# Biosystematics

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# 1 Introduction

Biosystematics seeks to classify ALL LIFE ON EARTH. As a result, people often view this subject as dense. Granted, this handout has a LOT of info, but that does not mean that it is impossible to learn or a waste of time. Take things one section, or even one subsection, at a time. People have spent millennia deciphering the book of life, so no one expects you to finish it in one day. Read this lesson repeatedly, as many times as you need to fully appreciate all the details. I believe the stories within will be worth the effort.

If a source for an image is not specified, then it is from *Campbell's Biology* $12^{th}$ *Edition*.

## 1.1 How to use this Handout

For this handout:

- **Key words will be bolded.**
- Obscure info will be in gray.
- Outdated info will be in red.
  - Biosys is an active field with new relations constantly being discovered! As a result, major changes can occur within a relatively short period. Here, any info that was in *Campbell's* $8^{th}$ *Edition* and has been updated in *Campbell's* $12^{th}$ *Edition* will be in red.
- Examples will be in blue.
  - Each example will have either no stars, *, or ** to indicate how obscure it is. No stars is standard knowledge, * can show up in competitions, and ** is obscure trivia that will likely never be of use.

Since this is a dense lesson, you will likely have to read through it many times before you can fully appreciate the knowledge it contains. I would recommend reading only standard text, making an effort to memorize bolded words on your first read-through. If you're ambitious, then you can start learning the gray info. If you're *really* ambitious, then you'll learn the examples, starting with the least obscure and working your way up to the most obscure.

## 1.2 Tips

In this handout, I will share the approaches that I have found to be useful when studying biosys.

First, I will include details for each organism in a bullet-point style. This serves two purposes. Since there is so much info in biosys, bullet points allow me to condense that info into the essential points. If you would like more elaboration, then you should read the phylogeny chapters in *Campbell's Biology*! Also, the diversity of life has allowed many fascinating features to develop. By looking at what makes organisms unique, it helps me become interested in them, making them easier to remember. In addition, it is these unique features that questions tend to ask about.

Second, I will introduce these organisms in a step-like fashion, from single-celled bacteria to multi-cellular humans. **NOTE: This does NOT mean that humans are the "pinnacle of**

**evolution"**. There are plenty of other organisms that are just as important: **There are more species of insects (hexapods) than all other organisms **combined**. They are a crucial part of most ecosystems and have specialized to fill a massive range of niches. It is because of reasons like this that many people think insects, not humans, "rule the world". The belief that "evolution led to humans" is a result of humanity's anthropocentric mindset. While it is important to understand that this belief is dangerous, I will present information in that manner since I believe that it is easier for our anthropocentric minds to understand.

Third, many organisms are often named by what they look like. This can help you remember details about an organism! For example, anything with *myce* in the name looks like a fungus.

# 2 Viruses

Viruses occupy a grey area between the living and non-living. They exhibit several qualities of life, as shown by their organized structure, yet they are unable to reproduce on their own. Instead, they "hijack" host cells by injecting their genetic information into the host cell, which the cell uses to make more viruses. For this reason, they are typically not considered to be living organisms. Instead, they live a "borrowed life".

## 2.1 History

Viruses were originally discovered studying Tobacco Mosaic Virus (TMV)

- 1883 - Adolf Mayer discovered that disease could spread between plants by rubbing sap from the infected plant onto a healthy plant
  - Thought it was caused by super tiny microbe
- Dimitri Ivanowsky passed sap through filter meant to catch microbes; infection still spread
  - Proved it couldn't be a traditional microbe, but Ivanowsky still thought it was just a super small microbe
- Martinus Beijerinck proved that the infectious particle could replicate, but not on its own - first concept of virus
- 1935 - Wendell Stanley crystallized TMV, finally proving its existence

## 2.2 General

Viruses are made up of nucleic acid genome surrounded by protein coat. This protein coat is called a **capsid** and is made up of subunits called **capsomeres**. Viruses can be classified based on the shape of the capsid:

- **Helical:** rod-shaped with proteins arranged in helix
- **Icosahedral:** shaped like a 3D icosahedron (20 faces)

- **Viral envelopes:** the envelope comes from the host cell membrane, with some viral proteins and glycoproteins incorporated
- **Bacteriophage:** Viruses that infect bacteria

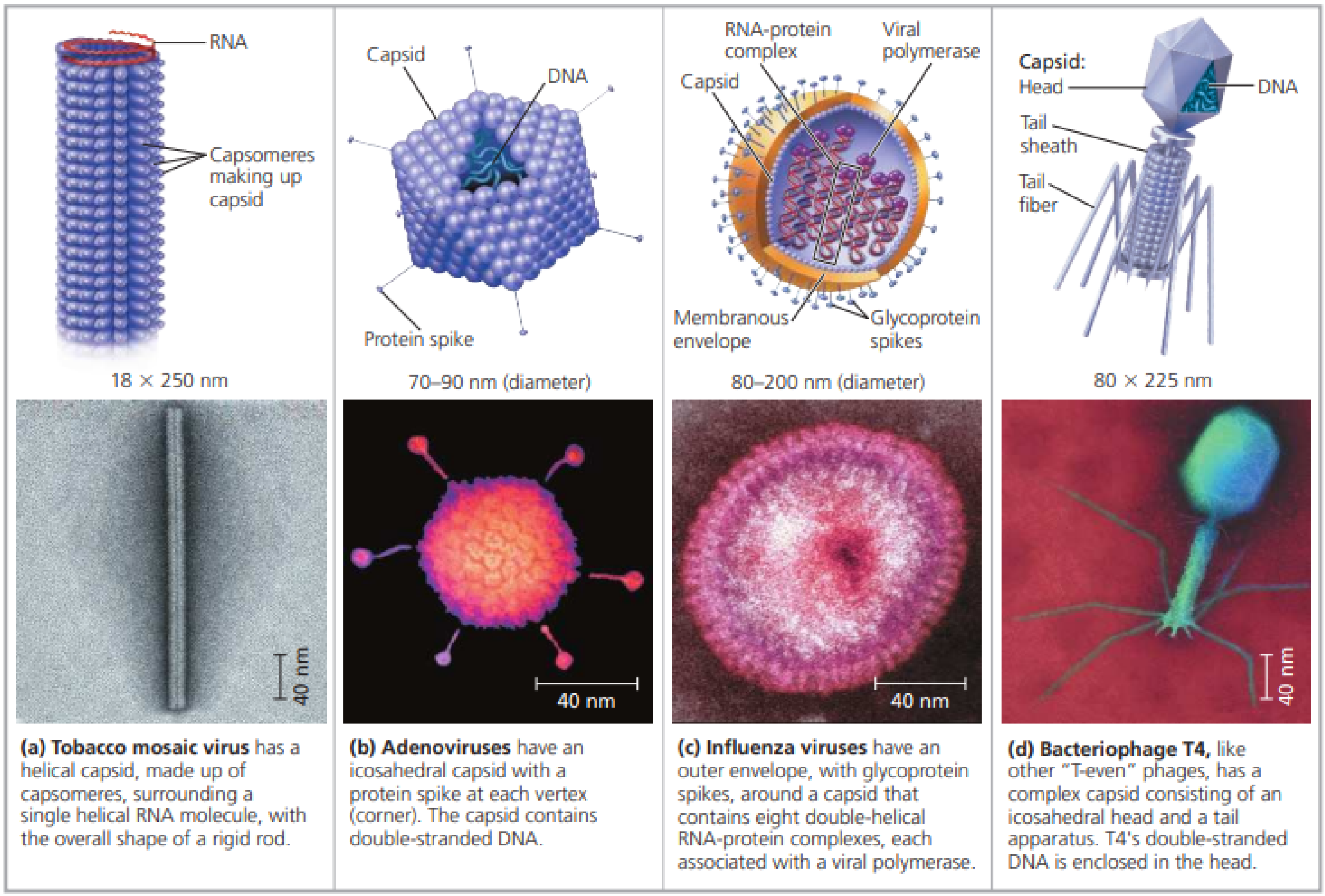



**Figure 1:** Types of capsids for viruses.

Each virus has a **host range** - the hosts that a virus can identify/interact with via surface proteins and receptors.

## 2.3 Bacteriophages

Bacteriophages infect bacteria **only**. Most have dsDNA. Most of them have the same structure with a **prolate** (extended icosahedron) head:

- **T-even phages are all very similar
- **T7 phages are stubby
- *$\lambda$ **phage** is *temperate* and has a long tail

Bacteriophages have two main systems for reproduction:

- **Lytic cycle:** Has the infected bacteria cell make a bunch of copies of the virus. The cell then lyses, releasing the viruses.
  - A **Virulent phage** follows this cycle.
  - Bacteria defend against this using **restriction enzymes** - enzymes that identify foreign DNA and cut it up. The discovery of these enzymes led to the development of the **CRISPR-Cas9 system**.

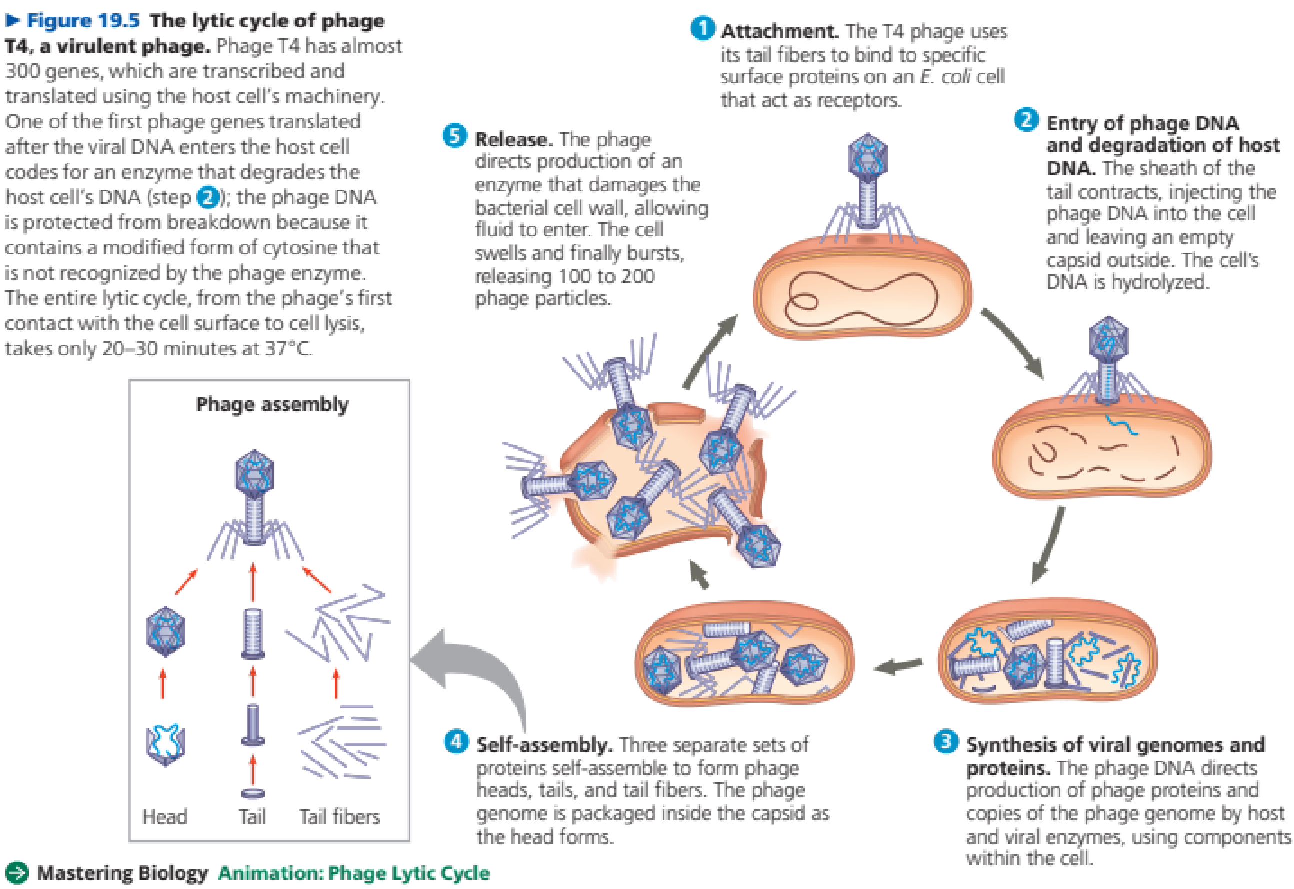



**Figure 2:** Lytic cycle of a virulent phage.

- **Lysogenic cycle:** Inserts a piece of the viral DNA called the **prophage** into the host DNA.
  - A **Temperate phage** follows this cycle
  - **Lys**ogenic does **NOT** include lysis!
  - The prophage replicates as the cell replicates. When the time is right, the cells switch to the lytic cycle and lyse.
  - Prophage can be responsible for toxins produced by some bacteria **(Bad E.Coli, diphtheria, botulism, scarlet fever).

