Branches on the Tree of Life
FUNGI

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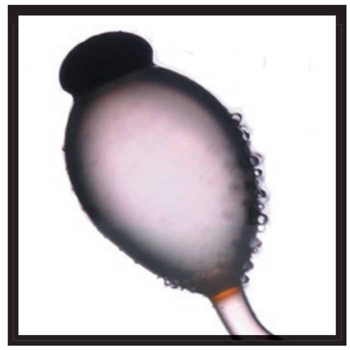
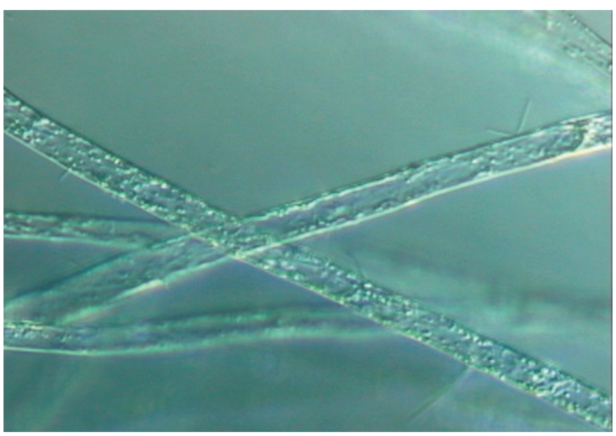
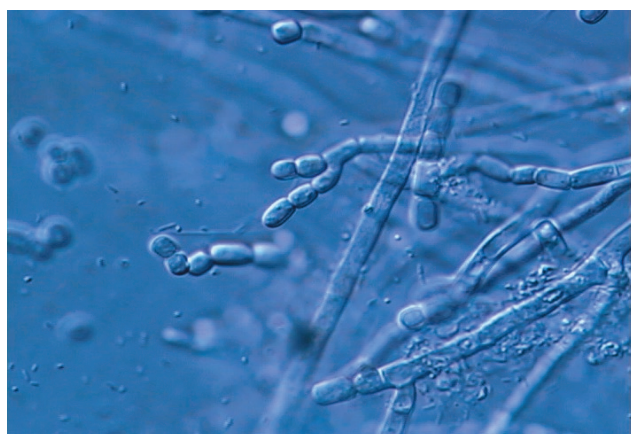


A fallen log on the forest floor reveals the hidden world of fungi. They grow as thread-like structures, called **hyphae**. And they are everywhere … in the soil … on the surface of most organisms … in every rotting creature. This program begins with a summary of the main characteristics of fungi and then goes on to provide details of the four main groups (phyla) of Kingdom Fungi.

Fungi are a very large and important kingdom of organisms. Like plants and animals, fungi are **eukaryotes** – their cells have nuclei. In one group (Zygomycetes), the tubular hyphae are long and have many nuclei inside one cell partition, a condition called **coenocytic**. Other fungi have partitions that break up the hyphae into smaller units. And still others are single-celled.





The thread-like hyphae of most fungi are microscopic in size. Fungi are **absorption-feeders**, releasing their digestive enzymes directly into the surrounding environment. The strong digestive enzymes easily break down cellulose and lignin in decaying plant tissues, presenting a potential problem for the fungus – self-digestion. Thus, fungi have cell walls made of molecules resistant to their own enzymes; linked polysaccharide molecules called **chitin**. The molecular products of digestion are absorbed back through the cell wall. Under ideal conditions, fungi can grow relatively rapidly. Elongation of the hyphae at a growing tip is revealed in the program with time-lapse cinematography on the microscope.

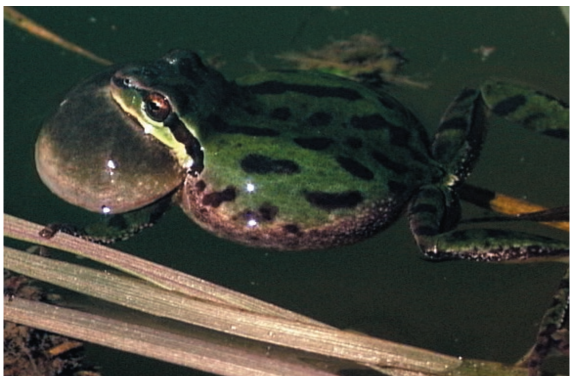
Being absorption feeders, fungi must live **in contact with their food**, which is often decaying plants or animal material. This lifestyle of breaking down decaying material is called **saprobic**. However, many fungi are parasites and a few are predators that feed by trapping animals such as nematode worms.

