THE ORIGIN OF LIFE

Life first appeared on this planet around one billion years ago. The atmosphere then was very different from what it is today. Today's atmosphere is mostly nitrogen (about 78%), oxygen (about 21%), and small amounts of carbon dioxide, helium, and neon. The atmosphere on early Earth, however, was mostly made up of hydrogen, ammonia, methane, and water. In addition, the climate of early Earth was fairly intense; there was more lightning, volcanic activity, and UV radiation than we experience today. According to a theory known as the **heterotroph hypothesis**, life began under these conditions. This is just one theory of many, and this heterotroph hypothesis is no longer accepted as the main theory of the origin of life.

Many scientists have conducted experiments in which they simulated the gaseous conditions of early Earth's atmosphere in a flask. Sparks of electricity were discharged into the gases to mimic lightning, and it was found that under these artificial conditions, amino acids and other building blocks of life (like RNA) formed spontaneously. You already know how important nucleic acids and proteins are to living organisms, so you can probably imagine that these early proteins and nucleic acids may have run chemical reactions and may have had the ability to replicate themselves. Eventually, the first cells were born. They were **heterotrophs**, meaning that they could not synthesize their own food.

Soon, food became scarce. In other words, the heterotrophs required nutrients at a faster rate than they were being formed spontaneously. This led to the evolution of **autotrophs**, organisms that could make their own food using solar energy.

These early cells were **anaerobic organisms**. Earth's early atmosphere contained little or no oxygen, but oxygen was a waste product of the early autotrophs, and gradually it accumulated. As the heterotrophs and autotrophs evolved, they learned how to use this oxygen to produce energy more efficiently. Eventually over millions of years, the oxygen-using organisms came to be the dominant organisms on the planet.

The most important things to remember about all of this are

- Today's atmosphere contains mostly nitrogen and oxygen, and the primary organisms on the planet are aerobic.
- Earth's early atmosphere DID NOT contain oxygen. It contained mostly hydrogen, ammonia, methane, and water, and the primary organisms at that time were anaerobic.

EVOLUTION

Consider a large population of people. Now think about all the genes of all the people in the whole population. This is the population's **gene pool.**

Within the population, some people have genes for dark skin and others for light skin. Some have an inborn gift for music and some for running quickly. Some have genes for brown eyes and some for green eyes. Each person in the population has a distinct set of genes, different from all others. This is called **genetic variability.**

> **The Fossil Record**
>
> Later in this chapter, you will learn how biologists classify organisms. Paleontologists (scientists who study fossils) also classify organisms. All the information that paleontologists have gathered and organized about past life is called the **fossil record.** The fossil record gives evidence about the history of life on our planet. This record of past life also shows how different groups of organisms have changed over time. This is evidence for evolution. Evolution can also be viewed as the gradual change in living things over long periods of time.

The words "genetic variability" tell us that gene pools have many, many different alleles in them. Every person has a set of genes (alleles) that is different from that of every other individual (except for identical twins, who DO have identical genes). What is true for people is true for every species on Earth. All individuals vary in the alleles they possess. For all populations of all species, there is genetic variability.

How does genetic variability happen? The answer is the **random mutation of DNA.** DNA mutation is the basis for genetic variability. DNA mutation simply means that an error was made during DNA replication. Normally, DNA replication is very, very precise. Adenine always pairs with thymine, and guanine always pairs with cytosine. However, very occasionally a mistake is made and adenine may pair with guanine. Or cytosine may pair with thymine. Or some other mistake may occur, which causes base pairs to be mismatched. The point is, the sequence of nucleotide bases in the DNA has been changed.

Remember that the sequence of bases in DNA is used as a template to create the sequence of bases in RNA, and the sequence of bases in RNA is used to create the sequence of amino acids in a protein. This means that if there is a change in the base sequence of DNA, there will be a corresponding change in the base sequence of RNA, and if there's a change in the base sequence of RNA, there's a good chance there will be a change in the order of amino acids in the resulting protein.

Suppose that a particular protein in question was a skin pigment protein. Suppose further that the change in the amino acid sequence caused that pigment protein to appear darker than before the mutation occurred. This would result in a darker skin color than before. If this mutation occurred in a chromosome in a sperm or an ovum, it could be passed on to offspring, and then all future offspring would display the new (darker) skin color. If the mutation occurred in a somatic (body) cell, it would not be passed on to offspring.