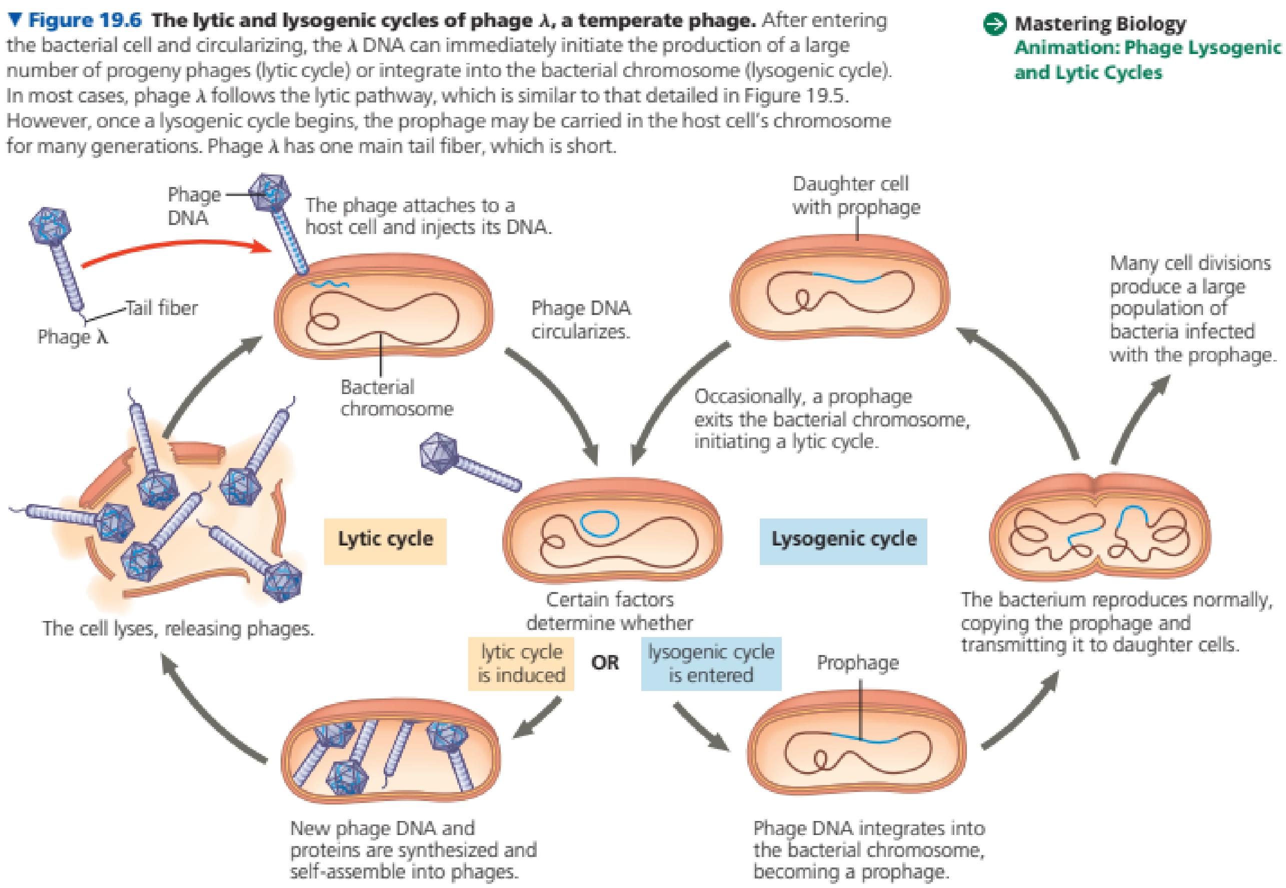



**Figure 3:** Lysogenic cycle of a temperate phage.

## 2.4 Animal viruses

Almost all animal viruses have a viral envelope. They are classified based on the type of nucleic acid they use:

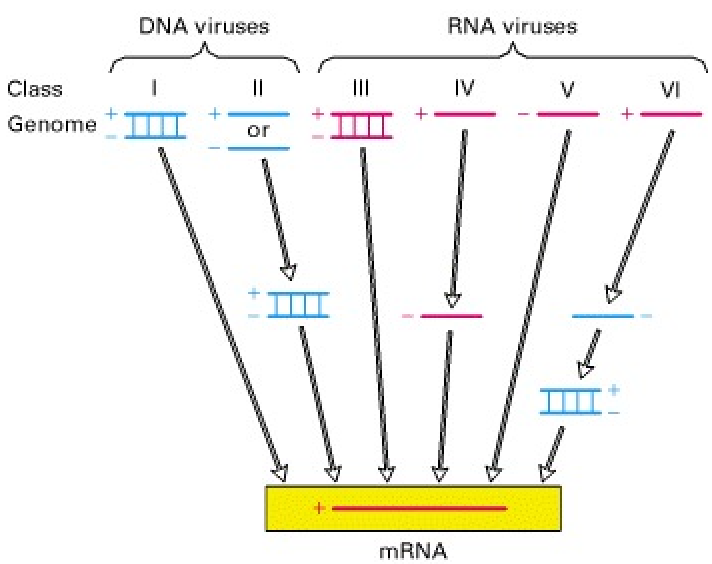



**Figure 4:** Baltimore classification of animal viruses by type of nucleic acid.

- Baltimore Classification System: Class 1 → 6 (you may want to mem the chart below)
- **Retroviruses** (6) are a special type of animal virus that use the enzyme **reverse transcriptase** to make DNA (called the **provirus**) from viral RNA. The provirus remains a part of the host cell DNA forever.
  - **Altered CCR5(GPCR) makes people resistant to HIV. Using this principle, Maraviroc (brand name Selzentry) was approved in 2007 to treat HIV infection.
- **Class 7 (dsDNA that uses reverse transcriptase) was later added for Hepatitis B

When animal viruses reproduce, they generally do not kill host cells because they do exocytosis (the host cell envelope becomes the viral envelope) [**EXCEPT: Herpesvirus gets envelope from Golgi]. They can leave behind DNA in the host cell and remain dormant (Although similar, this is NOT the lysogenic cycle, since that is only for phages).

Animal viruses play an important role in **epidemiology** since they are the source of many diseases. A virus that suddenly becomes apparent is an *emerging virus*. This can result in massive outbreaks, which can be classified as an **epidemic** (regional) or **pandemic** (infects several continents) depending on its scale.

**Table 19.1 Classes of Animal Viruses**

| Class/Family | Envelope? | Examples That Cause Human Diseases |
|---|---|---|
| **I. Double-Stranded DNA (dsDNA)** | | |
| Adenovirus (see Figure 19.3b) | No | Respiratory viruses |
| Papillomavirus | No | Warts, cervical cancer |
| Polyomavirus | No | Tumors |
| Herpesvirus | Yes | Herpes simplex I and II (cold sores, genital sores); varicella zoster (shingles, chicken pox); Epstein-Barr virus (mononucleosis, Burkitt's lymphoma) |
| Poxvirus | Yes | Smallpox virus; cowpox virus |
| **II. Single-Stranded DNA (ssDNA)** | | |
| Parvovirus | No | B19 parvovirus (mild rash) |
| **III. Double-Stranded RNA (dsRNA)** | | |
| Reovirus | No | Rotavirus (diarrhea); Colorado tick fever virus |
| **IV. Single-Stranded RNA (ssRNA); Serves as mRNA** | | |
| Picornavirus | No | Rhinovirus (common cold); poliovirus; hepatitis A virus; other intestinal viruses |
| Coronavirus | Yes | Severe acute respiratory syndrome (SARS); Middle East respiratory syndrome (MERS) |
| Flavivirus | Yes | Zika virus (see Figure 19.10c); yellow fever virus; dengue virus; West Nile virus; hepatitis C virus |
| Togavirus | Yes | Chikungunya virus (see Figure 19.10b); rubella virus; equine encephalitis viruses |
| **V. ssRNA; Serves as Template for mRNA Synthesis** | | |
| Filovirus | Yes | Ebola virus (hemorrhagic fever; see Figure 19.10a) |
| Orthomyxovirus | Yes | Influenza virus (see Figure 19.3c) |
| Paramyxovirus | Yes | Measles virus; mumps virus |
| Rhabdovirus | Yes | Rabies virus |
| **VI. ssRNA; Serves as Template for DNA Synthesis** | | |
| Retrovirus | Yes | Human immunodeficiency virus (HIV/AIDS; see Figure 19.9); human T-lymphotropic virus type 1 (HTLV-1) (leukemia) |

**Figure 5:** Examples of each class of animal virus.

Influenza is an important virus for humans. It comes in 3 types: A, B, C. *A is the type that causes pandemics

1. Flu viruses are named based on two proteins: **H = hemagglutinin** (16 variants), **N = neuraminidase** (9 variants)
2. *H1N1 = Swine flu. **There was a H1N1 pandemic in 2009. It also likely caused the Spanish flu pandemic in 1918-1920.
3. *H5N1 = Avian flu. This variant is more deadly than H1N1, but less transmissible.

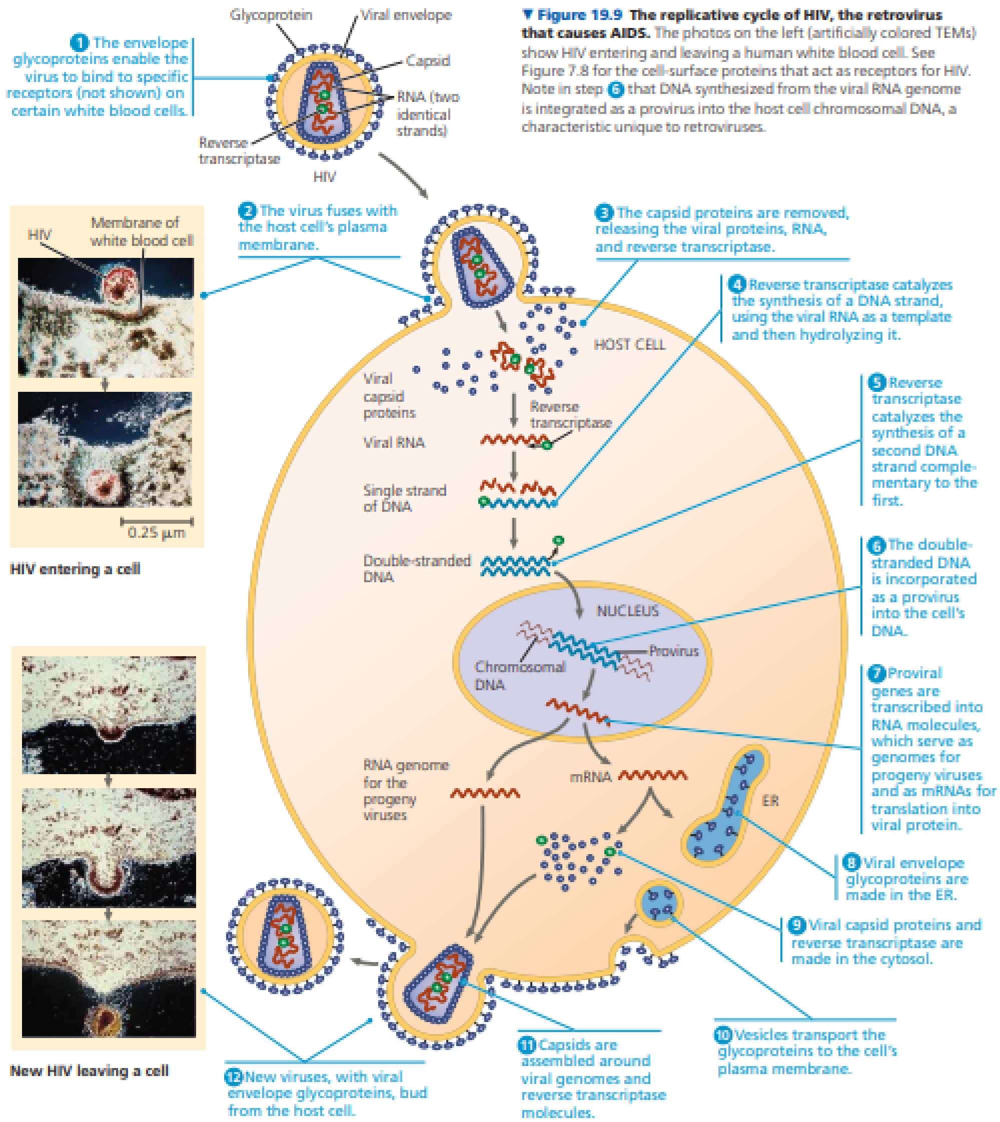



**Figure 6:** Life cycle of HIV.

**Example 2.1:** (USABO Opens 2017)

**9. Which statement about the life cycle of the human immunodeficiency virus (HIV) is most accurate?**

A. The viral glycoproteins that coat the mature virion's lipid envelope's outer surface are synthesized by host cell ribosomes in the cytosol.

B. The mature virus particle does not contain reverse transcriptase; the protein is translated from the RNA genome after entry into the host cell.

C. If a scientist were to extract just the viral genome from HIV virions and inject the nucleic acid into a human cell, the genome would integrate as a provirus into the host's genome.

D. In HIV positive individuals, HIV provirus can be found latent in CD4 positive cells years after initial infection.

E. The high error rate of reverse transcriptase enables the virus to evade the host's circulating antibodies by changing the antigenicity of its internal capsid protein.

**Solution:** As we saw in the diagram above, HIV contains reverse transcriptase, which is necessary for integrating the provirus into the host genome. Therefore, B and C are wrong. A is wrong because the ribosomes are located in the rough ER since they make membrane proteins. The correct **answer is D** since the virus remains part of the host DNA.

### 2.5 Plant viruses

Plant viruses typically use RNA and come in either a helical or icosahedral shape. A plant can acquire a virus from the environment (**horizontal transmission**) or from its parent (**Vertical transmission**)

**Viroids** are small circular pieces of RNA that infect plants. Unlike viruses, they possess no protein coat.

## 3 Prions

Prions are bits of misfolded proteins that can cause diseases:

- **Kuru:** disease spread through ritual cannibalism. AKA: laughing sickness
- Mad Cow disease, Creutzfeldt-Jakob disease, etc.

Prions were discovered by **Stanley Prusiner**. They are usually spread through contaminated food. When a person is infected (the specific mechanism is currently unknown), the prions cause normal proteins in cells to become prions. Like viruses, they are not alive, but they appear to use their hosts to replicate.

## 4 Bacteria

### 4.1 Features

We begin our tour of the living world with **prokaryotes** - cells without a nucleus. These single-celled organisms can be pathogens, or they can be *free-living*.

Here are important features unique to a bacterial cell:

- **Capsule:** sticky outer covering of polysaccharides or proteins. It is called a **slime layer** when it is more loosely attached.
- **Fimbriae:** hairs on the outside that allow the bacteria to attach to surfaces.
- **(Sex) Pili:** long filaments on the surface used for *conjugation*.
- **Nucleoid:** region in the cytoplasm where DNA is kept.
- **Endospore:** in tough times, bacteria make a resistant, dehydrated cell that lies dormant until rehydrated. This is called an endospore.

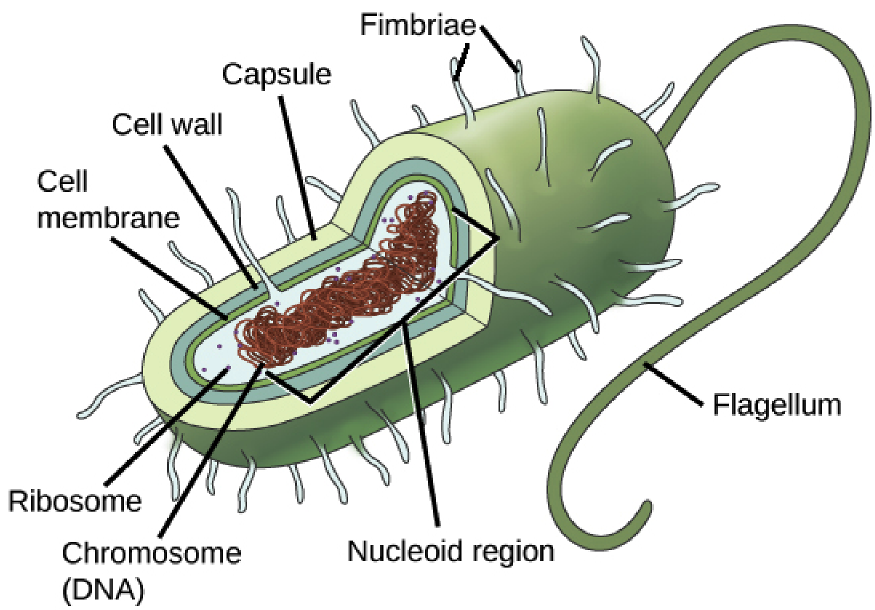



**Figure 7:** Diagram of a bacterium.

- **Flagellum:** A long tail that gives the cell motility. It is composed of a **motor** connected to a tail consisting of a **rod, hook,** and **filament**.
  - Proteins come from modified excretory system!
  - Most of the proteins in the flagella were modified from other functions. For example, mainy of the proteins in the motor originally formed channels for the bacterium's secretory system.
- **Heterocysts:** specialized cells in a colony that perform nitrogen fixation.
- **Exotoxins:** some bacteria release harmful chemicals.
- **Endotoxins:** some gram-negative bacteria have chemicals stored in the cell wall (lipopolysaccharide membrane) that are released only when the cell dies.

