This section surveys the major groups of organisms (three Domains and multiple ‘Kingdoms’), except for the multicellular Kingdom Animalia (later section). This overview of life is united by the major themes of macroevolution: from speculations on the origin of life itself, to the origin of multicellular life and the current diversity of living things. Our survey must be brief, given the time available for these topics. Most of the lectures in this section condense and highlight material in your text. You are not expected to know all the details in your text, but it will provide an important reference and source of practice questions.

Throughout this section you will find both taxonomy and classification schemes in flux, particularly for ‘protists’. The ongoing changes represent the attempt to apply modern systematics (i.e. cladistics) to better identify evolutionary (monophyletic) groups. You should be able to justify these changes and be able to read a cladogram. You also should be able to reconstruct the cladograms used in class; they summarize some of the most important information about these groups: synapomorphies (adaptations) and phylogenetic relationships. Molecular characters provide opportunities to identify relationships between all living things, particularly SSU-rRNA (small-subunit ribosomal RNA).

As these groups become better studied, and genetic characters (DNA) more accessible, a new problem has become evident. Although we normally think of DNA as being passed from ancestors to descendants, it also can be passed ‘horizontally’ - from one individual to another – even when these individuals may be from different species or even members of different domains! Examples include: transfer between prokaryotes or conjugation, the incorporation of endosymbionts such as mitochondria and chloroplasts, and viral particles that transfer genes from bacteria to humans. These gene transfers between otherwise distantly related groups suggest that any simple, branching tree cannot possibly describe the true relationships of living forms today. Rather, a ‘Ring of Life’ has been proposed to summarize ancestral relationships between the three Domains. We will provisionally accept the 3 Domain model and consider alternatives (see the first attached diagram, Tree of Life page; we will refer to these cladograms throughout this section: http://tolweb.org/tree/phylogeny.html).

Chapter 25 (25.1-25.4) Early Earth and the Origins of Life

The first part of this course focused on natural selection as the primary agent of evolution responsible for the biodiversity that exists today and in past eras. While evidence continues to accumulate in support of this theory, the origins of life are still shrouded in mystery. [Recall Darwin’s ending paragraph of the Origin of Species and the limits of science suggested by GG Simpson.] Still, a variety of experimental approaches have been applied to the question of life’s beginning – extending the theory of organic evolution. The results of these experiments provide support for a materialistic explanation for the origin of life. We will mention this work briefly in class, and you should take away the knowledge of:

1) the major events of earth’s history (on the scale of millions or billions of year), and
2) a scenario for the origin of life, and some experimental evidence to support it

Be able to cite dates (approximate) for the following events:

- 4.6 bya - origin of earth
- 3.5-3.9 bya - oldest prokaryotic fossil/ origin of life
- 2.7-2.3 bya - oxygen revolution (and earlier origin of photosynthesis)
- 1.8 bya - origin of eukaryotes (fossil)
- 1.2-(1.8?) bya - origin of multicellular life
- 542 mya - Cambrian explosion
- 500 mya - colonization of land by plants/fungi
Be familiar with the timing of these major eras and some of prominent taxa associated with each:

- **Precambrian**
- **Paleozoic**
- **Mesozoic**
- **Cenozoic**

What is the Anthropocene?

Scientists approach the origin of life with the assumption that living cells evolved from simple molecules. We can look at this evolution in terms of four hypothetical steps:

1. synthesis of simple organic molecules (monomers) from inorganic precursors
2. synthesis of organic polymers from monomers
3. aggregation of macromolecules into cell-like structures (e.g. **protobionts** / **protocells**)
4. evolution of a the hereditary material (e.g. RNA)

What is the importance of atmospheric oxygen to the origin of life (both its early absence and later accumulation)? Much more about the geological history of the earth is contained in this chapter, e.g. plate tectonics. Read it, learn it & enjoy it. Except for the specifics mentioned above, it will not be on the test.

**Chapter 26 (26.6) From Two Kingdoms to Three Domains (see Three Domain Cladogram handout)**

We reviewed most of this chapter (**systematics** and **cladistics**) in our first section. The last section describes the change from the Two Kingdoms of Linnaeus, to the Five Kingdom system and on to the current Three Domains and the ‘Ring of Life’. You should become familiar with the similarities and differences of these hypotheses, and the potential problems and benefits associated with these schemes.

**Be sure to know the names of the (old) five kingdoms & (new) three domains**, why the three-domain system was proposed (deepest split amongst living beings) and the problem with the ‘Kingdom Protista’. We will selectively focus on the newer groups identified in your text. For most groups of prokaryotes and protists, we will not be concerned whether their new ‘group/clade’ represents a phylum or kingdom.