Of course, not all individuals in the population would display the results of this mutation (darker skin color). Only the offspring of the individuals in which the mutation first occurred would display the results of this mutation. So, looking at the population as a whole, some individuals would have the original skin color, and some individuals would have the new, darker skin color. Through mutation, a new allele of the skin color gene was created. The population as a whole now displays genetic variability. There are also other sources of variations: independent assortment of chromosomes, crossing over during meiosis, and random fertilization. These all help pass on the mutations that occur.

Natural Selection

As you know, evolution can be described as a change in population over time. Interestingly, the driving force of evolution, **natural selection,** operates on the level of the individual. In other words, evolution is defined in terms of populations but occurs in terms of individuals.

What is the basis for our knowledge of evolution? Much of what we know about evolution is based on the work of Charles Darwin. Darwin was a nineteenth-century British naturalist who sailed the world in a ship named the HMS Beagle.

Darwin developed his theory of evolution based on natural selection after studying animals in the Galapagos Islands and other places.

Darwin concluded that it was impossible for the finches and tortoises of the Galapagos to simply "grow" longer beaks or necks. Rather, the driving force of evolution must have been natural selection. Quite simply put, this means that nature would "choose" which organisms survive on the basis of their fitness. For example, on the first island Darwin studied, there must once have been short-necked tortoises. Unable to reach higher vegetation, these tortoises eventually died off, leaving only the tortoises with longer necks. Consequently, evolution has come to be thought of as "survival of the fittest": Only those organisms most fit to survive will survive. Darwin elaborated his theory in a book titled *On the Origin of the Species.* In a nutshell, here's what Darwin observed.

- Each species produces more offspring than can survive.
- These offspring compete with one another for the limited resources available to them.
- Organisms in every population vary.
- The offspring with the most favorable traits or variations are the most likely to survive and therefore produce offspring.

GENETIC VARIABILITY AND EVOLUTION

When we say evolution, we are referring to changing gene pools. Changes in gene pools can occur through random mutation, as we've seen previously, but it can take a long time for this to have a significant effect on the population. More rapid changes in gene pools are caused by competition. More specifically, because of mutations, genetic variability exists. Because of genetic variability (different genotypes), there is physical variability (different phenotypes). And because of physical variability, some members of a population are better equipped to interact with their environment; in other words, they are better competitors.

Consider a population of frogs. Suppose that half of the frogs have alleles for dark skin color and half have alleles for light skin color. Now imagine that an earthquake separates the frogs into two populations. When it's all over, some frogs are left in Place 1 and others in Place 2.

Places 1 and 2 differ. In Place 1 there are predators that can see light-colored things but *not* dark-colored things. In Place 2 there are predators that can see light and dark colors. What's going to happen?

In Place 1, predators are going to prey happily on light-colored frogs. Many light-colored frogs will be eaten before they're even old enough to reproduce. But the predators won't have much luck with the dark frogs. Many dark frogs will live long enough to reproduce. They'll pass on the alleles for dark skin color to their offspring.

> **Isolation**
>
> The frog populations in this scenario are actually an example of **geographic isolation**. A new species may form when a group of individuals remains isolated from the rest of the species. One well-known example of geographic isolation is occurring in the southwestern region of the United States. Abert's squirrel and the Kaibab squirrel are from the same species. The two groups became isolated as the Grand Canyon formed. They still belong to the same species, but are beginning to evolve and show some differences. It is possible that in the future these squirrels will evolve into different species.

After a few frog generations, the frog gene pool in Place 1 will change. It won't be 50% alleles for light skin color and 50% alleles for dark skin color anymore. It might be 90% alleles for dark color and 10% alleles for light color. Why? The light-colored frogs are dying off—they get eaten before they reproduce. The dark-colored frogs don't have that problem. They're hopping, swimming, jumping—and reproducing.

Meanwhile, what's happening in Place 2? The predators in Place 2 see light-colored and dark-colored frogs equally well, so they eat light-colored and dark-colored frogs in equal numbers. Things are as they were before the earthquake. The gene pool stays 50% alleles for light skin color and 50% alleles for dark skin color.