**Table 27.2 A Comparison of the Three Domains of Life**

| | DOMAIN | | |
|---|---|---|---|
| **CHARACTERISTIC** | **Bacteria** | **Archaea** | **Eukarya** |
| Nuclear envelope | Absent | Absent | Present |
| Membrane-enclosed organelles | Absent | Absent | Present |
| Peptidoglycan in cell wall | Present | Absent | Absent |
| Membrane lipids | Unbranched hydrocarbons | Some branched hydrocarbons | Unbranched hydrocarbons |
| RNA polymerase | One kind | Several kinds | Several kinds |
| Initiator amino acid for protein synthesis | Formyl-methionine | Methionine | Methionine |
| Introns in genes | Very rare | Present in some genes | Present in many genes |
| Response to the antibiotics streptomycin and chloramphenicol | Growth usually inhibited | Growth not inhibited | Growth not inhibited |
| Histones associated with DNA | Absent | Present in some species | Present |
| Circular chromosome | Present | Present | Absent |
| Growth at temperatures $>100°C$ | No | Some species | No |

**Figure 8:** Comparison of major features among the three domains of life.

To see whether a bacterial cell wall has **peptidoglycan**, a **Gram staining** is performed. In a Gram stain, crystal violet is added with iodine. Then, it is washed with alcohol. If the bacteria has peptidoglycan, then it will hold onto the crystal violet and will appear **purple**, indicating that it is **Gram-positive**. Afterwards, red saffarin is added. Thus, if the bacteria does NOT have peptidoglycan, then all of the crystal violet will have washed out, and we will instead see the saffarin. As a result, the bacteria will appear **red** or **pink**, indicating that it is **Gram-negative**

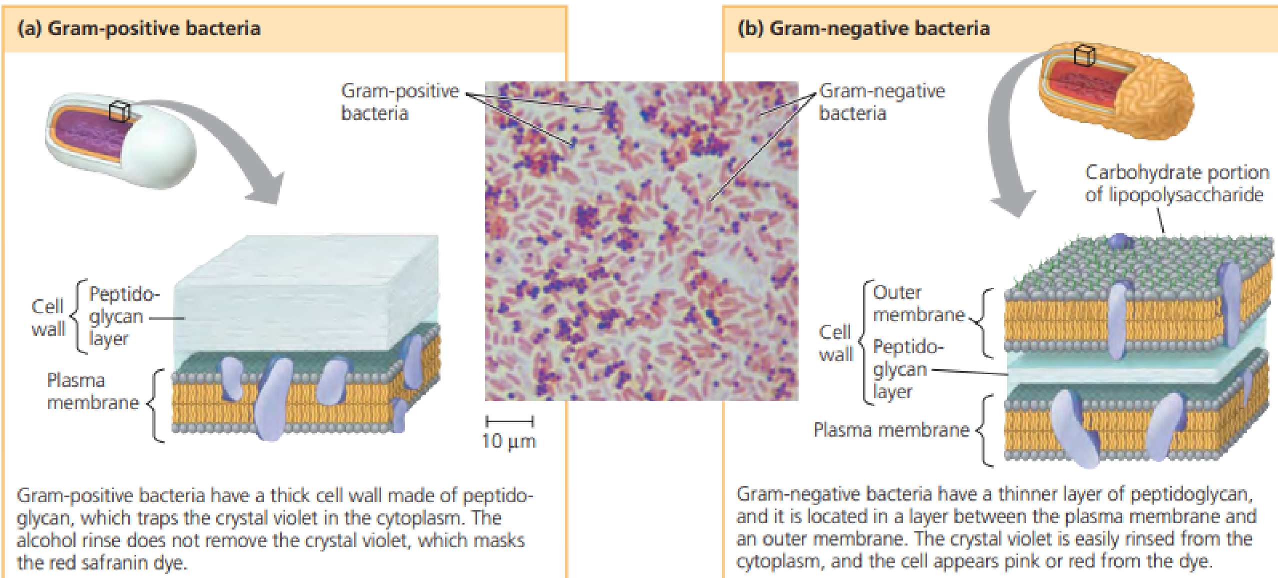



**Figure 9:** Comparison of Gram-positive and Gram-negative bacteria in a Gram stain.

Bacteria reproduce *asexually* through **binary fission**, which (as the name suggests) is when one cell splits into two. However, there are several ways in which different species of bacteria can transfer DNA with one another. This exchange of DNA is known as **horizontal gene transfer**:

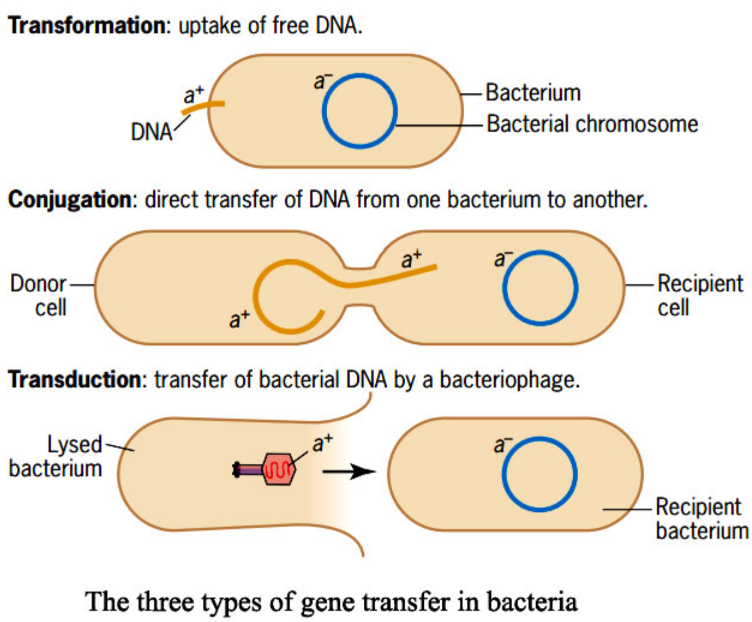



**Figure 10:** Types of horizontal gene transfer in bacteria. (Source: biotechnologymcq.com)

- **Transformation:** Bacteria can take up DNA that is floating in its environment. This is often seen as **electroporation**, when an electric shock creates tiny pores in the bacterial cell membrane that the DNA from the environment can slip through.
  - This was shown in the **Griffith** experiment, which used two strains of *Streptococcus pneumoniae.*
  - **Avery** took the Griffith experiment one step further by including enzymes that destroyed either protein or DNA, showing that DNA was the mode of genetic inheritance.
- **Transduction:** Bacteria can obtain DNA from a bacteriophage.
  - This was shown in the **Hershey** & **Chase** experiment, which used a T2 phage to infect *E. coli*
- **Conjugation:** the process in which two bacteria exchange DNA via **pili**.
  - There is a special piece of DNA called the **F factor** that codes for pili, allowing for conjugation. The F factor is usually located in a plasmid called the **F plasmid**. A cell with an F plasmid is called **F$^+$**, and one without is **F$^-$**. When an F$^+$ cell conjugates with an F$^-$ cell, it donates part of its F factor, converting the F$^-$ cell into an F$^+$ cell.
  - **Hfr cells** have the F plasmid built into their genome (the plasmid was incorporated into the bacterial chromosome during recombination).
  - **F'** (F prime): This is like a mix of an F$^+$ and Hfr cell. Essentially, the F factor is meant to be in the F plasmid, but due to improper excision, a chunk of it gets stuck in the bacterial genome.
- **R plasmids:** genes that make (antibiotic) resistant strains of bacteria

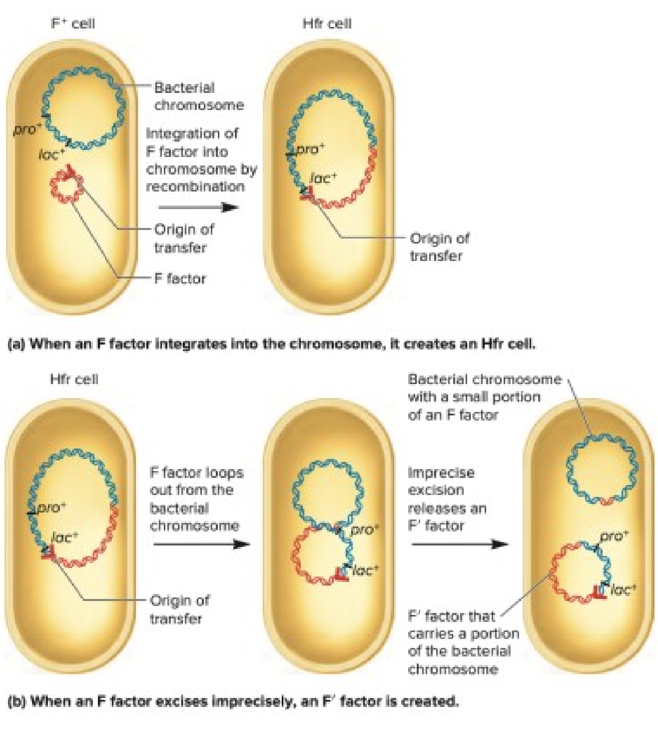



**Figure 11:** Relationship between F$^+$, Hfr, and F' bacteria. (Source: Brooker's Genetics)

## 4.2 Gram-positive bacteria

All bacteria in this clade are gram-positive and fall into one of three groups:

- **Actinomycetes:** fungus-like species that form colonies of branched cells. They are mostly free-living species that decompose organic matter in the soil.
  - **Two species cause tuberculosis (*Mycobacterium tuberculosis*) and leprosy. XDR-TB stands for extensively drug-resistant tuberculosis
  - ***Streptomyces:* used for some pharmaceutical drugs.
- **Mycoplasmas:** Only bacteria to lack cell walls (not including L-form bacteria). They are the tiniest known cells (.1$\mu$m) and have small genomes (***Mycoplasma genitalium* has only 517 genes). Many are free-living, but some are pathogens.
- Solitary species
  - **Bacillus anthracis:* causes anthrax
  - **Clostridium botulinum:* causes botulism
  - ***Staphylococcus* & *Streptococcus*: MRSA stands for methycilin resistant staphylococcus aureus. USA 300 was an especially bad strain of MRSA. Malcidins were a new antibiotic developed in 2018 to treat MRSA.

This is the second largest group of bacteria. All other bacteria are gram-negative.

## 4.3 Proteobacteria

This is the largest group of bacteria. They come in several types:

- **Alpha:** many members are close symbionts to eukaryotic organisms. It is believed that mitochondria evolved through the **endosymbiosis** of an alpha proteobacteria.
  - ***Rhizobium*: nitrogen-fixing bacteria in nodules of legumes
  - **Agrobacterium*: makes tumors in plants, used for gene editing in plants
- **Beta:** **includes *Nitrosomonas*, which converts ammonium to nitrate
- **Gamma:** Includes sulfur bacteria and many pathogens.
  - ***Thiomargarita namibiensis*: sulfur bacteria
  - **Legionella*: causes Legionnaire's disease
  - **Salmonella*: causes food poisoning
  - **Vibrio cholerae*: causes cholera
  - **Escherichia coli*: found in the intenstines. Some strains, like O157:H7, are dangerous pathogens
- **Delta:** Made up of two types of bacteria

  - ****Myxobacteria:** Another bacteria that looks like fungi. Secretes slime. In tough times they will congregate into fruiting bodies that release *myxospores*
  - ****Bdellovibrios:** Attacks other bacteria! They can charge up to $100\frac{\mu m}{s}$ (comparable to a human running $240\frac{km}{hr}$). It drills into its prey with digestive enzymes and rotates at 100 revolutions per second.

- **Epsilon:** pathogens of animals (has *bacter* in the name)
  - ***Campylobacter*: causes blood poisoning and intestinal inflammation.
  - **Helicobacter pylori*: causes stomach ulcers. **To prove that *H.pylori* cause ulcers, Australian biologist Barry Marshall chugged a glass full of them. He got a Nobel prize for it :)

### 4.4 Chlamydias

Chlamydias consist of parasites that are dependent on animal hosts. What makes them special is that their walls completely lack peptidoglycan.

- ***Chlamydia trachomatis*: most common cause of blindness in the world (Trachoma) and also the most common sexually transmitted disease in the US (Chlamydia).

### 4.5 Spirochetes

These bacteria rotate (spiral) through their environment. They are mostly free-living, but some of them are pathogens.

- ***Treponema pallidum*: causes sypgilis
- **Borrelia burgdorferi*: causes Lyme disease

### 4.6 Cyanobacteria

These are the only prokaryotes that perform photosynthesis! It is believed that chloroplasts evolved through the **endosymbiosis** of a cyanobacterium. Cyanobacteria compose Phytoplankton, which perform 20% of the photosynthesis in the world (plants do 50% and protists do 30%)

## 5 Archaea

Although archaea are also prokaryotes, they actually bare more similarities to eukaryotes than they do to bacteria!

### 5.1 Euryarchaeota

This phylum contains most of the **halophiles** (halo = salt, phile = loving, so these organisms live in really salty conditions!) and all of the **methanogens** (organsims that produce methane).

- **Pyrococcus furiosus*: An extreme thermophile (thermo = heat, phile = loving, so these organisms live in really hot places!). Since its enzymes function so well under high temperatures, it is the source of **Pfu polymerase**, which is used in PCR!

### 5.2 TACK Supergroup

This contains essentially all other archaea. It used to be composed of a bunch of smaller groups that were later combined into this supergroup:

- **Thaumarchaeota**
- **Aigarchaeota**
- **Crenarchaeota**: contains **thermohpiles**. They can perform nitrogen fixation.
- **Korarchaeota**: a new group discovered in 1996. They live in hydrothermal vents and hot springs.

### 5.3 Lokiarchaeota

This section contains archaea that are very similar to eukaryotes. For that reason, they could be useful in identifying the least common ancestor between the three domains.

**Example 5.1:** (USABO Opens 2018)

**49. Which is not a difference between bacteria and archaea?**

A. Presence of introns in archaea.
B. Presence of some histones in archaea.
C. Extremophilic growth of archaea.
D. Bacterial presence of peptidoglycan.
E. All of the above are differences.