(Chytrids - Beginnings of Kingdom Fungi)

Estimates for the origin of Kingdom Fungi vary from as recent as 600 million years ago to as long ago as 1500 million years.

Molecular studies of the genes of fungi, plants and animals indicate that fungi and animals are more closely related to each other than to the plant kingdom. Plants probably split off millions of years before the split of animals and fungi. The analysis of gene sequences also indicates that the early fungi were probably similar to the modern fungi known as chytrids.

Modern chytrids play a role in the decay and digestion of many aquatic animals. Recently, chytrids have been implicated in the serious decline of frog populations in many parts of the world. The chytrids grow inside cells of the skin and disrupt the frog's breathing.



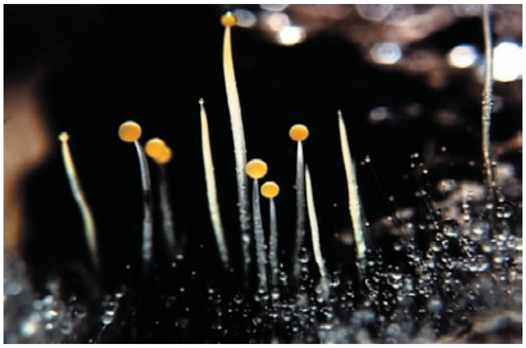
Chytrids are the only group of fungi with swimming spores or gametes. The flagellated cells are produced in ball-like sporangia and when released they swim off to find a new source of food.

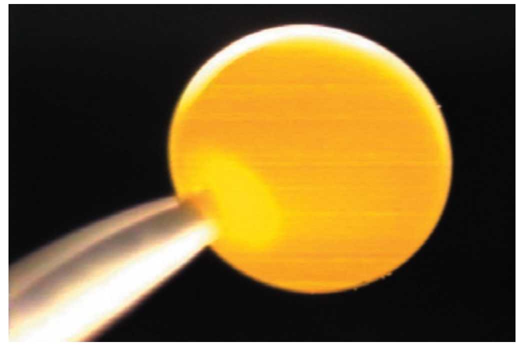
(Zygomycete Fungi – Common Decomposers)

A major split in the Fungus line occurred about 500 million years ago. By this time, early animals were swimming in the seas and plants were beginning to test life on the land. During this period in earth's history, levels of ozone began to build up in the upper atmosphere. This increasing ozone absorbed more and more of the ultraviolet light that had prevented life on land. As animals and plants moved onto land, a new branch of Fungi also diversified – a group that fed primarily upon the nutrients stored by these multicellular organisms –– phylum Zygomycota.

Today, Zygomycetes are some of nature's most important decomposers, and they are particularly good at breaking down animal wastes. Feces is rich in nutrients that pass right through an animal's digestive system, so it is a good habitat for species of Zygomycetes.

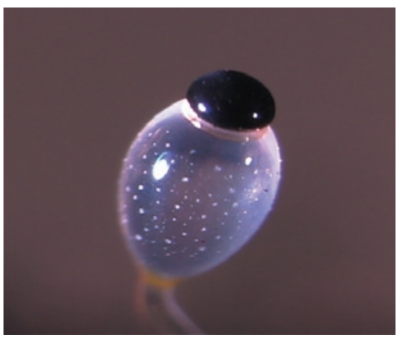
The hyphae of the fungus secrete digestive enzymes and absorb the products of digestion, turning much of the feces into spores. Hundreds of spores are produced in a spore chamber, or "sporangium" elevated on a hyphal stalk. When the spores mature, being up in the air will help them be carried away by the wind to a new source of nutrients.





Soon after Halloween, a candle-cooked pumpkin provides a treasure of nutrients that can be harvested by fungi. Over time, hyphal threads go to work on the fruit. Elevated sporangia grow from every surface. Fruit flies, attracted by the fermenting pumpkin inadvertently pick up the spores and transport then to other fruits in the neighborhood. In fact, fruitflies and other insects play an important role in the decay process by transporting fungal spores from one fruit to another.