That's Evolution: The Frogs in Place 1 Evolved

As we said previously, evolution means that a population undergoes a change in the frequency of alleles in its gene pool. If there's a change in the frequency of alleles in a population's gene pool, the population evolves.

Continuing from the example on the previous page, the frogs in Place 1 evolved because their environment changed. When it came to surviving in the new environment, dark-colored frogs did better than the light-colored frogs. They competed better. The frogs didn't know they were competing, but they were. They were competing to survive, and the dark-colored frogs were better competitors than the light-colored ones. Why? Their dark color allowed them to escape their predators.

United We Evolve, Divided We Don't
Remember that while the genetic makeup of an entire population changes over time, the genome of a single individual does not.

Individuals might compete for food, for water, or for all kinds of things in all kinds of ways and for all kinds of reasons. *The better competitors are better at staying alive, and they have a better chance of reproducing.* This is called natural selection. Again, natural selection just means that better competitors are better survivors and have a better chance of reproducing. Nature "selects" them to reproduce.

When organisms reproduce, they pass their genes on to their offspring. In each generation, more and more individuals resemble the better competitors; fewer and fewer resemble the poorer competitors. So the gene pool changes.

Now let's summarize.

> **Evolution** is a change in a population's gene pool. It happens because
>
> - genetic variability allows some individuals to be better competitors than others. In the "game" of natural selection, they win;
> - the winners survive, reproduce, and pass their genes on to their offspring;
> - the offspring have genes like those of their parents. Hence, the gene pool changes. With each generation, it has more and more of the alleles that come from the better competitors.

Being Fit

Another way of saying that an organism is a better competitor is to say that the organism is more "fit." **Fitness** describes an organism's ability to contribute to the next generation's gene pool by producing surviving offspring.

Consider two fish, one that swims slowly and one that swims quickly. Each fish lays 100 eggs. When the eggs hatch, the babies of the slow-swimming fish mostly get eaten by predators. Only 8 of the 100 survive. But the babies of the fast-swimming fish escape the predators more easily, and 32 of the 100 survive. We would describe the fast-swimming fish as being more fit than the slow-swimming fish because it produced more surviving offspring and therefore contributed more to the next generation's gene pool than the slow-swimming fish.

Evolution and Species

Suppose two individuals—such as a bumblebee and a dog—have such different genes that their gametes can't meet and form a new individual. We say the two individuals belong to two different **species.** When we say "different species," we mean individuals that can't produce viable offspring together.

Think again about our frogs, separated by an earthquake. Imagine that, over time (hundreds of thousands of years, perhaps), the frogs in Place 1 undergo so many changes to their gene pool that they wouldn't be able to mate with the frogs in Place 2, even if they were brought together again. The frogs in Place 1 and the frogs in Place 2 would be considered to be separate species. We would say then that evolution caused **speciation.**

> Speciation is simply the formation of a new species, by evolution.

Another way to describe what happened to the frogs is to say they underwent **divergent evolution.** Divergent evolution is the process by which two populations of the same species end up having different behaviors and traits. They used to have similar traits, but as a result of a changing environment they changed, and over time, their behaviors and traits were no longer similar; in other words, they **diverged.** In the case of the frogs, the pressure to change came from the fact that the different environments had different types of predators.

If the evolution of the populations continues, and after a very long time the populations can no longer mate and produce offspring (which is what happened to our frogs), then the two populations are now two separate species—speciation occurred. So speciation is just the extreme form of divergent evolution.

Sometimes, similarities in structure among species give evidence of their evolutionary history. One example is in the forelimbs of all mammals: These all consist of the same skeletal parts. Obviously, the function of a whale's flipper is very different from that of a bat's wing. But these have similar structures, despite their differing functions. **Homologous structures** are common in species that share a common ancestor.

What If Two Populations Become More *Similar* to One Another?

Consider a population of rodents and a population of insects that inhabit the same environment. Suppose that in this particular environment there are many ground-dwelling predators. If the rodents and the insects could somehow get off the ground, they would be safe from the predators. Suppose further that through mutation and genetic variability, and over a long period of time, the insects developed a set of modified legs that could expand to act as glider wings, so that whenever a large gust of wind came around the insects would become airborne. This would keep them off the ground and away from the predators. More of them would survive, and, gradually, the majority of this population of insects would have this "flying" ability.

