel (hence the old family name), though there are some exceptions. Leaves are often deeply lobed, some even lacy. The general nature of their essences is acrid and hot, containing slightly irritating constituents that can be useful in stimulating tissue function and elimination (like *Angelica* for reproductive and GI tissue; *Parsley* for urinary tissue; *Wild Carrot* for uterine tissue). One exception is the true *Poison Hemlock*, the only member of this family to have alkaloidal constituents. Not surprisingly, it is calming and antispasmodic (way too calming – i.e. lethal – if taken in excess). Many members of this family are violently poisonous.

Lamiaceae (Labiatae)
This is the mint family. Flowers have a distinctive two-lipped trumpet shape, and the leaves are usually toothed and opposite on the stems, which is square. Generally, members of this family are valued for their aromatic volatile oils, leading to a generalized use as carminatives and antispasmodics, particularly of the GI tract. Now, a good relaxation in the GI tract can have profound effects overall, so their use is not limited to digestive complaints and often finds a nervine application.
Lemon Balm, Peppermint, Pennyroyal, Scullcap, Motherwort

Asteraceae (Compositae)
This is the sunflower family. Its characteristic is a flower made of many smaller inflorescences, often five-parted, clustered together like a pincushion and surrounded by common "petals" and a corolla of sepals. While there are some generalizations to be made about this family (often antiseptic and lymphatic), it is very broad and diverse.
Yarrow, Echinacea, Aster, Wormwood and the Artemisias, Dandelion, Burdock

Rosaceae
This is the rose family. It is distinguished by a classic five-part flower that looks like an apple or wild rose blossom. This family is usually rich in vitamins and flavonoids, good for the circulation and immunity. There is usually a sour taste, especially in the fruit.
Rose, Apple, Hawthorn

Liliaceae
This is the lily and iris family, who, along with the grains and grasses make up the bulk of the common monocots. They have three or six part flowers, are usually very regular and symmetrical, and possess long, slender, entire leaves that are usually basal. They often contain soothing, mucilaginous constituents although this is not universally true! Many others, like *Blue Flag* or *Calamus*, contain some acridity (although they are also demulcent).
Solomon's Seal, Orris, Garlic

Malvaceae
This is the mallow family, which can be taken broadly to include Brassicas, or on its own. In the latter case, we see variable flowers usually with four or five parts. There is usually a characteristic fuzziness or hairiness ("stipules") on the plant. Constituents include mucilages and demulcents, along with some flavonoid content. Some members are toxic (Rhodonendrons, etc…).
Marshmallow, Laurel, Okra

Papaveraceae
This is the poppy family. There are many different flower presentations (although all tend to be ephemeral and short-lived), and the predominant unifying characteristic of this family is acrid latex (juice) and high alkaloid content. These are usually powerful / poisonous plants.
Opium poppy, California poppy, Celandine, Bloodroot

Ranunculaceae
This is the buttercup family. It is the "oldest" of the flowering plant families, or closest to the root of the taxonomic tree. Its pistils are separate, leading to individualized, separate ovaries. Many members of this family are quite toxic, but some have tempered their medicines to make them slightly more amenable to human use.
Black Cohosh, Hepatica, Stavescare, Pulsatilla

Scrophulariaceae
This is the figwort family. Its members have diverse flowers, but often they look like flowers of the *Lamiaceae* except that they have three protrusions on the lower "lip", instead of two. Often used for "scrophula", or recurrent skin eruptions (therefore, decent lymphatics), they have a broad range of function.
Mullein, Lobelia, Linaria, Foxglove

Araceae
This is the wild ginger family. The flowers are usually very strange, and diverse – some carnivorous plants are members of this family. Their unifying characteristic is a strong acridity and powerful counter-irritating powers.
Wild ginger, Jack-in-the-pulpit

Araliaceae
This is the ginseng family. They all seem to have palmate, divided leaves whole leaflets are toothed. Their flower, with the exception of *Spikenard*, is usually a round, globular cluster. Almost all members of this family contain steroidal saponins, polysaccharides and specialized compounds that have all been valued as adaptogens, blood sugar balancers, and strength/immunity enhancers.
Ginseng, Wild Sarsaparilla, Spikenard, Devil's Club, Siberian Ginseng