**Solution:** We know A and B are true, as shown in the table earlier that compared the three kingdoms. C is true since archaea are notable for living in extreme environments. D is true since that is what defines Gram-positive bacteria. Therefore, the **answer is E**.

## 6 Protists

Leeuwenhoek first discovered protists when he looked at pond water through a microscope and was amazed at how the seemingly empty water was teaming with life. Protista has historically been the catch-all group that includes any eukaryotes that don't fit into the other three kingdoms. Many of them are unicellular, but some are multicellular. Many of them are solitary, but some form colonies. There are very few traits that can be used to unite all protists. For that reason, many biologists don't consider protista to be an actual kingdom and split it into many kingdoms. However, since it has historically been a useful group for biosys, we will treat it like a single kingdom.

***Also, there are 3 really weird species of algae (**haptophytes, cryptophytes, hemimastigophores**), and no one has a clue what group they're a part of. The only relevant info is that coccolithophores are haptophytes.

## 6.1 Features

While many organisms are either photosynthetic or heterotrophic, Protista contains some **mixotrophs**, which are organisms that use both photosynthesis and heterotrophic means for nutrition.

While we're talking about the evolution of organisms, I might as well address the evolution of certain organelles. Both mitochondria and chloroplast are unique among the organelles in that they have double membranes, their own DNA, their own ribosomes, and they control their own replication. Essentially, they act as mini-cells within the cell! These observations have led to the theory of **Endosymbiosis** (endo = inside, symbiosis), the belief that mitochondria and chloroplasts first evolved when a protist engulfed a smaller prokaryote. Instead of digesting that prokaryote, they lived in harmony, with the eukaryote providing shelter and the prokaryote providing energy.

- *Mitochondria arise from alpha proteobacteria
- *Chloroplasts arise from cyanobacteria
- **These organelles originally had 3 membranes (2 from the prokaryote, 1 from the eukaryote), but one was lost over time.
- ** For some organisms, secondary endosymbiosis occurred, where an even larger eukaryote engulfed the prokaryote-eukaryote symbiote, resulting in 4 membranes, 1 of which was lost over time. In this case, the nucleus that was in the engulfed eukaryote remains as a vestigial nucleus called a **nucleomorph**.

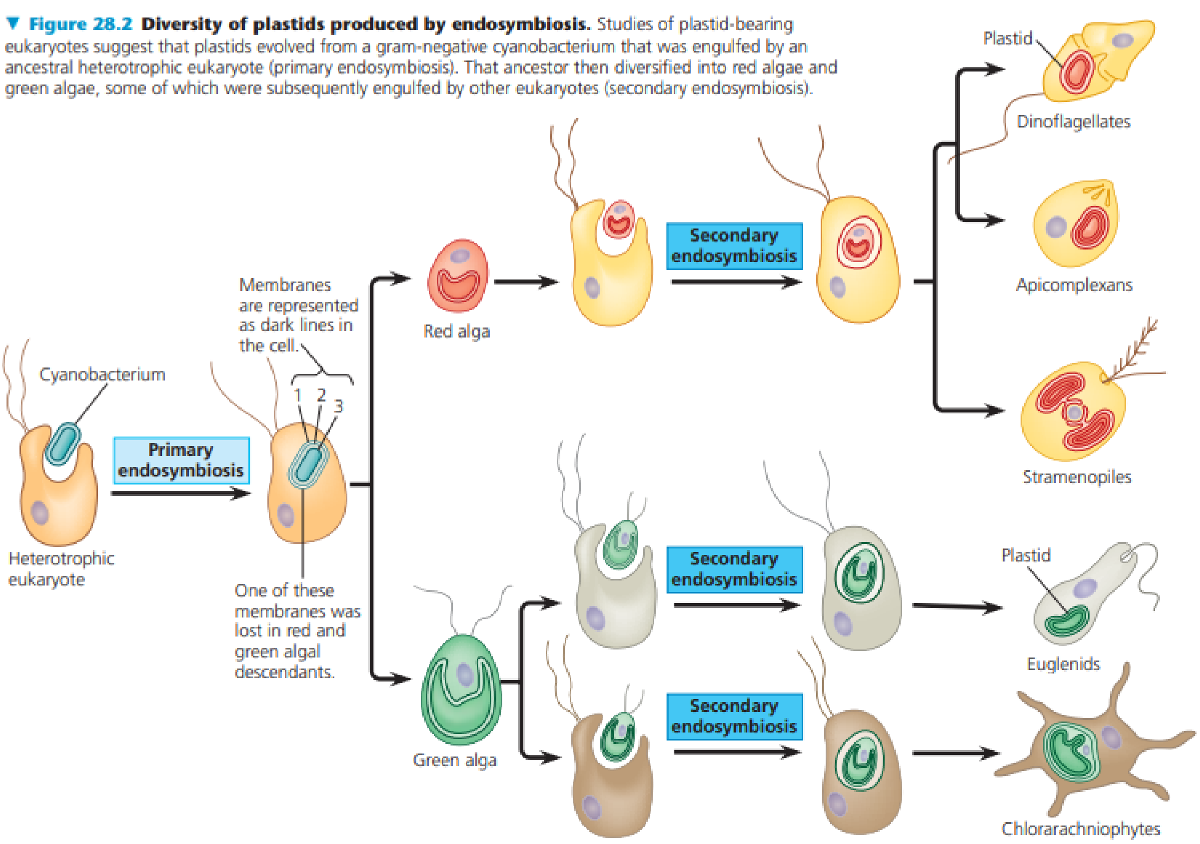



**Figure 12:** Diagram of endosymbiosis, showing the process and the organisms it results in.

## 6.2 Excavata

Some members have an "excavated" feeding groove, which is where the name comes from. Also, the existence of this group is relatively debatable.

- **Diplomonads:** These organisms have special organelles called **mitosomes**, which are just reduced mitochondria. Diplomonads have 2 nuclei and many flagella.
  - Many of them are parasites, such as ***Giardia intestinalis*, a parasite in animal instestines.
- **Parabasalids:** these organisms have special organelles called **hydrogenosomes**, which are reduced mitochondria that produce hydrogen gas.
  - ***Trichomonas vaginalis* infects the vagina.
- **Euglenozoans:** These organisms are characterized by a rod with a spiral/crystalline structure in their flagella.
  - **Kinetoplastids:** Has big mitochondria with a **kinetoplast**, an organized mass of DNA.
    - **Trypanosoma:* Causes **African sleeping sickness** (Trypanosomiasis), which is spread by the **tsetse fly**. They also cause **Chagas' disease**. *Trypanosoma* is able to evade the host's immune system by constantly switching its surface proteins.
  - **Euglenids:** Has a pocket on one end of the cell where 2 flagella come out. They can be photosynthetic or mixotrophic.

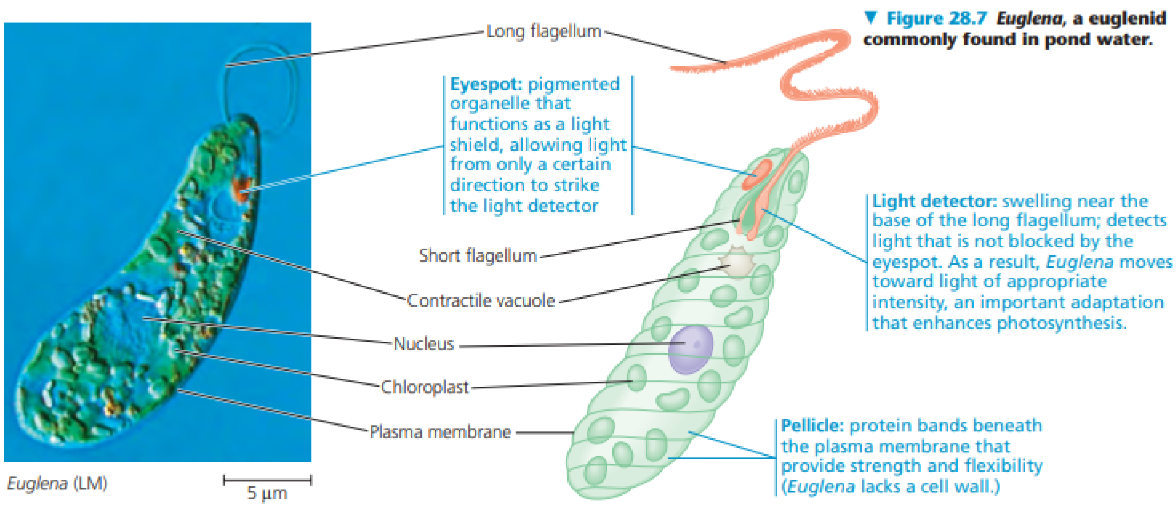



**Figure 13:** Diagram of Euglena.

## 6.3 SAR

This group used to be split into **Chromalveolata**, which included the Alveolates and Stramenophiles, and Rhizaria. Now, all three groups are merged together into the SAR group.

For many organisms in this clade, the composition of their shells is important. If they have **calcium carbonate** or **silica**, then when these organisms die, their shells will fall onto the seafloor as sediments and turn into an **ooze** over time. *Diatoms* and *Radiolarians* make **siliceous ooze**. *Forams* and *Coccolithophores* make **calcareous ooze**.

- **Alveolates:** The name comes from the membranous sac (alveoli) that these organisms contain under their membranes. Not sure what its use is.
  - **Dinoflagellates:** These organisms have **cellulose** plates for armor. Two flagella (Di - flagella) stick through the cracks in the armor. These flagella cause the organism to spin as it swims.

    Dinoflagellates also have the most complex subcellular structure in existence, the **ocelloid**! This is basically a mini-eye for dinoflagellates.
    - *Phytoplankton. Their carotenoids (red/orange pigments) cause the water to turn brown/pink during blooms. These blooms are often called **Red Tide**. ***Karenia brevis* is a specific species in the Gulf of Mexico.
  - **Apicomplexans:** These organisms live as parasites of animals. They have a complex life cycle that needs 2 different hosts. Their sporozoites have a complex of organelles for infecting hosts at the cell's apex, which is where the name comes from.

    Apicomplexans are believed to evolve from secondary endosymbiosis of red algae. However, they are not photosynthetic and instead contain a vestigial apicoplast.
    - *Plasmodium*: causes **malaria**, which is transmitted by the **Anopheles** mosquito. Since the merozoite infects the host's red blood cells, people heterozygous for sickle cell anemia (RBC is sickle shape instead of biconcave) have some immunity against malaria. **You should know the stages of its life cycle

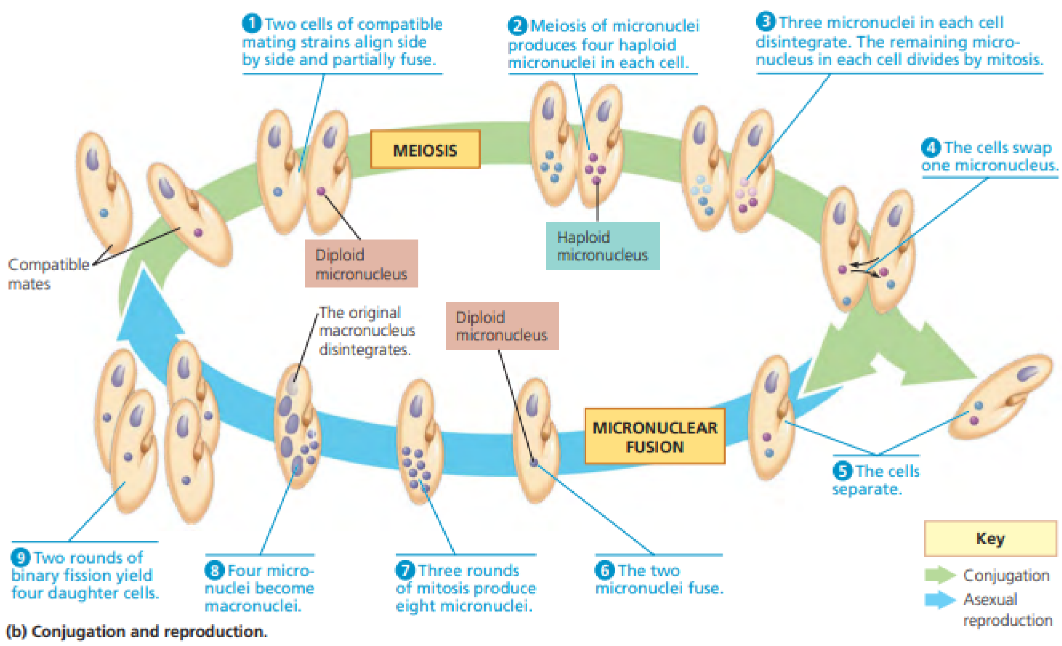



**Figure 14:** Life cycle of a ciliate.

– **Ciliates:** Has lots of cilia, hence the name. They also have 2 specialized nuclei! The **macronuclei** controls the cell like a normal nucleus does, while the **micronuclei** is exchanged with other ciliates during **conjugation** (a form of sexual reproduction).