What about the rodents? What if, also through mutation and genetic variability, over this same long period of time, they developed extensive skin folds between their front and back legs that allowed them to remain airborne when leaping from tree to tree?

Clearly the two populations—the insects and the rodents—could never mate and produce offspring. But they have become more similar to one each other in terms of behaviors and traits. Both populations developed specialized structures that allowed them to "fly." In other words, their traits and behaviors converged. Evolution that results in the production of similar traits and behaviors between two separate populations and/or species is called **convergent evolution.**

Something to remember about convergent evolution is that it NEVER results in speciation (the formation of two separate species). Furthermore, it can NEVER bring two completely different species into a single species.

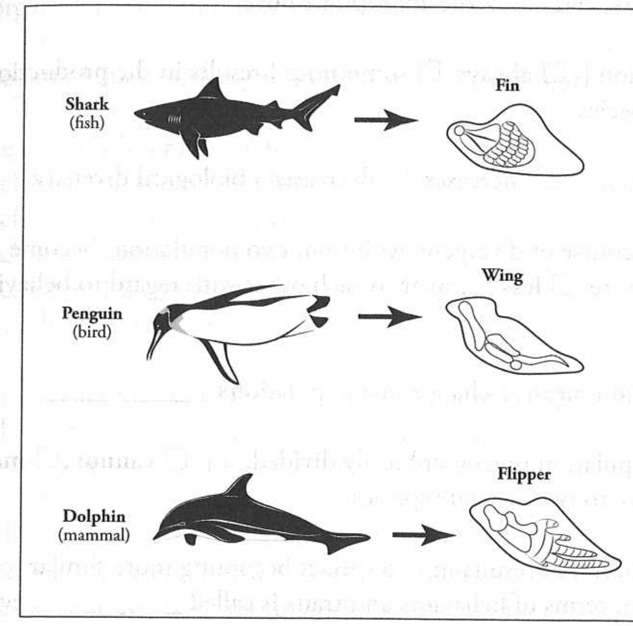
It is important to recognize that not all similar structures are inherited from a common ancestor, or homologous. In the example above, the insects and rodents both have wings. However, these are not homologous structures, they are analogous. **Analogous structures** are similar adaptations that result from convergent evolution.

Homologous vs. Analogous Structures

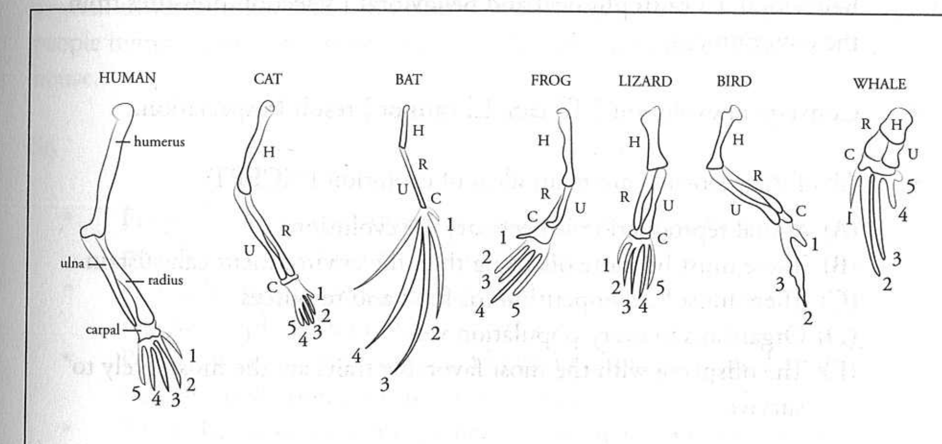
In summary, here are some of the key differences between these two structures.

Type of Structure	Analogous	Homologous
Functionality	Same	Different
Fundamentals	Different	Same
Ancestry	Different (convergent evolution)	Common (divergent evolution)
Examples	Wings in birds/insects	Human arm and whale flipper

The following illustrations also help to show commonalities and distinctions between these two types of structures.



Analogous Structures



Homologous Structures

One Last Thing to Remember

As a population evolves because of pressures from its environment, sometimes structures that were important at one time become unimportant as the environment, the population, and the population's behaviors change. These useless structures become smaller and smaller and eventually are not seen in the organisms except as remnants of their former selves. These remnants are called **vestigial structures.** Examples of vestigial structures are the appendix in humans and leg bones in snakes.