Pilobolus and *Rhizopus*



The dung of grass-eating mammals (such as cows, deer, moose, etc.) is home to a fascinating zygomycete fungus known as *Pilobolus*. Inside a cow pie, *Pilobolus* feeds on nutrients that have passed through the cow. Eventually it sends up tubes, each tipped with a fluid-filled bulb. On top of the bulb is a black spore packet. But how does *Pilobolus* get transferred from one cow pie to another? Its simple approach is to have its spores pass through the cow's digestive system and then out with the cow pie as it is deposited. In short, *Pilobolus* spores must be eaten by a cow in order to complete the cycle.

The problem is that cows don't eat grass near a dung pile. It's a behavior that helps them avoid parasites. That's why you usually see a ring of high grass surrounding each cow pie in a field. To be eaten by the cow, *Pilobolus* spores must somehow get far enough away from the cowpie to be on the fresh grass. *Pilobolus* is adapted for this problem. The fluid-filled bulb acts as a water canon, propelling the spore packets up to two meters away from the cow pie.

The program shows an experiment that anyone can do to explore this fascinating adaptation. A dry cow pie is placed in a cookie tin and some water is added to activate the *Pilobolus* spores. The lid is lined with white paper, and a central (1 cm) hole is cut on the top. Then a bright light source is placed over the hole. The results of this experiment (2-4 days later) reveal that Pilobolus can aim its spore packet directly at a light source, no matter where it emerges on the cow pie. It does this by bending the stalk as it grows. The mechanism involves a light-sensitive region at the base of the bulb, which is shaded by the black spore packet only when the "canon" is aimed directly at the light source. Back in the pasture, this behavior assures that spores are fired through gaps in the tall grass around a cow pie.

This dispersal strategy also serves other organisms, in particular, parasitic nematode worms that live in the gut of the cow and send their eggs out with the feces. When the baby nematodes hatch they climb up the *Pilobolus* tubes to the spore packet where they hitch a free ride to their next host.

Another common Zygomycete fungus will occasionally be found in the kitchen cupboard – *Rhizopus stolonifer* – the common bread mold. *Rhizopus* finds new bakery items by means of air-born spores. Once the baked good is invaded, it won't be long before black sporangia full of spores are formed. The hyphae are haploid (1N – one set of chromatids), so these spores are produced by asexual reproduction.

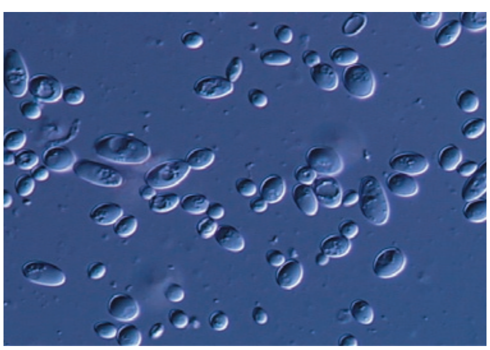
But *Rhizopus* also reproduces sexually. If two mating types are present, hyphal strands, called stolons, line up. Haploid gametes are produced, and fuse together. The result is a diploid sporangium, that undergoes meiosis to produce a new batch of haploid spores. This sexual process offers many opportunities for mixing genes, adding to the genetic variability of *Rhizopus stolonifer*.

Phylum Ascomycota (Cup Fungi and Yeasts)

The **Ascomycetes** fungi probably evolved around 3-400 million years ago. This group is now very prolific, with about 30,000 known species. The group includes the cup fungi and true yeasts.

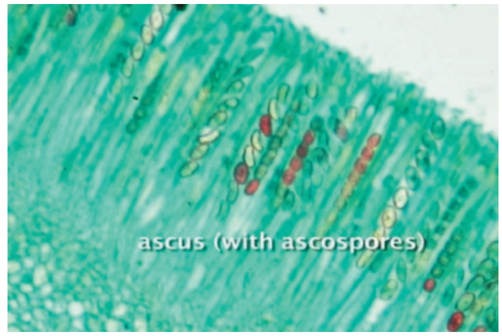
In the early fall, grapes show a dusting of white – actually a coating of fungi. The microscope shows that this coating is made up of yeasts – a large group of single-celled ascomycete fungi. Yeasts are important for their role in the production of bread, wine, beer and many other food products. Yeasts reproduce by asexual division – simply dividing or budding off new individuals.