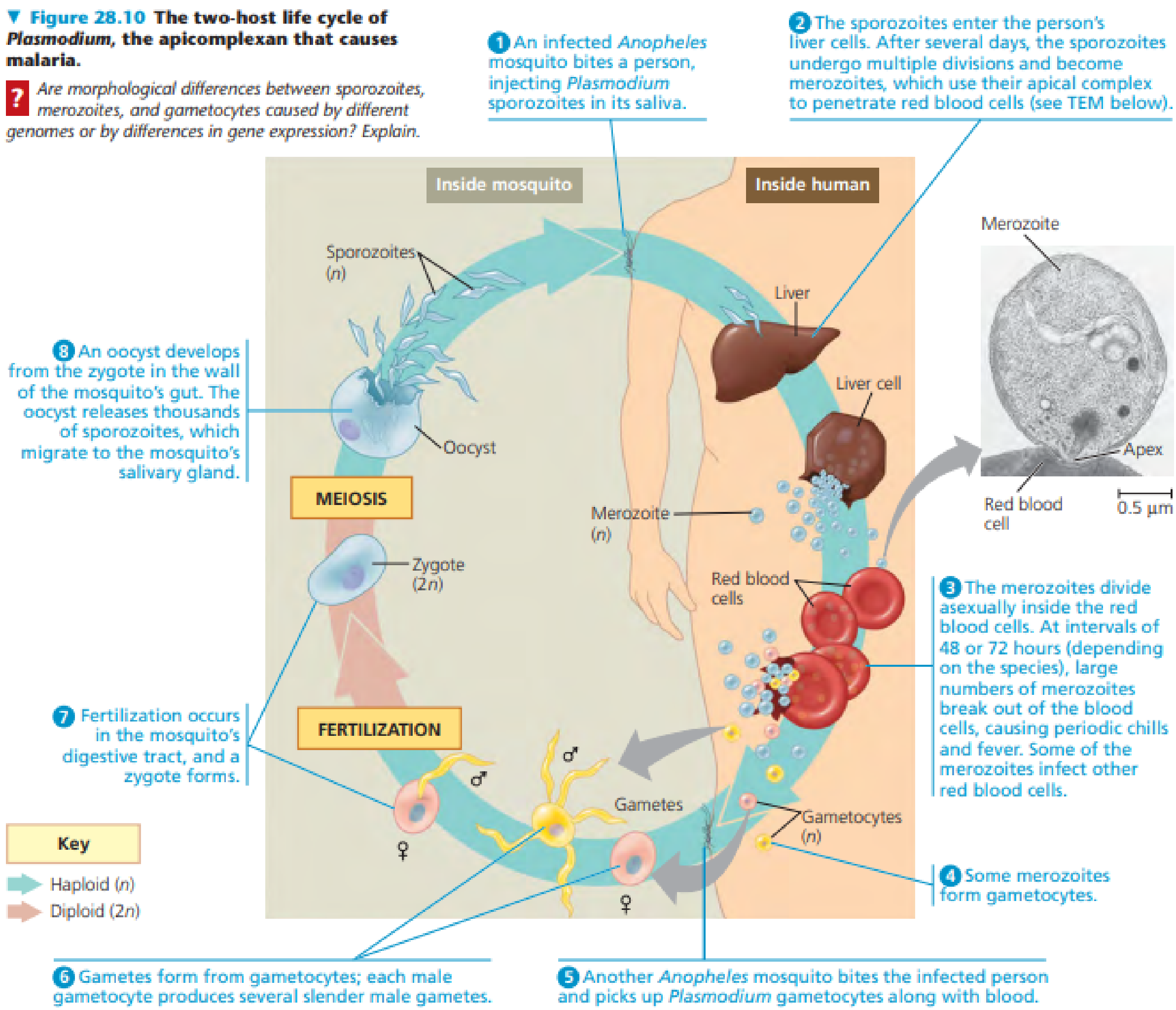



**Figure 15:** Life cycle of *Plasmodium*.

- **Stramenopiles:** Has "hairy" flagella (stramen = "straw", pile = "hair"), which usually paired together with smooth flagella. This group has many photosynthetic eukaryotes:

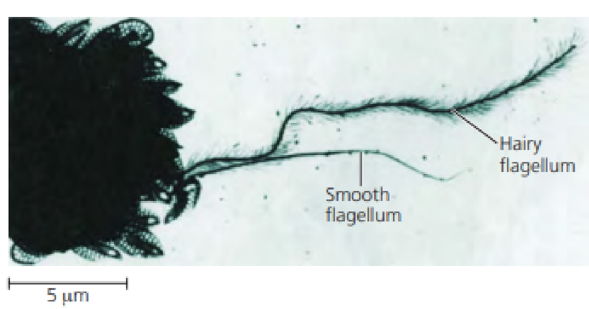
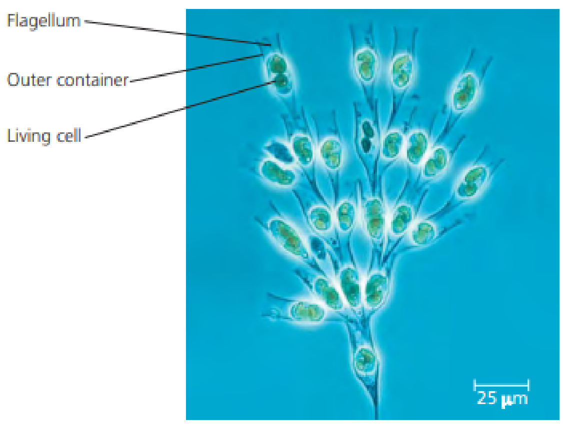
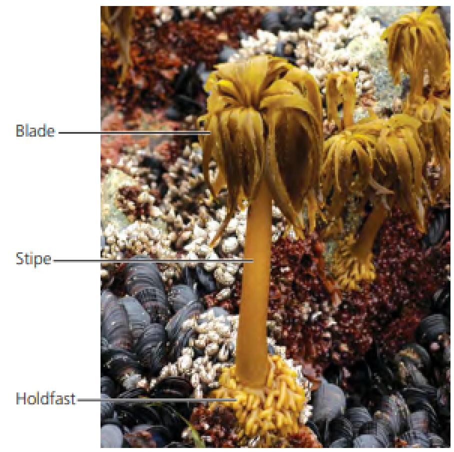



**Figure 16:** Stramenopile flagella.

- **Diatoms:** Has super strong *silica* shell. When they die, their remains fall onto the sea floor and become **siliceous ooze**. Their remains can also form **diatomaceous earth**, which is found on the western coast of the US and is used as a filtering medium
- **Golden Algae:** Has yellow/brown carotenoids. There isn't much notable about them, but some say that they form a V shape since they have two flagella on one end.
  - **Most are unicellular, but *Dinobryon* is colonial



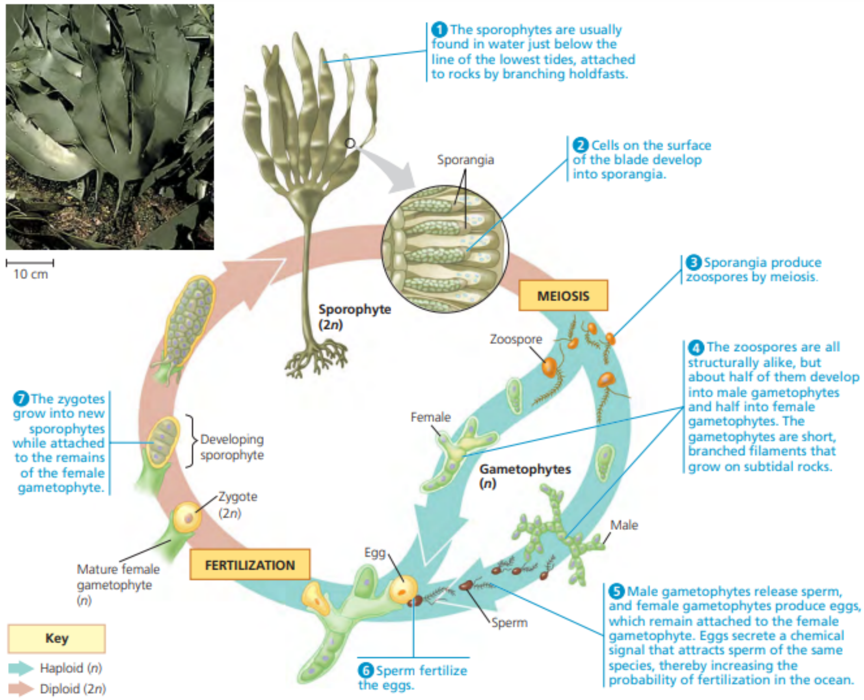

▲ **Figure 28.14 *Dinobryon*, a colonial golden alga found in fresh water** (LM).




▲ **Figure 28.15 Seaweeds: adapted to life at the ocean's margins.** The sea palm (*Postelsia*) lives on rocks along the coast of the northwestern United States and western Canada. The thallus of this brown alga is well adapted to maintaining a firm foothold despite the crashing surf.

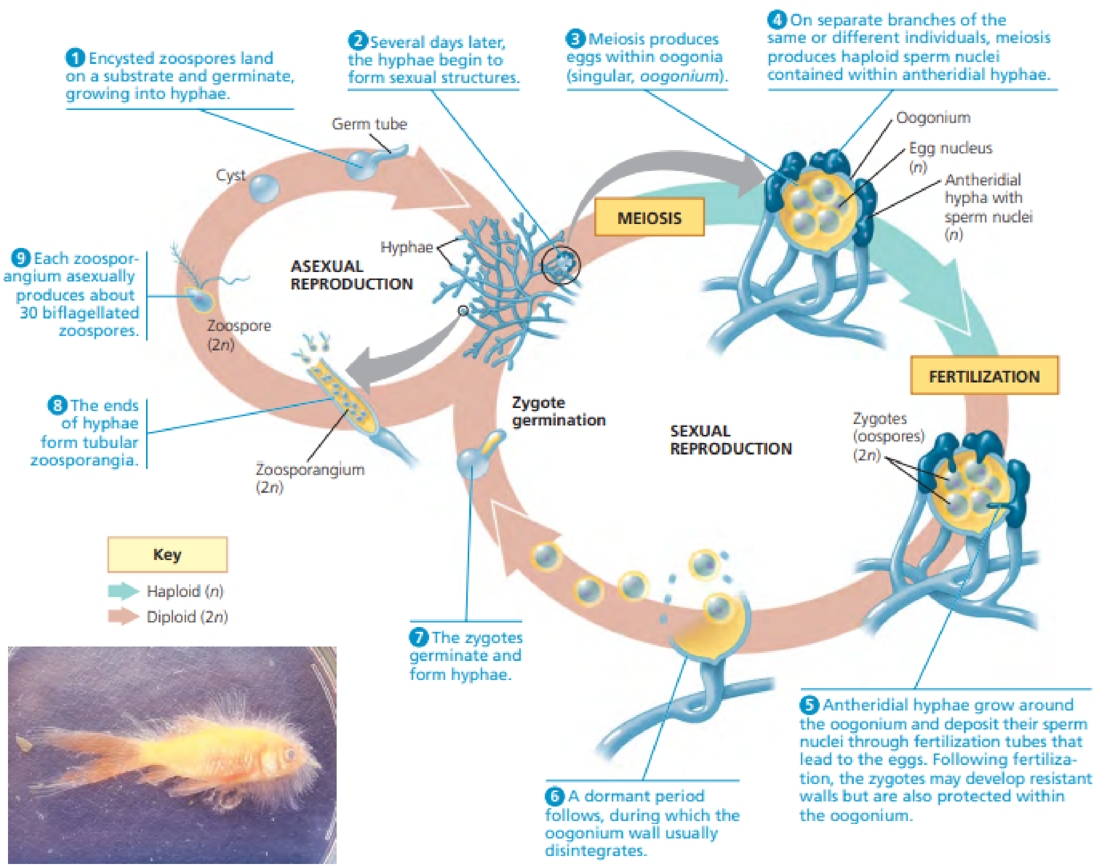
**Figure 17:** Golden algae (left) and brown algae (right).

- **Brown Algae:** This is the largest and most complex of all the algae. They have brown carotenoids (hence the name). If an alga looks like a plant, then it is called a **thallus**. Like a plant, they have an analog for roots (**Holdfast**), stems (**Stipe**), and leaves(**Blades**).
  - Many seaweeds are brown algae, like ***Laminaria*, which is used for Japanese kombu. It is heteromorphic.
  - ****Algin**, which is used in foods like pudding, comes from the cell wall of brown algae.
- **Oomycetes:** Has no plastids, so gets nutrients as a decomposer or parasite. Oomycetes look like fungi, and act like fungi, but are not fungi since they have *cellulose* in their walls, not chitin.
  - **Water molds (decomposers, freshwater), white rusts, and downy mildews (parasites, land)
  - ** *Phytophthora infestans* causes potato late blight, which resulted in the Irish potato famine




▲ **Figure 28.16 The life cycle of the brown alga *Laminaria*: an example of alternation of generations.**

**Figure 18:** Life cycle of brown algae.




▲ **Figure 28.17 The life cycle of a water mold.** Water molds help decompose dead insects, fishes, and other animals in fresh water. (Note the hyphal mass growing on the goldfish in the photograph.)

**Figure 19:** Life cycle of water mold.

- **Rhizaria:** This clade is based on DNA evidence. As a result, its members are very diverse in structure, but many of them are amoeba with threadlike/spiky **pseudopodia**. A pseudopod (pseudo = fake, pod = foot) is an extension of the cytoplasm that allows an amoeba to drag itself around.

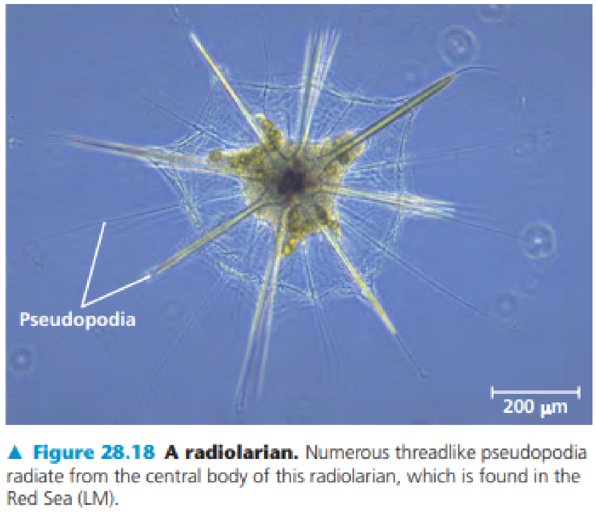



**Figure 20:** A radiolarian; note the spiky pseudopodia.

  - **Radiolarians:** Has *silica* skeletons, which means they form **siliceous ooze**!
  - **Forams (foraminifera):** Has *calcium carbonate* **test**, which means they form **calcareous ooze**! In warmer waters, forams will incorporate more Mg into their tests. This means we can use the calcareous ooze as a proxy to measure past temperatures and, therefore, climates!
  - **Cercozoans:** All the other amoebas in rhizaria. Many of them are parasites or predators:
    * **Chlorarachniophytes are mixotrophs that formed from secondary endosymbiosis
    * ***Paulinella chromatophora* is an autotroph with unique ancestra. They have a weird sausage-shaped internal structure.

## 6.4 Archaeaplastida

This clade contains algae and **plants**. See, this is why Protista is not a true kingdom. Plants, animals, and fungi, which are true kingdoms, are subsets of the clades that we use to classify protists.

- **Red Algae:** Red algae are most abundant in tropical waters. The reddish color is due to the pigment **phycoerythrin**. Since blue light does not penetrate far into open water, there is less phycocyanin and more phycoerythrin the deeper you go. That is why the deeper the algae is, the redder it is. Unlike other algae, red algae lack flagella.

  - ***Porphyra* is used in Japanese nori

- **Green Algae:** These are very similar to plants and contain the closest living relatives to plants. As a result, **Viridiplantae** is an idea for a new kingdom that includes plants and green algae.
  - **Charophytes:** Very similar to plants.
    - *******Chara* and *Coleochaete* are good examples
    - ***Zygnematophyceae* are the most closely related to plants

    Furthermore, these are the only algae to share 4 key characteristics with plants:

    1. Rings (rosettes) of cellulose synthesizing proteins (other algae have linear).
    2. Peroxisomes
    3. Their flagellated sperm have a very similar structure
    4. Phragmoplast
  - **Chlorophytes:** Usually found in freshwater and are simple unicellular organisms, like *Chlamydomonas*. However, some are more complex:
    - *Volvox* can form colonies, which can be in the shape of balls or as filaments that contribute to pond scum.
    - *Ulva* is a multicellular organism that practices alternation of generations (a process that is described in the plants section).
    - *Caulpera* performs repeated cell division without cytokinesis, making a big mass of conjoined cells.