GETTING ORGANIZED: PHYLOGENY

When we organize people and their addresses, we could think like this.

Country • State • County • Town • Street • Street Number • Person

- The country has many states.
- Each state has many counties.
- Each county has many towns.
- Each town has many streets.
- Each street has many street numbers.
- At each street number, there might be several people.

All the people living in one house have a lot in common. They live in the same house, on the same street, in the same town, in the same county, in the same state, in the same country.

All people living on the same street also have a lot in common: street, town, county, state, and country. They don't have as much in common as do the people living in the same house, but they do have a lot in common.

How about people living in the same town? They have a few things in common as well: town, county, state, and country. They have less in common than do the people living on the same street and less still than do the people living in the same house.

So

- People living in the same house have more in common than do people simply living on the same street.
- People living on the same street have more in common than do people simply living in the same town.
- People living in the same town have more in common than do people simply living in the same county.
- People living in the same county have more in common than do people simply living in the same state.
- People living in the same state have more in common than do all people simply living in this country.

Country • State • County • Town • Street • Street Number • Person

Less in common ⟶ ⟶ ⟶ ⟶ More in common

The Same Is True for Species

There are many species on Earth. Biologists assign them "addresses" using this arrangement.

Domain • Kingdom • Phylum • Class • Order • Family • Genus • Species

Less in common ⟶⟶ ⟶ More in common

Here's how to remember that.

Dumb King Phillip Came Over From Germany—So?

Domain • Kingdom • Phylum • Class • Order • Family • Genus • Species

Look at the organizational scheme and realize

- Each domain is made up of one or more kingdoms.
- Each kingdom is made up of many phyla.
- Each phylum is made up of many classes.
- Each class is made up of many orders.
- Each order is made up of many families.
- Each family is made up of many genera (plural of *genus*).
- Each genus is made up of many species.

Realize also that

- Organisms of the same species have more in common than do organisms simply belonging to the same genus.
- Organisms of the same genus have more in common than do organisms simply belonging to the same family.
- Organisms of the same family have more in common than do organisms simply belonging to the same order.
- Organisms of the same order have more in common than do organisms simply belonging to the same class.
- Organisms of the same class have more in common than do organisms simply belonging to the same phylum.
- Organisms of the same phylum have more in common than do organisms simply belonging to the same kingdom.
- Organisms of the same kingdom have more in common than do organisms simply belonging to the same domain.

When we say that organisms have things in common, what we mean is that different organisms came from common ancestors, and they share some traits from those ancestors of long ago. Scientists classify organisms based on their evolutionary relationships **(phylogeny)**. **Taxonomy** is the fancy term given to the science of classification and naming.

Remember this man's name: **Carolus Linnaeus**. Carolus Linnaeus came up with what is known as the modern system of classification, called the **binomial system**. The binomial system of classification is based on a two-part name for each organism. The first part is the organism's **genus**, and the second part is the organism's **species**. The genus is capitalized, but the species is not. Both words are italicized.

Common name:	***Genus***	***species***
Dog:	*Canis*	*familiaris*
Wolf:	*Canis*	*lupis*
Sugar maple:	*Acer*	*sacchaum*
Human:	*Homo*	*sapien*

KEY DOMAINS AND KINGDOMS

For the exam, not only should you know the main characteristics of the domains and each of the six kingdoms, but you should know something about a few of the phyla within those kingdoms. You should also know the general order in which these organisms evolved.

Generally speaking, life began with unicellular anaerobic organisms and became progressively more complicated as these organisms continued to evolve. The following outline is constructed in the order of evolution of the three domains and their kingdoms.

I. Domain Bacteria

This domain is made up of prokaryotes and includes the bacteria most people are familiar with, from harmful disease-causing organisms (like *E. coli*) to the beneficial bacteria used to make yogurt and cheese. They lack a nucleus and any membrane-bound organelles (they have ribosomes, which are not bounded by membranes), and have a circular DNA genome. We will talk more about bacteria in the next chapter.

Domain Bacteria has one kingdom, which is called Eubacteria. This domain (and kingdom) includes the **Cyanobacteria**, which are also known as blue-green algae. The Cyanobacteria contain chlorophyll and can photosynthesize.