Another important group of ascomycete fungi are often found on rotting oranges. These fungi can also be grown in culture, and when this was done in the 1940s it was discovered that this mold, *Penicillium*, produces chemicals that killed or suppress competing molds and bacteria. This was the beginning of antibiotics. A different species of *Penicillium* is prized for the flavor it imparts to blue cheese.

Most species of ascomycetes are multicellular, rather than unicellular, and they have fruiting bodies where they reproduce sexually. Morels are a popular edible group of species, but these should be carefully distinguished from the similar false morels and elfin saddles which can be deadly poisonous.

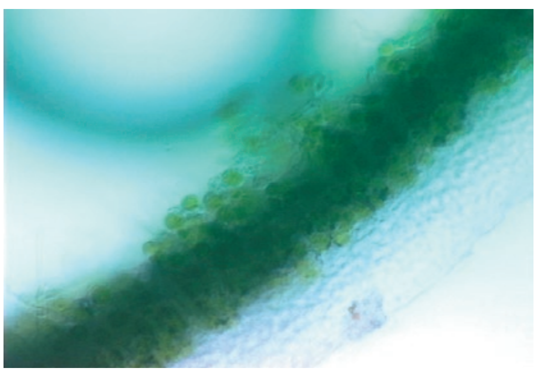
Many ascomycete fungi have cup-shaped fruiting bodies – thus the common name – cup fungi. The cup is a dikaryotic structure (N + N) formed when two mating strains of (1N) hyphae fuse together and grow into a "fruiting body". By examining a thin section of the cup on the microscope, you can discover the characteristic structure of the group – the ascus, a sac containing "ascospores". The ascospores



are produced after the two different nuclei in the dikaryotic cup fuse together and then divide through meiosis into four daughter cells. They divide again giving eight ascospores in an ascus. The advantage of a sexual life cycle is that it keeps reshuffling the genetic deck, allowing an ascomycete to be adapted for the particular demands of its environment. For example, a species of cup fungus, *Ascobolus*, grows on dung piles as a successional species after *Pilobolus* has matured. And like *Pilobolus*, it shoots its spores away from the dung where it more likely to be consumed and passed into a new dung pile by another grazing animal.

Lichens (A special group largely belonging to the Ascomycota)

More than half of the Ascomycete fungi discovered so far are actually members of an intimate partnership. Instead of a saprobic lifestyle where they break down organic matter, and slurp up the digested chemicals, these fungi rely on food provided by tiny green algae (or cyanobacteria) living within their tissues. The algae cells can be viewed by preparing a thin sliver of lichen tissue with a razor blade to be examined on the microscope.

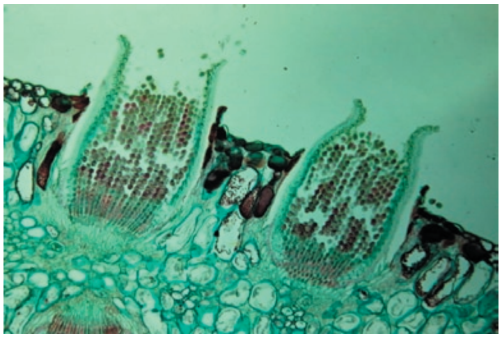


The algae carry out photosynthesis, making energy-rich molecules which they share with the host fungus. The fungus provides a sturdy home. This symbiotic relationship makes it possible for lichens to live on almost any landscape – among other places, they are found on high mountains and on arctic and antarctic rocks. Many lichens have specific mineral requirements such as the bright orange lichens found only where there is an abundance of phosphates.

While most lichens (over 90%) are host to green algae, some contain cyanobacteria. The symbiotic cyanobacteria can convert nitrogen from the air into nitrogen compounds usable by other organisms – a biochemical capacity not possible for the green algae symbionts. When lichens fall from trees to the ground, they decay, releasing nitrogen compounds into the forest. This slow but constant addition of nutrients is vital to forest ecosystems. There are about 20,000 different species of lichens, but only about 25 different genera of green algae and 15 different genera of cyanobacteria living in them.

Phylum Basidiomycota (Mushrooms, Rusts, etc.)

The most familiar phylum in Kingdom Fungi is the Basidiomycota, the group that includes mushrooms. However, the program starts its treatment of this group with two examples that look nothing like mushrooms – corn smut and wheat rust. Both of these basidiomycete fungi are parasitic on other organisms. Wheat rusts and many related rusts have life cycles involving two different host plants. Knowing these cycles, and eliminating one of the host plants, has helped agriculturalists to control the damage done by these parasites. In the case of wheat rust (Puccinia), eliminating the plant, Barberry (Genus Berberris) from areas of wheat cultivation effectively prevents the rust from spreading through the crops.