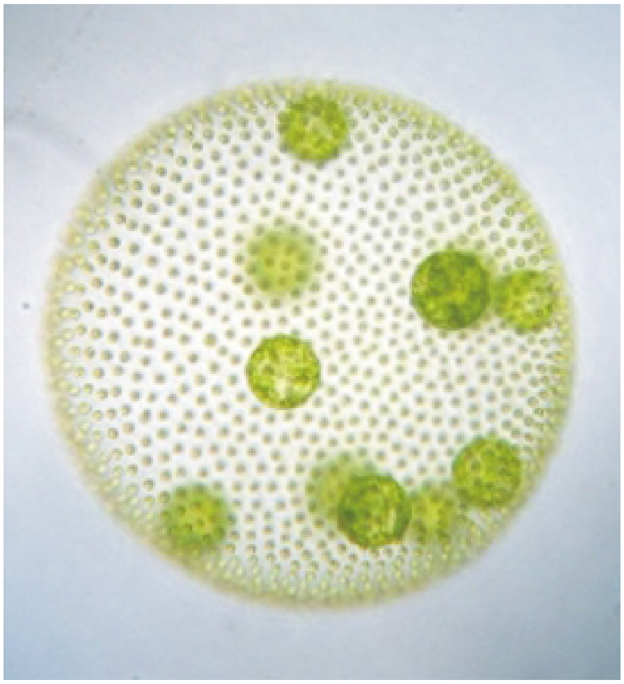


**Figure 21:** Volvox, a chlorophyte that forms colonies.

- **Land plants:** These guys get their own section because they are so important!

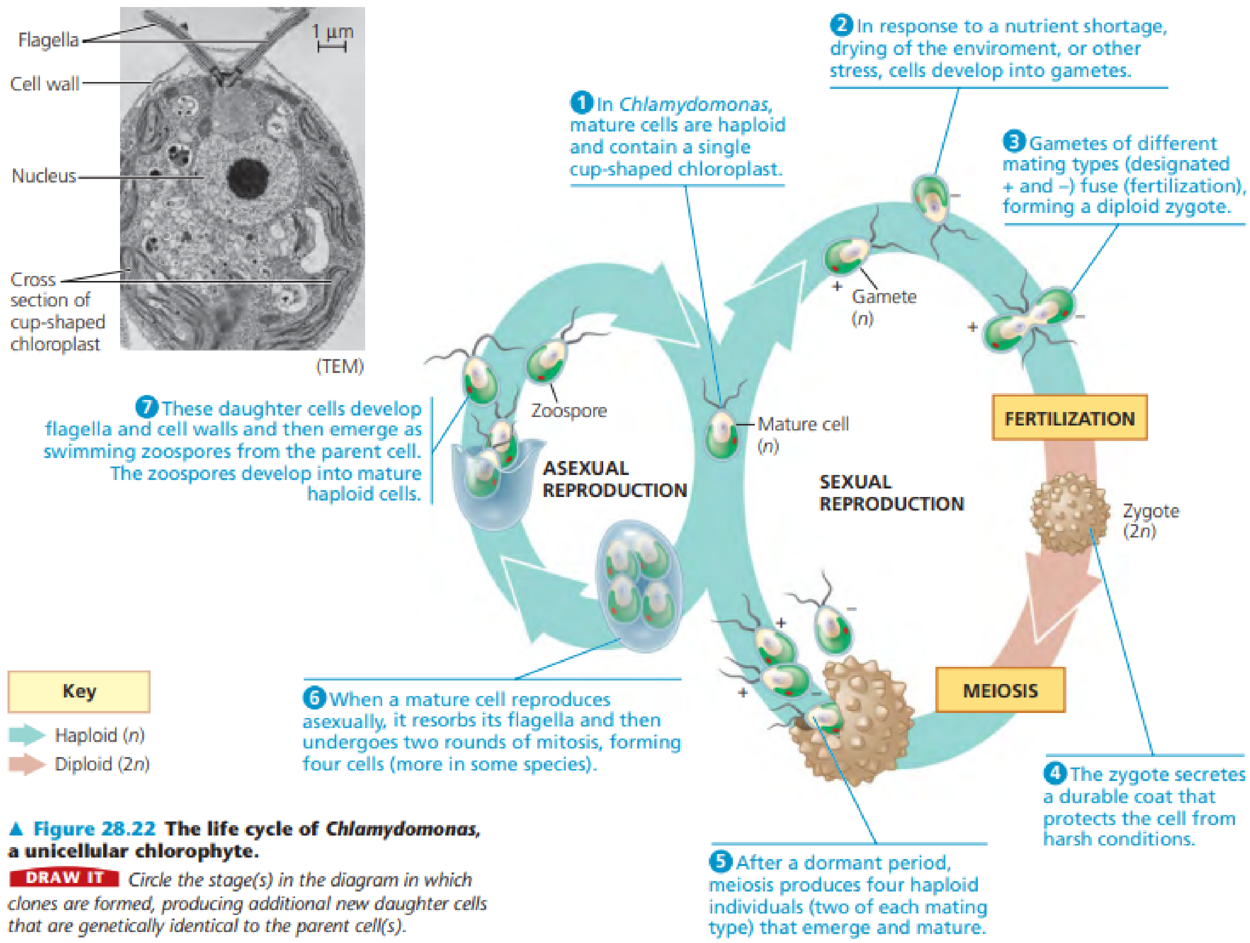



**Figure 22:** Life cycle of an unicellular chlorophyte.

**Example 6.1:** (USABO Opens 2018)

**50. Which is not a similarity between land plants and green algae?**

A. Rosette complexes for cellulose synthesis.
B. Lignified cell walls.
C. Peroxisome enzymes.
D. Structure of flagellated sperm.
E. Formation of a phragmoplast.

**Solution:** This question is simply asking about the 4 traits that land plants and charophytes (a type of green algae) share. Therefore, the **answer is B**, since they share the other 4 choices.

## 6.5 Unikonta

This clade contains Animals, Fungi, and other amoeba-like organisms:

- **Amoebozoans:** These are amoeba with lobe/tube-shaped pseudopodia.
  - **Slime molds (mycetozoans):** They look like fungi, act like fungi, but are not fungi.

They come in two types based on their cell structure:

* **Plasmodial slime molds:** These slimes perform repeated cell division without cytokinesis. As a result, they form a connected mass called a **plasmodium**. They are usually brightly colored yellow/orange. Since all of the cells are connected, cytoplasmic streaming (the movement of cytoplasm fluid from one side of the cell to another) results in a flow that travels across the plasmodium and is cool to watch.

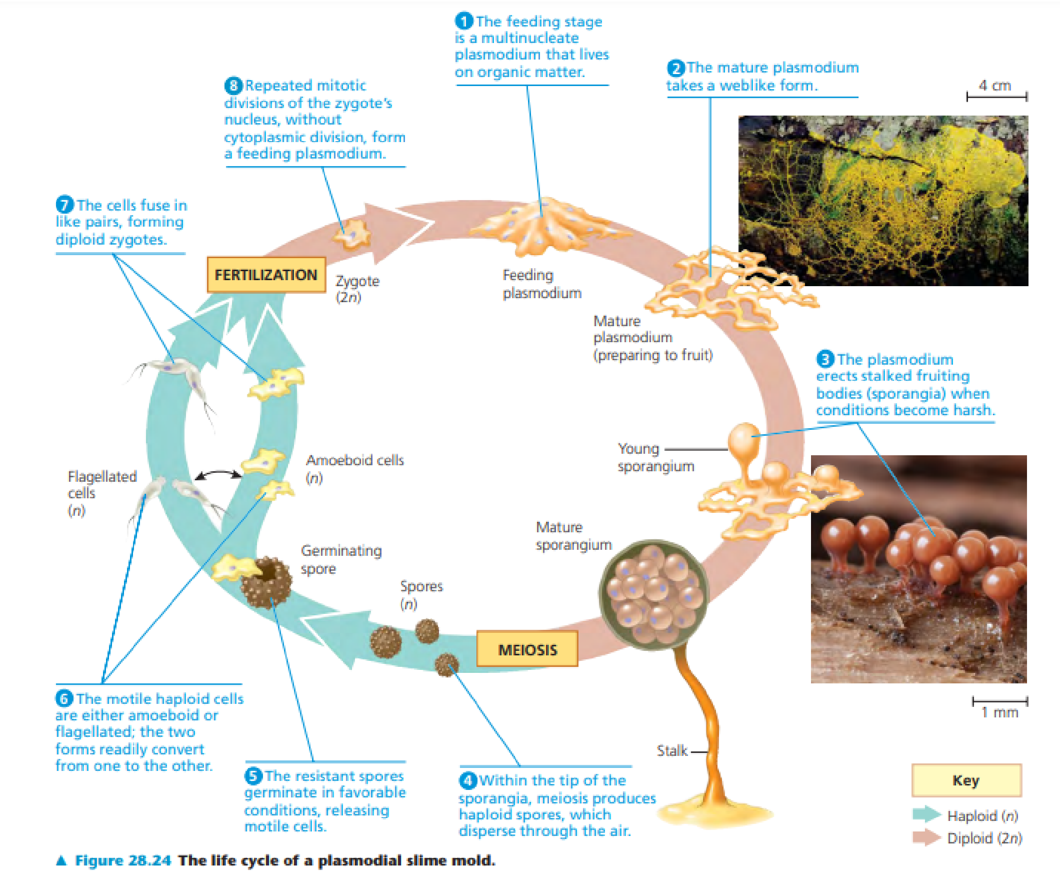



**Figure 23:** Life cycle of a plasmodial slime mold.

* **Cellular slime molds:** Cytokinesis does occur in these organisms. They exist as cells that live on their own. However, when conditions get tough, they aggregate into fruiting bodies, where only the ones at the top get to reproduce. This is what makes *Dictyostelium discoidem* a model organism for studying multicellularity. In a multicellular organism, not all cells get to reproduce. However, if evolution encourages organisms to pass their genes onto the next generation, then it doesn't make sense, for the individual cell, to put yourself in a position where you can't reproduce. Thus, this sort of **altruism**, giving up your own chance at reproduction for another's, doesn't make sense from an evolutionary standpoint. By studying *Dictyostelium*, biologists realized that some cells can be "cheaters", which have a mutation that makes it so that they are *never* part of the stalk. As a result, they are always on the top and always reproduce. Other cells were able to identify cheaters because they lacked specific preoteins on their cell surface and punished the cheaters by excluding them from the fruiting bodies. This is why cells don't cheat on one another, and is one explanation for why altruism exists.

– **Gymnamoebas (Tubulinids):** They don't really have any defining traits. They are just amoeba that do stuff.

– **Entamoebas:** Parasites of vertebrates (and some invertebrates)

  * *E. histolytica* causes amebic **dysentery**

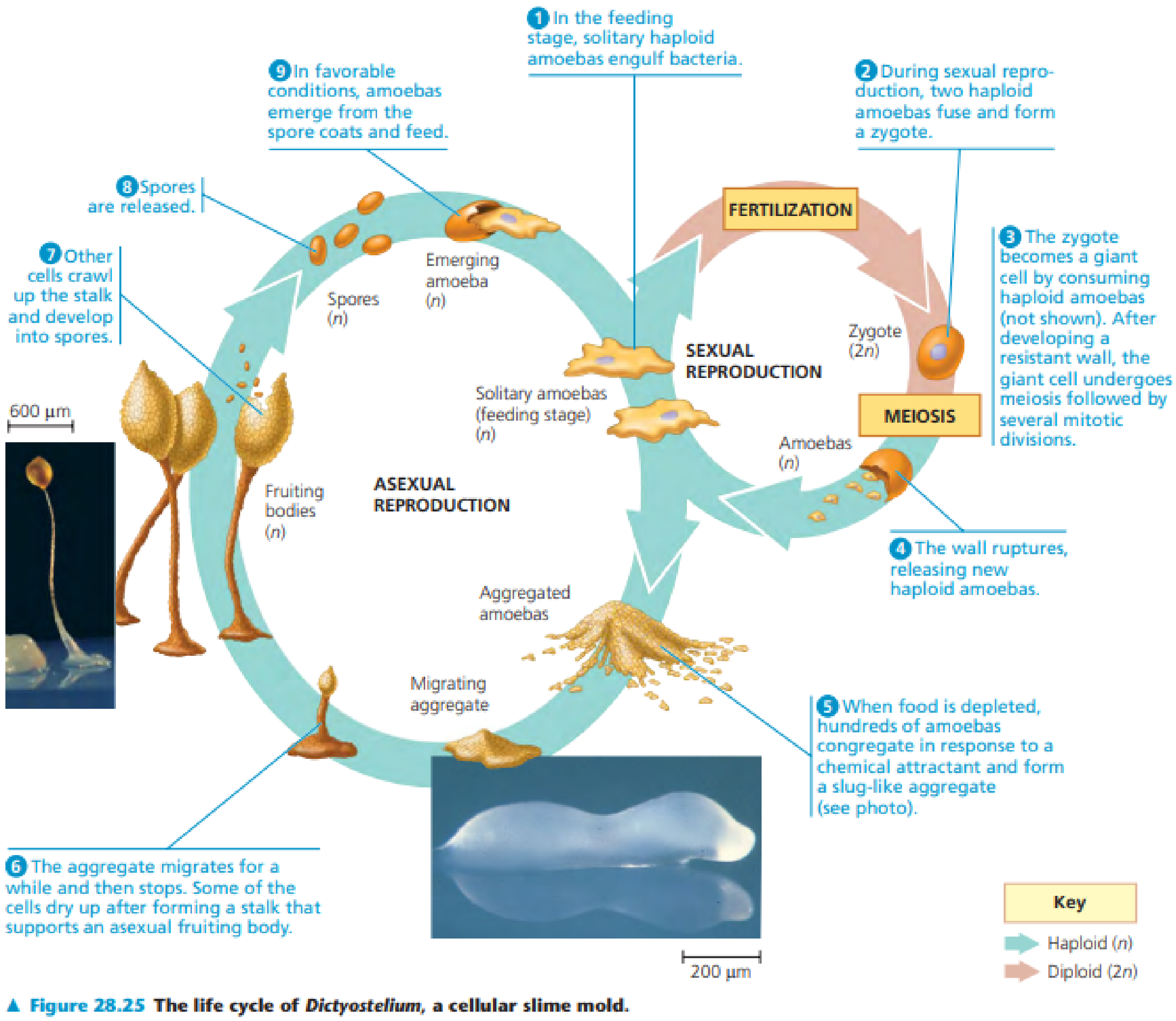



**Figure 24:** Life cycle of a cellular slime mold.

- **Opisthokonta:** This includes fungi and animals and their close relatives!

  – **Nucleariids** and **fungi:** Nucleariids are the closest living relatives of fungi. Fungi are so important they get their own section!

  – **Choanoflagellates** and **animals:** Choanoflagellates are the closest living relatives of animals and contain features found mainly in animals, like cadherin proteins. The coiled coil domain (its a structural feature in proteins) is conserved among animals.