II. Domain Archaea

This domain is also made up of prokaryotes, in the kingdom Archaebacteria. Like Domain Bacteria prokaryotes, Archaebacteria lack nuclei and organelles and have a circular DNA genome; however, they also have some features in common with eukaryotes (such as multiple types of RNA polymerase and methionine as the initiator amino acid, just to name a couple). Domain Archaea organisms often live in extremely harsh environments that most other organisms could not tolerate; for this reason they are described as "**extremophiles**" (think of them as the X-Games enthusiasts of the living world). They include the **extreme halophiles** (that live in extremely salty conditions), the **extreme thermophiles** (that live in extremely hot conditions), and the **methanogens** (extreme anaerobes that release methane gas as a waste product).

III. Domain Eukarya

As its name implies, this domain is made up of eukaryotes. All eukaryotes contain nuclei, membrane-bound organelles, and linear DNA. They are divided into four main kingdoms, the characteristics of which are described on the next page.

A. Kingdom Protista

Protists are eukaryotes and contain organelles and a true nucleus. Most are unicellular, but some form colonies, and some are truly multicellular (algae). This kingdom can be divided into three main groups, or ***phyla***: **protozoa** (animal-like protists), **algae** (plant-like protists)—except for cyanobacteria, the blue-green algae—and a few fungus-like **protists.** When you study these phyla, don't get too concerned about learning the "official" names. Most questions on the exam will refer to these organisms using their more common names, shown here in parentheses.

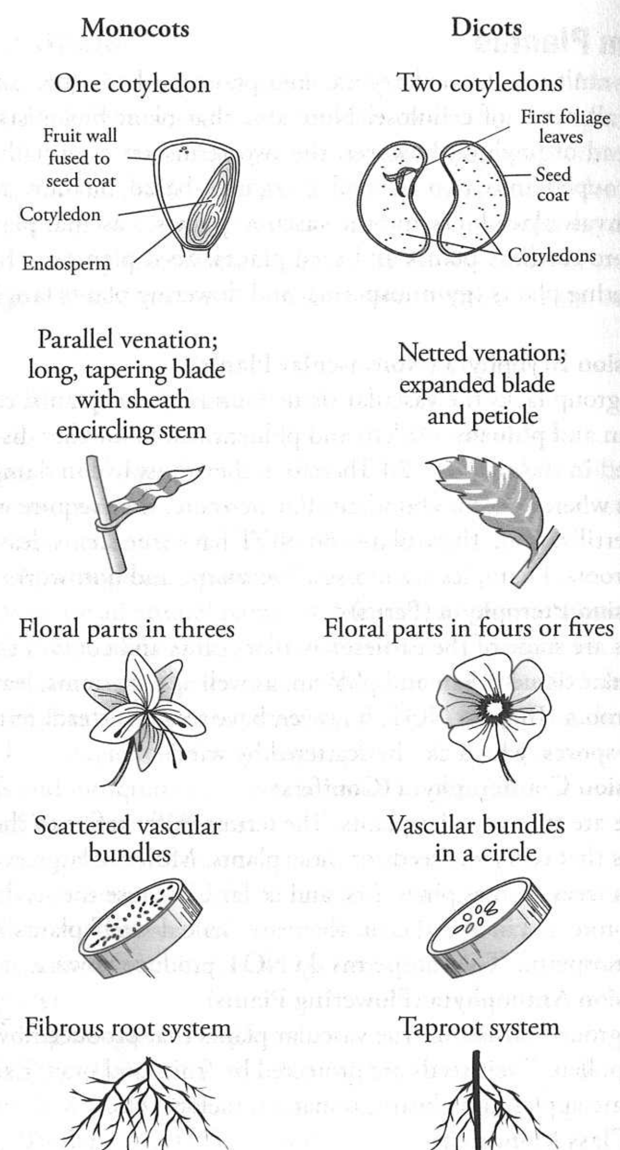
What's in a Name
It might be helpful to remember that a name ending in *-phyta* refers to plants and one ending in *-mycota* refers to fungi.