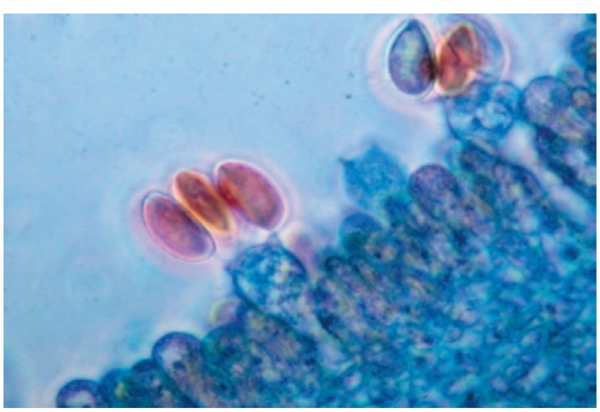


There are over 16 thousand known species of mushrooms including some of the tastiest, and some of deadliest foods in nature. A person should never eat wild mushrooms unless they can be positively identified as an edible species. This is usually a job for trained specialist – a mycologist. For example, *Amanita muscaria* (the "fly agaric") has been eaten in some parts of the world for its hallucinogenic properties, but this is a really bad idea because it is courting with serious illness or even death. The fly agaric contains many highly toxic chemicals in addition to the psychoactive ones. A similar-looking mushroom, *Amanita phaloides*, carries the name "death angel". Only 15 grams of this mushroom will kill a person. Death angel mushroom poisoning causes complete kidney failure, and is an extremely painful way to die.

The mushroom that is visible above the ground is really just the fruiting body of the fungus—an elevated platform for launching air born spores. Most of the fungus is underground -- a mass of hyphae known as a mycelium. As the mycelium grows, activity is often concentrated at the outside edge, thus explaining the formation of circle of mushrooms known as a fairy ring.

Fungi in the ground are the largest, and possibly the oldest, living organisms on our planet. In one Washington State forest, a single individual honey mushroom mycelium was found to cover over 1500 acres. Clumps of genetically identical mushrooms were found scattered over the entire area.

The phylum name, Basidiomycota, comes from the microscopic spore-producing structures known as basidia, a word meaning club-shaped. A single mushroom may produce millions, or even billions of spores. You can get some idea of the scale of spore production by making a spore print – simply cut a mushroom stalk away from the cap, and place the cap on a piece of paper for a day or more. The spores fall to the paper where their color can be noted – a useful piece of information during identification.

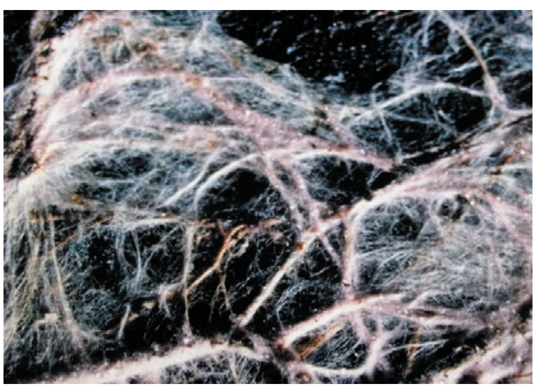


The surface area for spore production is increased in several ways. Gills are a common method, with each gill bearing millions of basidia. Thousands of downward-pointing spines in the coral fungus and the tooth fungi also increase surface area. Pores can increase the surface for spore production. The boletes are one group of pore bearing fungi. Another group is the polypores or bracket fungi. They're common in

almost any forest, where they emerge from the bark of decaying trees. Other Basidiomycete fungi such as the puffballs and earth stars, produce their spores internally, waiting for a disturbance to set their offspring free. One of the neatest spore dispersal tricks is found in the birds nest fungus. It produces spore packets in a cup and lets rain drops toss them out. Stinkhorn fungi secrete a vile smelling substance which attracts flies. The flies pick up some of the sticky, spore-laden ooze, and carry it to other locations.