# 7 Plants

## 7.1 Features

Plants practice something known as **alternation of generations**. What this means is that the organism can actually exist in two forms, a *diploid* **sporophyte**, and a *haploid* **gametophyte**. *Diploid* **sporophytes** produce *haploid* **spores**. Spores become the *haploid* **gametophytes**. The gametophytes produce *haploid* **gametes**. Gametes that fuse to create an embryo that will become the sporophyte.

The embryo grows inside the female gametophyte and is nourished by specialized cells called **placental transfer cells**. This is why plants are also called embryophytes. Thus, if one generation is full of sporophytes, the next will be full of gametophytes, and vice versa. This is why it is called alternation of generation! If the gametophyte looks different from the sporophyte, then the organism is **heteromorphic**. If they look the same, then the organism is **isomorphic**. We will see that for the earliest plants, the gametophyte is dominant. However, as plants got more complex, the gametophyte became smaller and the sporophyte became the larger and dominant form.

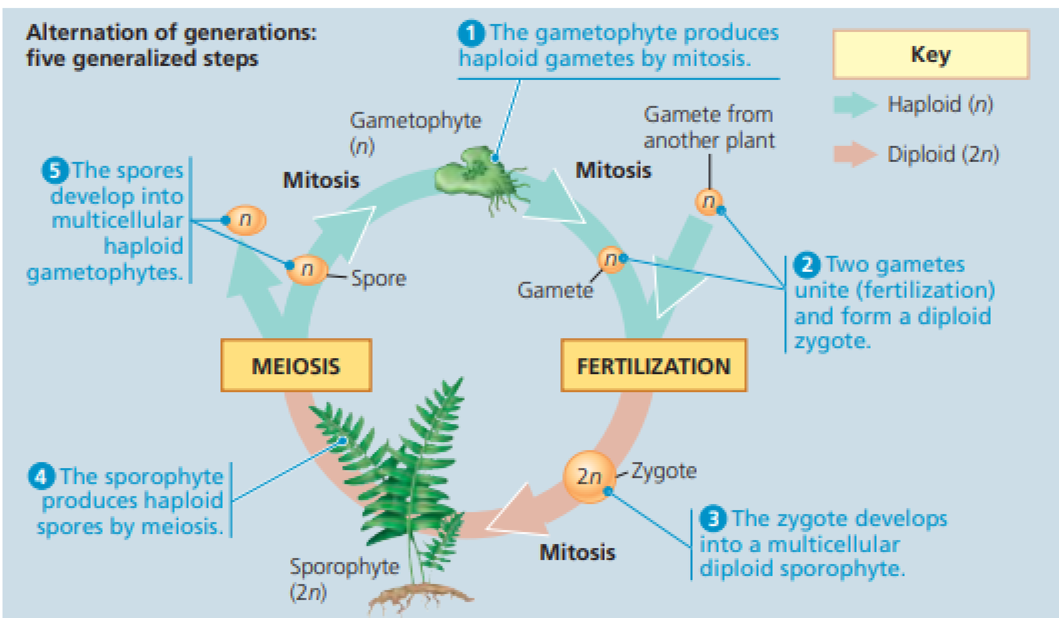



**Figure 25:** Diagram of alternation of generations.

- **Sporangia** are the multicellular organs in the *sporophyte* where spores are made. In the sporangia, the diploid cells that make the spores are called **sporocytes**. The spores are covered by **sporopollenin**, a durable polymer that prevents gametes from drying out. This trait allowed plants to survive on dry land.
- **Gametangia** are the multicellular organs in the *gametophyte* where the gametes are made. The female gametangia is the **Archegonia**, which produces eggs. The male gametangia is the **Antheridia**, which produces sperm.

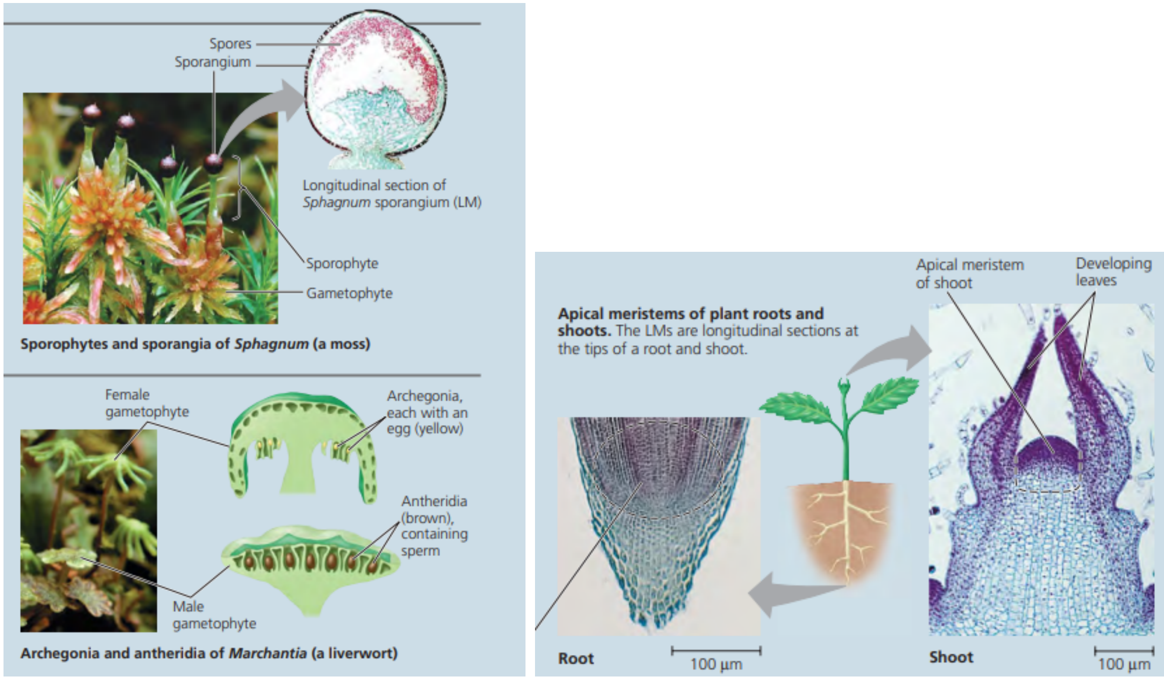



**Figure 26:** Traits unique to land plants.

Alternation of generations is one of the traits that makes plants unique from charophytes.

- Sporopollenin in the spore walls is another unique feature, allowing plants to move from the water to dry land. Plants have also adopted other traits that make them better adapted for dry land, such as a waxy **cuticle** and **stomata** on their leaves. As we move to more evolved plants, we will see that they stop relying on water and instead display these features.
- **Apical meristems** are regions of meristematic tissue at the tips. These regions are unique to plants, allowing them to continuously grow.

## 7.2 Bryophytes (Nonvascular plants)

Bryophytes, being some of the earliest plants, lack vascular tissue. As a result, they grow low and near water. Another reason why bryophytes grow near water is that the sperm needs water to swim to the egg.

The gametophyte is the dominant stage:

- **Protonema:** One-cell thick filaments that cover the ground like carpet.
- “buds” result in gametophores (basically the gametangia of seedless plants).
- **Rhizoids:** Fake roots! What makes them different from roots is that they are mainly for *anchorage*, while true roots are mainly for absorption of water/nutrients. *In mosses, rhizoids are made up of filaments of cells. In liverworts and hornworts, rhizoids are made up of a single, elongated cell.
- **Brood bodies:** These are tiny plantlets that break off from the main plant, resulting in a form of asexual reproduction.

The sporophyte is dependent on the gametophyte for nutrition:

- **Foot:** fake root
- **Seta:** analog to stem
- **Capsule:** The tip where spores are released. There is a ring of teeth on the capsule, called the **peristome**, which functions as the opening mechanism. In dry conditions, the peristome opens. In wet conditions, the peristome closes.

Bryophytes contain 3 major clades:

- **Liverworts (Hepatophyta):** Liverworts are the basal taxon of plants, meaning they were the first to branch off. Their gametophyte can be described as either **thalloid** (liver-shaped) (**Marchantia*) or leafy (***Plagiochila*)

  This is the only clade to not have a cuticle in either generation.

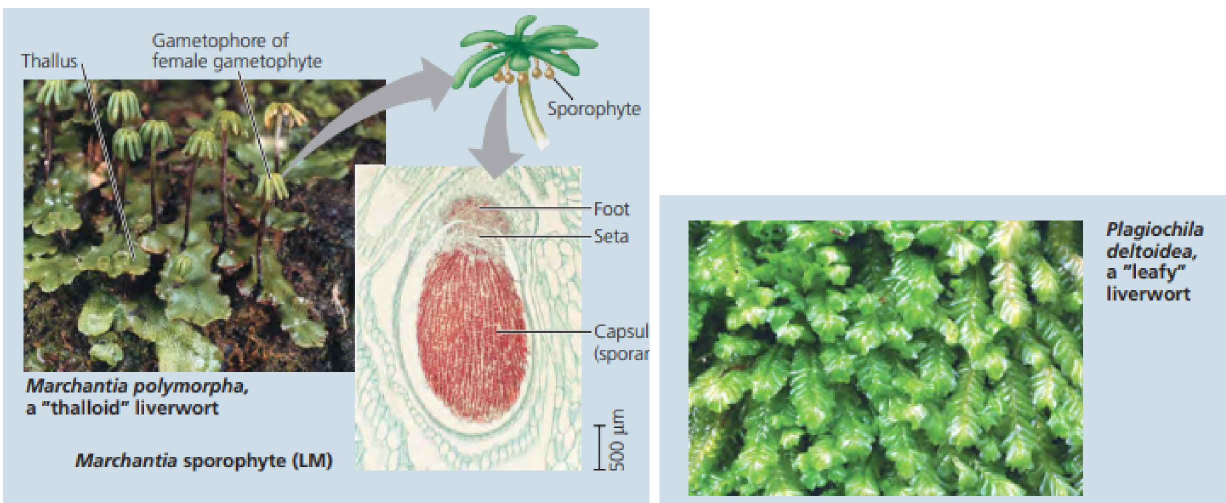



**Figure 27:** Examples of liverworts.

- **Mosses (Bryophyta):** Their name causes Bryophyta to often be confused with Bryophytes. Bryophyta means moss, and is the clade that contains mosses. Bryophytes means moss-like, and includes all of the non-vascular plants Mosses have long sporophytes (20cm tall) and can live in extreme environments.
  - *Sphagnum* moss in bogs gets turned into peat. LOW everything (acidity, oxygen content, temperature, etc.) prevents the decomposition of peat, allowing for coal formation! **Phenolic compounds in the moss protect it from UV radiation.

  There are many organisms that are called mosses but are actually not. The most common fake mosses are:

  - Spanish moss: it's either a lichen or flowering plant depending on the species
  - Club mosses: it's a seedless vascular plant
  - **Irish moss: it's a red seaweed

– **Reindeer moss: it's a lichen

- **Hornworts (Anthocerophyta):** Forms a carpet where the sporophytes stick out as tiny horns (hence the name). The gametophyte does *not* have cuticles.


**Figure 28:** Sporophyte and gametophyte of a hornwort (left) and moss (right).

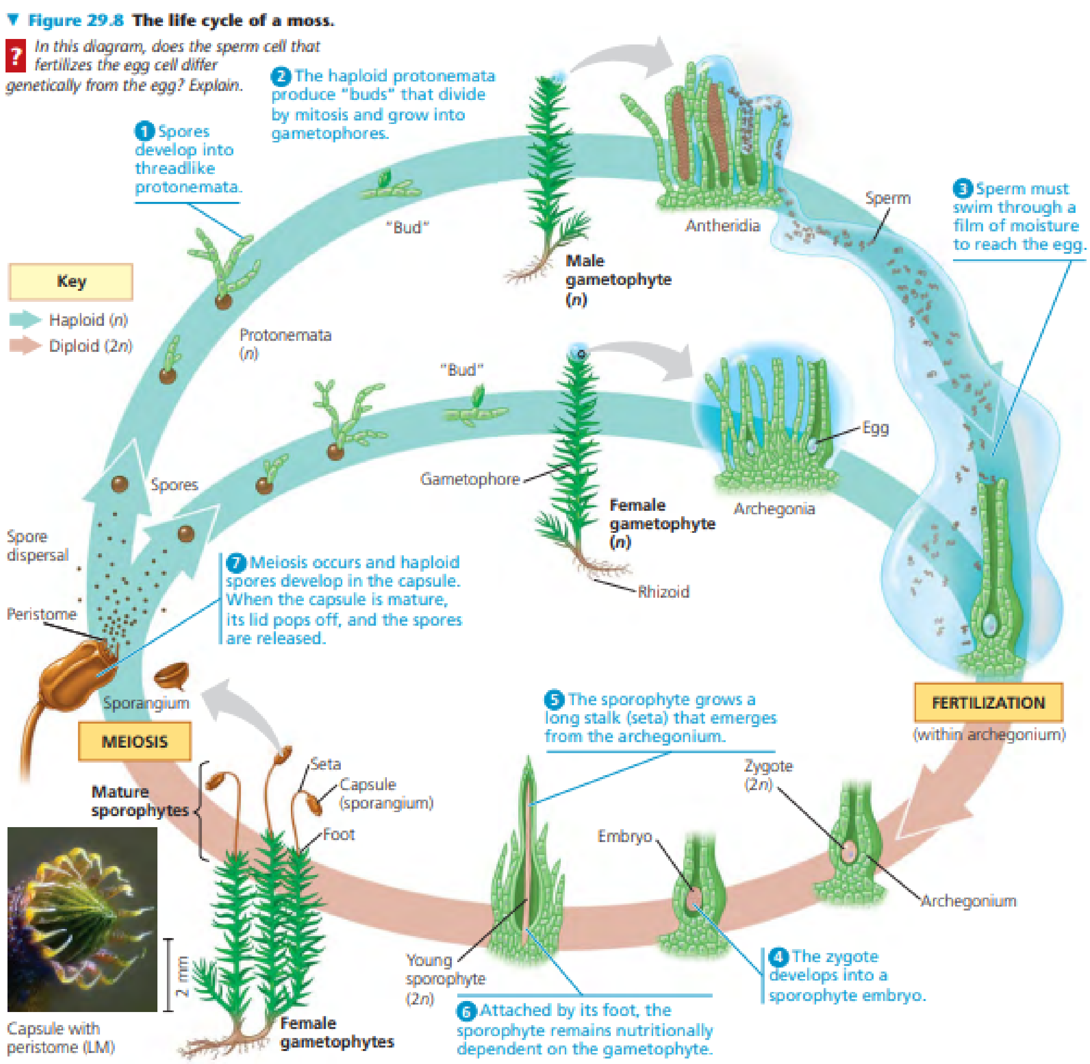



**Figure 29:** Life cycle of a moss.

## 7.3 Seedless vascular Plants

These plants have a vascular system, allowing them to grow taller. Seedless vascular plants first emerged during Devonian period, but died out when the climate got drier. Like bryophytes, their sperm swims through water to reach the egg, so they are usually found in damp environments. Unlike bryophytes, the **sporophyte** is dominant! In addition, seedless vascular plants are vascular, which means they have **xylem**, **phloem**, **roots**, and **leaves**. However, these structures are not fully developed, so they are not considered "true".