1) Phylum Rhizopoda (Amoebas)
Amoebas are all unicellular and move about using cellular extensions called pseudopodia. They are found in soils and also in freshwater and marine environments. Some are parasitic, such as those that cause amoebic dysentery in humans.
2) Phylum Apicomplexa (Sporozoans)
Sporozoans are all animal parasites. Some cause serious human diseases such as malaria, caused by the parasite plasmodium. Most members of this phylum have life cycles with both sexual and asexual stages that often require two or more different host species for completion. For example, plasmodium requires both humans and mosquitoes to complete its life cycle.
3) Phylum Ciliophora (Ciliates)
This group of unicellular organisms is characterized by their use of cilia for movement and feeding. An example is paramecium.
4) Phyla Myxomycota and Acrasiomycota (Slime Molds)
These organisms resemble an overgrown amoeba. They contain many nuclei.
5) Phylum Euglenophyta (Euglena)
These are unicellular, photosynthetic algae. They move with a flagellum (a whip-like tail).
6) Phylum Bacillariophyta (Diatoms)
These unicellular organisms have unique glass-like walls and live in both freshwater and marine environments. These walls remain behind when the organism dies and form the sediments known as diatomaceous earths. Diatomaceous earth is useful as a filtering medium. Diatoms make up an important part of the marine food chain and are the most important producers in phytoplankton.
7) Phylum Phaeophyta (Brown Algae)
These organisms are commonly known as seaweeds and are the largest and most complex of the plant-like protists. All are multicellular, and most live in marine environments. Some are very large such as the giant kelp.

B. Kingdom Plantae

All plants are multicellular, eukaryotic, and photosynthetic (i.e., autotrophs) and have a cell wall made of cellulose. Note also that plant biologists use the term **division** instead of phylum; however, the two terms are essentially synonymous. Plants are grouped into two general categories based on how they transport water: the **nonvascular plants** and the **vascular plants.** Vascular plants are further subdivided into **seedless plants** and **seed plants.** Seed plants are further divided into nonflowering plants (**gymnosperms**) and flowering plants (**angiosperms**).

1) Division Bryophyta (Nonvascular Plants)
This group lacks the vascular tissue found in most plants, called **xylem** and **phloem.** (Xylem and phloem will be further discussed in the chapter 12.) Therefore, they must live in damp areas where water is abundant. Furthermore, they require water for fertilization. These plants do NOT have true stems, leaves, and roots. Examples are mosses, liverworts, and hornworts.
2) Division Pterophyta (Ferns)
Ferns are some of the earliest vascular plants and contain the vascular tissue xylem and phloem, as well as true stems, leaves, and roots. They do NOT, however, have seeds. Instead, ferns have **spores,** which can be scattered by wind.
3) Division Coniferophyta (Conifers)
These are true vascular plants. The term **conifer** refers to the cones that carry the seeds of these plants. Most are large evergreen trees such as pines, firs, and cedars. Because the seeds are not protected in a seed coat, these are "naked-seed" plants, or gymnosperms. Gymnosperms do NOT produce flowers.
4) Division Anthophyta (Flowering Plants)
This group consists of true vascular plants that produce flowers and pollen. Their seeds are protected by fruits and nuts. Examples are apples, lima beans, tomatoes, melons, etc.
   a) Class Monocots
   Monocots are named for their single-seed leaves (*mono* = one) called **cotyledons.** Other characteristics of monocots include parallel veins in their leaves, flower parts in multiples of threes, a complex arrangement of vascular tissue in their stems, and a fibrous root system.
   b) Class Dicots
   Dicots have two seed leaves (two cotyledons), netlike veins in their leaves, flower parts in multiples of four or five, vascular tissue arranged in a ring, and a taproot system.



C. Kingdom Fungi

Fungi are all eukaryotic, almost all are multicellular, and they have a cell wall made of chitin. One exception is yeast, which is a unicellular fungus. Most fungi have a filamentous structure and are multinucleate. They lack chloroplasts and are therefore heterotrophic (cannot produce their own food). They lack a digestive system and are absorptive feeders. Absorptive feeding is the process of taking up small organic molecules from the environment. Because they often live on decaying material, they are classified as decomposers.

1) **Division Zygomycota**
This group of fungi reproduces sexually and includes common molds as well as mycorrhizae (mutualistic associations between plant roots and fungi).

2) **Division Basidiomycota (Club Fungi)**
This group consists of about 25,000 members, including mushrooms, shelf fungi, and puffballs. Some are edible.