You should be able to list the characters for the three domains provided by your text (Table 27.2, handout; Canvas, Modules) and draw a cladogram (tree) with these characters. According to this hypothesis, which two Domains are most closely related? What three synapomorphies support this hypothesis?

**Chapter 27. Prokaryotes and the Origins of Metabolic Diversity**

Prokaryotes are the most abundant group of organisms, with the longest evolutionary history, and the greatest diversity of nutritional modes. They evolved all of the major metabolic pathways. The rest of the living world (Eukaryotes) depends on their continued existence today. Be able to describe their basic characteristics (Bacteria): size, organismal structure (e.g. single-celled, colonial), type of cell wall, condition of DNA within cell, presence or absence of other organelles, flagella, and reproductive mode (much of this is review from Bio181 and incorporated on Table 27.2).

**NOTE: the description of ‘Prokaryotes’ in your text refers primarily to Bacteria. The characters described may not be representative of the Archaea.**

Describe three characters (size, shape, stain) used to distinguish prokaryotes with a light microscope. How useful are these methods for determining phylum? species?

In the five-kingdom classification, where do the prokaryotes fit in? How does this differ from the three-domain classification? Which scheme would a cladist prefer? Why? Be able to list at least three characters that support the three-domain system.
Be able to describe how rapid reproduction (short generation times with binary fission) and mutations allow for rapid evolution in this group. Moreover, Bacteria can exchange genetic material in three ways: transformation, transduction and conjugation. Describe.

Be able to define, describe and give an example of the four modes of nutritional acquisition found in prokaryotes. Which of these are also found in eukaryotes? Which are unique to prokaryotes?

Be familiar with the general metabolic pathways that evolved in prokaryotes: glycolysis, chemiosmosis, photosynthesis, aerobic respiration and nitrogen metabolism & fixation. Which are unique to prokaryotes? Which are found in eukaryotes? Which are associated with the endosymbiotic theory? For those pathways not found in eukaryotes, be familiar with ongoing symbioses between prokaryotes and eukaryotes (e.g. nitrogen metabolism).

Prokaryotes lack chloroplasts and mitochondria, yet the endosymbiotic theory suggests that chloroplasts and mitochondria arose from bacterial symbionts. What structure(s) found in living prokaryotes support this theory?

The Archaea (Archaebacteria) represent many ‘normal’ prokaryotic forms as well as their more famous extremophiles, organisms found in extreme temperatures or salinities, and the methanogens. Some thermophiles associated with hydro-thermal vents of may resemble the earliest life forms.

The Domain Bacteria includes both the heterotrophic bacteria and the Cyanobacteria. What types of nutritional mode are found within these groups? Be familiar with the three types of symbiosis (mutualism, commensalism, parasitism) and one example for each that includes a prokaryote. What major ecological roles do bacteria play in the modern world? In what ways do humans attempt to use bacteria?

Chapter 28. ‘Protists’ and The Origins of Eukaryotic Diversity

As discussed above, the old ‘Kingdom Protista’ (5 kingdom version) was a catch-all grouping of a diverse assemblage of Eukaryotes that lacked the distinct characteristics of the three ‘crown kingdoms’ K. Animalia, K. Fungi and K. Plantae. ‘Protists’ were generally defined as simple, single-celled (mostly) eukaryotes associated with damp or aquatic environments. They were often grouped by their body shape or ‘grade’, and mode of nutrition:

- Algae – photosynthetic forms (autotrophic)
- Protozoa – animal-like forms (heterotrophic): flagellates, ciliates and amoeboid forms

These terms as well as ‘protist’ will be used, but not as taxonomic terms.

‘Protists’ represent the richest group in terms of eukaryotic diversity. However, as originally defined, the ‘Protista’ were either paraphyletic or polyphyletic (or both). The current effort to disband the ‘Protista’ in favor of new monophyletic groups (aka ‘Supergroups’) reflects the cladistic approach to systematics.

The Tree of Life Web Project provides regular updates on ‘protists’ and other taxa (see handouts and website: [http://tolweb.org/tree/phylogeny.html](http://tolweb.org/tree/phylogeny.html)). Much progress has been made over the last few years in resolving ‘protists’ into a few Supergroups. Twelve years ago, the list of ‘unaffiliated’ groups on the Tree of Life ran three pages, with nearly 60 monophyletic groups identified! The most recent update (October, 2009) leaves only 16 taxa in the ‘protists of uncertain placement’ section. Initially, SSU-rRNA was used as a primary character to define these groups; nuclear DNA and other molecular comparisons have provided further support for the current phylogeny.
The Tree of Life differs only slightly from your current text, but is worth reading for its more detailed description of synapomorphies and related discussion. Previous editions of your text had ten or more Supergroups or ‘Candidate Kingdoms’ (6th & 7th editions). The 8th and 9th editions referred to five Supergroups, and your current text names only four Supergroups, identical to the Tree of Life.