Mycorrhizae – making plant life easier

If you go searching for edible mushrooms you'll soon find that some mushroom species are only found near certain kinds of trees– a king bolete at the foot of a pine, a chanterelle near a hemlock. If you could look underground, you'd discover that the mycelium of the fungus is tightly pressed to the roots of the tree, or even threaded inside the roots. This relationship is called a mycorrhizal association, and it usually benefits both tree and fungus. The tree gets water, nutrients and minerals extracted from the soil by its partner, and the fungus gets food produced by photosynthesis.



Thousands of plant species have joined forces with mycorrhizal fungi. In fact, it's thought that plants could not have invaded the land without the mycorrhizal partnerships they formed with fungi in the harsh landscape of 400 million years ago.

This plant, Indian Pipe, has no chlorophyll, so it can't make its own food. But it can tap into the mycorrhizal association formed by a tree and a fungus, using the fungus as a conduit to steal food energy from the tree.

SUMMARY

Fungi are eukaryotic organisms that evolved over 650 million years ago, becoming one of the three dominant kingdoms of multicellular life. They usually have a thread-like body that digests food externally and transports it inside through cell walls made of chitin.

Fungi are key ecological participants on planet earth – they recycle dead plants and some animals – they form partnerships with algae to pioneer the landscape, and they join forces with trees to form powerful mycorrhizal associations. Fungi are remarkably successful, with over 70,000 known species, and perhaps a million yet to be described.

With four major branches -- Chytrids, an ancestral aquatic group… Zygomycetes, a branch that includes many of the molds… Ascomycetes, the cup fungi and true yeasts and Basidiomycetes, the mushroom-forming group, fungi provide a fascinating, diverse and often mysterious Kingdom of Life.

NOTE: With tremendous advances in molecular genetics, paleontology, and chemical classification techniques, the phylogeny and classification of Kingdom Fungi has undergone significant revision in recent years. The **Branches on the Tree of Life** program follows these recent developments. In some cases, textbook treatments of the fungi may differ from the approach taken here.

In particular, the group called the imperfect fungi (Fungi Imperfecti or Deuteromycota) has been included in texts as a main branch of fungi in which only asexual reproduction occurs. Traditionally, fungi have been assigned to taxa on the basis of sexual reproductive structures, leaving species apparently lacking sex to be tossed together in something of a "grab bag" group – the Fungi Imperfecti. New techniques now allow these asexually-reproducing fungi to be assigned to specific groups based on chemical affinities and genetic relationships. Virtually all of the economically important organisms of "Fungi Imperfecti" have now been re-assigned to Zygomycota, Ascomycota, or Basidiomycota – thus, the "Fungi Imperfecti" has lost its value as a classification group.

Branches on the Tree of Life DVD - **FUNGI**

Questions

1) Since fungi survive by digesting the molecules of live or decaying plants and animals, how do they avoid digesting their own tissues?

2) What environmental factor limits the growth and survival of fungi?

3) What evidence would biologists use to determine that ancestral chytrids were probably one of the first groups of fungi to evolve?

4) What advantages do swimming spores provide for chytrids? What disadvantages?

5) How do fruits protect themselves from invasion by fungi that can start from spores?

6) In terms of how ecosystems function, why is it important to have decomposer fungi?

7) Describe the life cycle of *Pilobolus*. What causes the ejection of Pilobolus spores, and how are they aimed?

8) What is the role of antibiotic compounds in the survival and success of the species of fungi that make these compounds?

9) Where does meiosis occur in an ascomycete fungus? What stage(s) of the ascomycete fungus has two sets of chromosomes?

10) Lichens are often recognized as "pioneer" species in most ecosystems. What does this mean, and why are lichens well-suited to this roll?

11) What is the most significant difference between lichens that harbor only green algae and those that harbor cyanobacteria?

12) Why are most people very unlikely to see the largest organisms in a forest?

13) Name four methods used by mushrooms to increase the surface area for spore production.

14) How might you explain the observation that when certain trees in a forest are cut down, they will sometimes grow bark over the entire cut surface of the stump and continue living?

15) How is it possible for certain plants to live their entire lives without chlorophyll and photosynthesis?

16) Draw a diagram of the evolution of the four main branches of Kingdom Fungi, and discuss the approximate geological time frame for the splitting off of each phylum lineage and the reasons why these evolutionary splits occurred at those times.

Research Questions:

17) Research the Kingdom Chromista, and describe its relationship to Kingdom Fungi (if any).

18) Investigate what antibiotics other than penicillin are derived from fungi.