D. Kingdom Animalia

Animals are eukaryotic, multicellular, and heterotrophic. This is the most diverse of the six kingdoms. You should ***definitely*** know the characteristics of each of the following phyla (but again, don't worry too much about the official names).

1) **Phylum Porifera (Sponges)**
Sponges are **sessile** (nonmoving) animals. They have a perforated body wall made of two layers of cells. Water is drawn through the body wall into the animal, where food in the water is trapped and ingested. Most sponges live in marine environments.
2) **Phylum Cnidaria (Coelenterates)**
These animals have body walls made of two layers of cells and a central, sac-like digestive system. They exhibit radial symmetry. Examples are hydra, jellyfish, and sea anemones.
3) **Phylum Platyhelminthes (Flatworms)**
Animals in this group exhibit bilateral symmetry and moderate cephalization (a head). They include planaria (nonparasitic), flukes, and tapeworms (both parasitic).
4) **Phylum Mollusca (Mollusks)**
Mollusks are soft-bodied animals with hard external shells, such as snails, oysters, and clams. Exceptions are octopi and squid, which have only reduced, internal shells. Mollusks have three major body regions: a **foot** for movement; a **visceral mass**, where organs are contained; and a **mantle**, which may secrete a shell.
5) **Phylum Annelida (Segmented Worms)**
These animals have a closed circulation and a mouth and anus, and they excrete waste through **metanephridia.** The best example is the earthworm; this group also includes leeches.
6) **Phylum Arthropoda (Arthropods)**
This is the most diverse phylum in the animal kingdom, with nearly one million different species and more than 10^{18} (one billion billion) members. Arthropods have jointed appendages, a hard exoskeleton containing chitin, and a segmented body with a head, thorax, and abdomen. They have an open circulatory system and eliminate wastes through **Malpighian tubules.** Arthropods include crustaceans (e.g., crabs), insects (e.g., moths, ants), and arachnids (e.g., spiders). This is the largest and most diverse phylum.
7) **Phylum Echinodermata (Echinoderms)**
These slow-moving or sessile animals exhibit radial symmetry and spiny exoskeletons (*echinoderm* means "spiny skin"). They have a water vascular system ending in tube feet that function in feeding, gas exchange, and movement. Examples are sea stars, sea urchins, and sand dollars.

8) **Phylum Chordata (Chordates)**
Chordates have a hollow notochord, a dorsal nerve cord, pharyngeal gill slits, and a tail (at some point in their development). Almost all are vertebrates. Chordates include fish, amphibians, reptiles, birds, and mammals.

a) **Class Chondrichthyes** (Cartilaginous Fishes)
These fish have flexible skeletons made of cartilage instead of bone and well-developed jaws and fins. They breathe through gills. Some lay eggs, and some bear live young. Examples are sharks and sting rays.

b) **Class Osteichthyes (Bony Fishes)**
These fish have true bone skeletons. They breathe through gills and lay large numbers of eggs, which lack shells. They live in both freshwater and marine environments. Examples are bass, tuna, and trout.

c) **Class Amphibia (Amphibians)**
These animals are well adapted to both land and water. Their eggs lack shells and must be laid in the water. They have an aquatic larval stage and undergo a metamorphosis into a terrestrial adult. They breathe through lungs and/or skin. Examples are frogs and salamanders.

d) **Class Reptilia (Reptiles)**
Reptiles are terrestrial animals with thick, scaly skin adapted to resist water loss. They live well in dry areas, although some inhabit water. Their eggs have shells to resist dehydration, or they bear live young. They breathe through lungs. Examples are crocodiles, lizards, and snakes.

e) **Class Aves (Birds)**
Birds are tetrapods with the forelimbs modified as wings. They breathe through lungs and lay shelled eggs. They are endothermic. Examples are owls, eagles, sparrows, and penguins.

f) **Class Mammalia (Mammals)**
Mammals are endothermic, have hair, and nourish their young from mammary glands. They breathe through lungs. Most bear live young. Examples are rodents, kangaroos, antelope, and humans.

An easy way to remember the order in which phylum Chordata evolved is to remember the word "FARM," but with a "B" stuck in the middle of it—"FARBM."

F: Fish
A: Amphibians
R: Reptiles
B: Birds
M: Mammals