We will accept these four Supergroups within the Domain Eukarya:

- **Excavata**
- **SAR**
- **Archaeplastida**
- **Unikonta**

Be familiar with the synapomorphies listed for each group and know all names in bold. We will attempt to identify groups by other morphological structures as well.

Chapter 28 begins with a discussion of the origins of eukaryotes, particularly the endosymbiotic theory. Be able to describe the endosymbiotic theory and several lines of evidence that support this theory. Also, be able to refer to this idea when discussing different groups of algae and the origin of green plants. What other changes were necessary for the evolution of the eukaryotic cell? Be able to provide at least one hypothesis that might explain the evolution of one of these characters.

**Supergroup Excavata**

Many of these organisms have an excavated groove on their side used in feeding. They also are united by cytoskeletal features. Included are two main branches, the Diplomodida/Parabala group and the Euglenozoa. The diplomonad/parabaslid clade share unusual mitochondria (or absent, by loss) and often live in anaerobic environments.

The Euglenozoa consists of the older Euglenophyta (note the ‘–phyta’ ending for plant or algae) and a group of flagellates (Zoomastigophora, or just Mastigophora) now known as Kinetoplastids. These groups share an unusual crystalline rod in their flagella. The euglenids (e.g. Euglena) are primarily autotrophic, but have heterotrophic capabilities (i.e. mixotrophic). The kinetoplastids are typically symbionts. Be familiar with the examples seen in lab (e.g. Trypanosoma and those seen in termite guts).

**Supergroup SAR (Straminopila, Alveolata & Rhizaria clades)**

This group combines two previous supergroups, the Chromalveolata and Rhizaria. The Chromalveloata was defined by a hypothesized secondary endosymbiotic event (a red alga as the endosymbiont). Note: If this hypothesis is true, photosynthesis has been lost in several of the chromalveolate lineages. The Chromalveolata include the Alveolata and Stramenopila. Some question this event, and the exact relationships between these two groups. Still, we will provisionally accept this grouping. Molecular evidence now supports the inclusion of the Rhizaria as the sister group to the Chromalveolata, hence the new Supergroup.

The Stramenopila unites several groups of algae and the water molds. Be familiar with stramenopili (hair-like structures on the flagellum), a synapomorphy of the group. This group is also known as the Heterokonta, a reference to their two different flagella (one with stramenopili and one without). Note the chloroplast similarities (e.g. chlorophyll c) that had earlier suggested relatedness between the algal groups. The term algae refers to a grade of organization. Is the term algae useful in classification?

Know these groups: Bacillariophyta /Diatoms, Phaeophyta, Chrysophyta and Oomycota. What other characteristic links the water molds to these algae?
Supergroup SAR (Straminopila, Alveolata & Rhizaria clades) - continued

The **Alveolata** includes three groups: **Dinoflagellata**, **Apicomplexa** and **Ciliophora**. Be familiar with the character that unites this group, **alveolae**, and be able to identify the members of this group particularly the ciliates (e.g. **Paramecium**).

The **Rhizaria** include amoeboid forms, mostly with thread-like pseudopodia. Your text mentions three groups: **Radiolaria**, **Foraminifera** and **Cercozoa**. Read about these groups and be able to place them in their superorder. Note: The Tree of Life cladogram includes the Rhizaria in the Chromalveolata clade.

**Supergroup Archaeplastida**

The **Archaeplastida** are named for the origin of their chloroplast: the initial source of all eukaryotic photosynthesis. An ancestral archaeplastidan engulfed a cyanobacterium that gave rise to the chloroplast. The group split into two groups, the red algae, or **Rhodophyta**, and the green alga/land plant clade, or **Viridiplantae**.

The **Rhodophyta** are well defined by their unique combination of photosynthetic pigments. What other group has **phycobilins**? What are the advantages of red pigments?

The **Viridiplantae** is a new group that includes the **Chlorophyta** (green algae) and the **K. Plantae** or **Embryophyta**. They share several characters including identical photosynthetic pigments, which is why both groups appear green. Which of the groups is monophyletic? We will focus on the plant members of this group (Chapters 29, 30 & 35) with a quick review of the green algal relatives.

**Supergroup Unikonta**

This new group includes some classic protozoa, e.g. **Amoeba**, as well as two of the multicellular ‘crown’ kingdoms, the Animalia and Fungi. Synapomorphies include a single flagella (in some) and a single centriole (a second gained in some). The Unikonta consist of the **Opishtokonta** (including Animalia and Fungi, with a single posterior flagellum) and the **Amoebozoa**. Monophyly of each of these groups is better accepted than the hypothesis for the united **Unikonta**. We will study the **Animalia** and **Fungi** separately. Be familiar with the **Amoebozoans** below:

- **Chaos (Pelomyxa)**
- **Amoeba**
- **Plasmodial** and **Cellular Slime Molds**

Did multicellularity evolve once, twice, three-times, or more?

**Chapter 29 & 30. Plant Diversity I & II: How Plants Colonized Land & The Evolution of Seed Plants** [additional material in **Chapter 38. Plant Reproduction & Development**]

**Kingdom Viridiplantae** Chapters 29 & 30 describe the four major ‘grades’ in the Kingdom Plantae and associates each group with one or more adaptations. Note most of these grades represent more than one lineage. As the branch points between lineages are better resolved, new taxa are being named. Another major issue in plant systematics is resolving the relationship of the Plantae to the various groups of green algae. Green algae and plants share structural similarities (e.g. their chloroplasts have the same photosynthetic pigments, storage product, etc.) and molecular evidence supports their common ancestry. As the closest living relatives of the plants are identified, new clades are named to include them with the plants. We will note general relationships, without much detail on which algae are the closest relatives.
Be able to define plants by their unique suite of characters, the evolutionary relationship between the Embryophyta (Plantae), Chlorophyta, and Charaphyceae (once considered part of the Chlorophyta). Which are monophyletic groups? In particular, be able to reconstruct the Plantae Cladogram handed out in lab. It includes the main groups of plants and their adaptations/synapomorphies.

The origin of plants is associated with the evolution of the embryophyte condition. Be able to describe this condition and its advantages to plants. Early plants are also associated with substances that protect them from dessication. Be familiar with the origins of sporopollenin and the cuticle with stomata in some plants. Which of these evolved uniquely within the plants?

One of the critical evolutionary trends in plants is the change from a gametophyte dominant / sporophyte dependent condition to the angiosperms where the sporophyte is dominant and the gametophyte is dependent. We will include extra details about angiosperm reproduction from Chapter 38.

Living plants can be divided into four main grades. Each is often represented by an earlier taxonomic term to describe the members of the clade, similar to our use of ‘protista’, although these groups are no longer considered monophyletic. Be able to describe each group in terms of their new features (adaptations) and approximate dates of their origin. The grades are:

- **Nonvascular plants** (vs. Vascular plants) aka ‘bryophytes’ include the *Bryophyta* proper (mosses), *Hepatophyta* (liverworts) and *Anthocerophyta* (hornworts)

- **Vascular plants: Tracheophyta** (monophyletic)
  - Seedless Vascular plants (vs. Seed plants) aka ‘pterophytes’ include the *Pterophyta* proper (e.g. ferns) your text uses a new term the *Monilophyta*, and the *Lycophyta* (club mosses)
  - Seed plants: Spermatophyta (monophyletic)
    - Gymnosperms (monophyletic?): ‘naked seeds’ – groups below
    - Angiosperms/Anthophyta (monophyletic): ‘contained seeds’ (fruit)/flowering plants

Be able to describe the environmental differences between aquatic and terrestrial life, and the evolution of plants in this new environment. How does the environment differ for parts of the plant living in the soil vs. the air? What specializations occur in the newly evolved roots and leaves?

Be able to define the Pterophyta (Monilophyta) and discuss these plants in light of the evolution of vascular tissues. How do pterophytes differ from bryophytes in life history? When did vascular plants evolve? How similar is the ancient *Aglaophyton* to the modern *Psilotum*? What factor(s) may have selected for the sporophyte generation to become dominant? What benefit may plants enjoy from maintaining an alternation of generations?

What adaptations are found in the Gymnosperms (Coniferophyta) that might explain their success relative to the pterophytes? (consider changes in whole structure and reproduction). When did gymnosperms evolve? When did they dominate the flora of the earth? How are the conifers important to humans?

* The current text (10th edition) uses *Monilophyta* for the first time, as does your lab manua.. The original *Pterophyta* all seedless vascular plants: club mosses (etc., current Lycophyta) as well as ferns and their closer relatives. Various classification schemes and taxonomic names can be found in current literature. Be able to recognize *Pterophyta* as (mostly) equivalent to your text’s *Monilophyta*. 
What new reproductive adaptations occur in the Angiosperms / Anthophyta? Be able to discuss their importance in the success of this group. Also, be able to describe an additional adaptation of the Angiosperms. How are the angiosperms important to humans?

What is coevolution? Be able to provide examples that shaped the angiosperms.

Where does mitosis and meiosis occur in the life cycles of each of the representative phyla of plants (mosses, ferns, pines, and flowering plants)? For each group be able to identify, define or describe the reproductive parts and processes:

- gametangia
- sporangia
- microgametophyte
- megagametophyte
- pollen tube
- embryo sac
- generative cell
- double fertilization
- ovary
- ovule
- megaspore
- microspore
- endosperm
- sepals
- petals
- stamens
- anther
- filament
- pistil / carpel
- stigma & style
- seed
- fruit
- cotyledon
- micropyle

Be able to describe the four evolutionary trends found in flowers: 1) Reduction in number of parts, 2) Fusion of parts, 3) Radial -> Bilateral symmetry, and 4) Change in ovary position from superior to inferior. In reference to flowers, be able to define the terms complete / incomplete and perfect / imperfect.

Be able to identify the parts of the developing embryo as seen in lab.

**Chapter 35. Plant Structure & Growth**

Our focus in this chapter is on the general morphology and anatomy of flowering plants. Angiosperms are divided into two distinct classes: C. Monocotyledones (monocots) and C. Eudicotyledones (previously, Dicotyledones or dicots). Descriptions of plant parts differ between these classes.

Be able to identify and describe the differences in embryos, leaf venation, stems, roots and flowers for the dicots and monocots. Which of these groups often has secondary growth?

What are three types of roots? What are four functions of roots?

What is the shoot system? Be able to define and describe: node, internode, apical bud, axillary bud, petiole, and blade. What is the purpose of the apical bud? axillary bud?

What happens if the apical bud is removed?

Be able to name the five cell types and three tissue types. Which cell type is most common? Mature parenchyma cells may play many roles, identify three. Can a mature parenchyma cell give rise to an entire plant? Can an animal cell do this?

Describe the different types of vascular tissues and cells:

- xylem
- tracheid
- vessel element
- phloem
- sieve tube member
- companion cell

Which of these are alive at maturity? What is their function(s)?
What are the three meristematic tissues? What mature tissues do they give rise to?

What is the arrangement of these tissues in the primary root? Why are the vascular tissues sequestered inside the stele? How does this arrangement of vascular tissues differ from that found in the stem of a monocot? In the stem of a dicot?

What are the three zones found in root tips? What is the function of the root cap? Where do lateral roots arise? What is the function of root hairs, where are they found, and why not closer to the root tip? Why are the apical meristems of shoots NOT covered by a shoot cap?

How does the vascular arrangement of the shoot differ from a leaf? Note: this difference is one way that you can distinguish between the petiole of a complex leaf vs. a small stem.

Be able to identify and describe the function of these cells or structures in a leaf:

upper & lower epidermis  palisade parenchyma  stomata  guard cell

What is the difference between primary and secondary growth? Which is only common in the dicots? Which gives rise to wood? What cell types make up wood? Be familiar with the different arrangement of tissues found in secondary growth.

Chapter 31. Kingdom Fungi

We will likely get to the Fungi after Exam II and include with their close relatives, the Animalia. Coverage will may limited by time. Be sure to know the synapomorphies/characters of the Fungi and the Phyla described here; their life cycles and role in the ecosystem as decomposers, parasites, mutualists (lichen and mycorrhizae) and the importance of yeast to humans.

Be able to define this kingdom by its unique combination of life history (haploid when multicellular), mode of nutrition (heterotrophic absorbers), and structure (e.g. hyphae, chitinous cell walls). How are hyphae adapted to an absorptive mode of nutrition?

Phylum Chytridiomycota was recently added to this kingdom. Why? What does the presence of flagella in this group suggest about the origin of K. Fungi? What other Kingdom is closely related to the Fungi?

Know the three traditional groups of fungi. How does differences in plasmogamy, karyogamy, and length of dikaryon/heterokaryotic condition define the different phyla of fungi? What is the relationship between the dikaryon/heterokaryotic condition and exposure to the air? (sun?)

Fungi are often categorized by their ecological roles, as either saprobes, parasites, or decomposers. They are also characterized as molds, yeasts, lichens & mycorrhizae. Be familiar with each of these types, but be aware that these forms represent many independent events of convergent evolution.

Be able to describe three types of symbioses: mutualism, commensalism, parasitism. Which two of these are common in fungi? How important is the fungal role of decomposer in the world’s ecosystems?

Be able to describe fairy rings as an example of fungal growth and life history.

Be able to discuss and explain the conditions associated with sexual and asexual reproduction in the fungi. What are the Deuteromycota?