Leaves can be classified:

- **Microphylls:** small spine-shaped leaves connected by a single vascular strand. They are found in **Lycophytes** only!
- **Megaphylls:** leaves with a branched vascular system. Their formation is described by the **Zimmermann telome theory**, which says that the steps of megaphyll formation are **overtopping**, **planation**, and **webbing**. These steps describe how branches can grow on top of each other, eventually merging into one leaf.

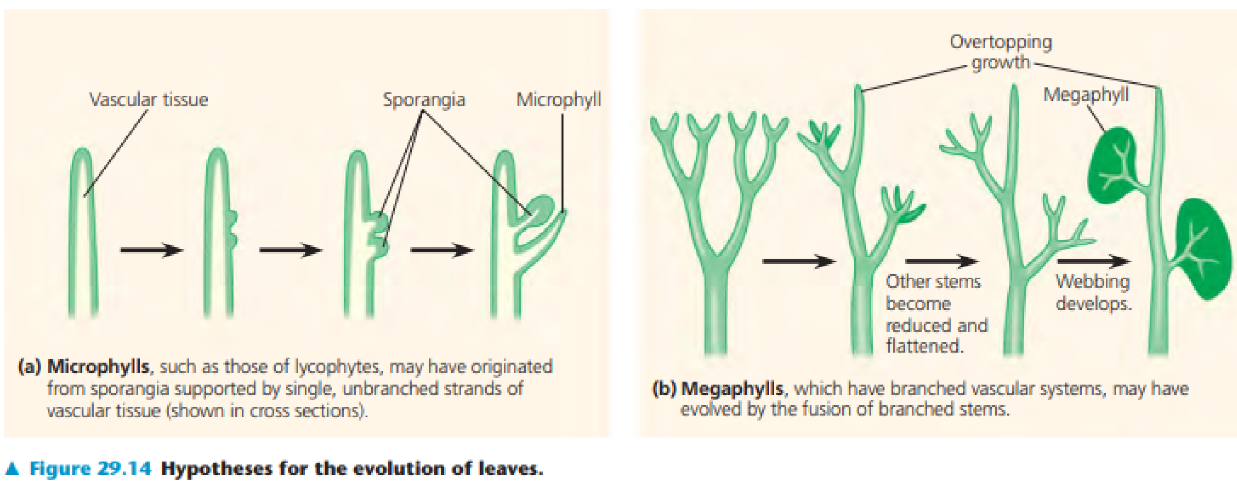



**Figure 30:** Diagram showing how microphylls and megaphylls may have formed.

- **Sporophylls:** modified leaves that bear sporangia. There are many layers to the organization of sporangia; from largest to smallest, they are **Strobili** > **Sporophylls** > **Sori** > sporangia. Essentially each of these terms is just a collection of the next smallest thing.

  Most seedless vascular plants are **homosporous:** they have one type of sporophyll that makes spores. These spores become bi-sexual gametangia that produce both eggs and sperm.

  All seed plants and a few seedless vascular plants (**spike mosses** and **quillworts**) are **heterosporous**:

  - **Megasporangia:** these make **megaspores**, which become the *archegonia* (produces eggs).
  - **Microsporangia:** These make microspores that become *antiheridia* (produces sperm).

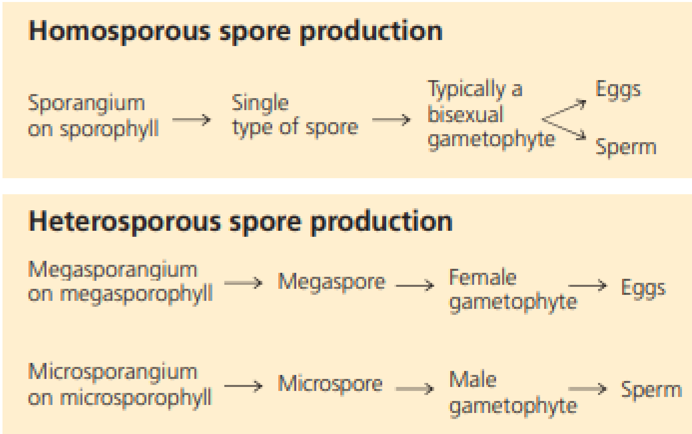



**Figure 31:** Types of spores.

The seedless vascular plants fall into two major groups:

- **Lycophytes (Lycophyta):** Many lycophytes are **epiphytes**, plants that grow on other plants. Their roots only branch at the tip, so they make a Y shape.
  - **Club mosses:** They produce cloud spores so rich in oil that magicians use them as flash bombs!
  - **Spike mosses**
  - **Quillworts**

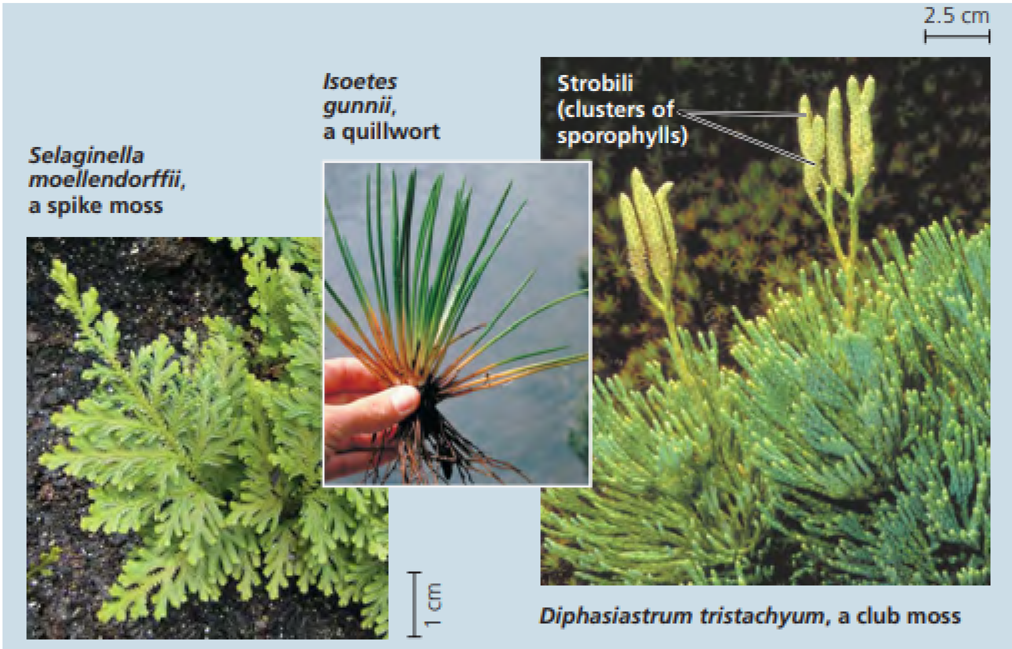



**Figure 32:** Examples of lycophytes.

- **Monilophytes** ((Used to be called **Pterophytes (Pterophyta)**))
  - **Ferns:** ferns have large leaves that are called **fronds**. The coiled tips of fronds are called **fiddleheads**. Some ferns catapult their spores with a springlike structure

- **Horsetails:** Also called arthrophytes (jointed plants) because their stems have joints where rings of leaves grow out of. Their roots usually grow in waterlogged soil.
- **Whisk ferns:** These are the simplest nonvascular plants. They have no roots! In addition, they have scale-like outgrowths that lack vascular tissue.

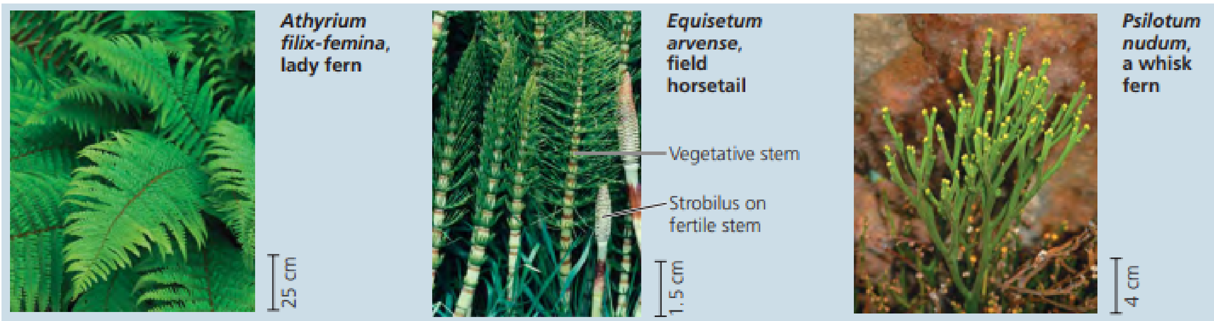



**Figure 33:** Examples of monilophytes.

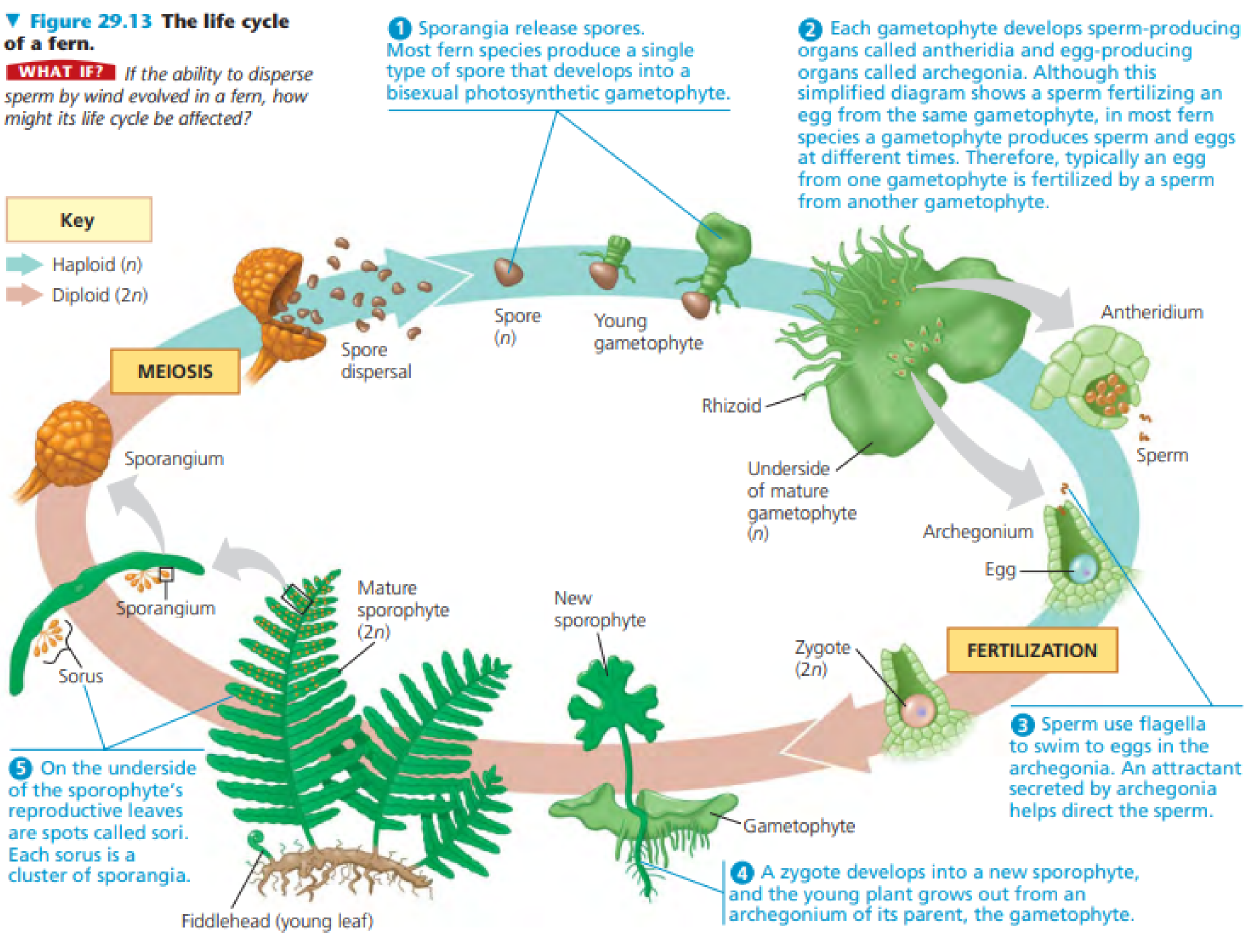



**Figure 34:** Life cycle of a fern.

## 7.4 Seed plants

In seed plants, the gametophyte is so reduced that it is actually tiny enough that it can grow *within* the sporangia, keeping it protected. All seed plants are heterosperous:

- The archegonia contains ovules, which becomes the **seed** after fertilization. Seeds are useful because the contain plenty of nutrients in them and will only **germinate** (begin growing) during favorable times. This allows for better survival of the offspring, which explains why seed plants have been so successful. In flowering plants, the ovules are contained within an **ovary** (AKA: embryo sac), which will become the fruit after fertilization.
- The antheridia produces pollen grains. What makes seed plants unique is they no longer need water for pollination (fusion of gametes), making them better adapted to drier climates.

Seed plants fall into two major clades:

### 7.4.1 Gymnosperms

Their name means "naked seeds", which remarks on the fact that they lack an ovary (fruit) to protect the seed. Instead, seeds are stored in **cones**. Gymnosperms became dominant near the end of the Permian.


**Figure 35:** Examples of Gnetophytes.

Gymnosperms have 4 major clades:

- **Progymnosperms:** fossils that show the evolutionary transition from seedless vascular plants to gymnosperms. The most famous examples is *Archeopteris.
- **Conifers (Coniferophyta):** This is the largest phylum of gymnosperms. conifers are mostly **evergreen**, but some of them are **deciduous**. Here are a few examples:
  - **Douglas fir: quick growing tree that provides most of commercial timber.
  - **Common juniper: their "berries" are actually fleshy cones
  - **European larch: an example of a deciduous conifer
  - **Wollemi pine: a living fossil
  - **Sequoia: these are the tallest trees in existence
  - **Bristlecone pine: these are the oldest trees in existence
- **Gnetophytes (Gnetophyta):** Made up of only 3 genus
  - *Gnetum*
  - *Ephedra*
  - *Welwitschia*

- **Cycads (Cycadohyta):** Cycads have cones and palm-like leaves. They were prominent during the Mesozoic (dino time). They have flagellated sperm.


**Figure 36:** Examples of cycads (left) and ginkgos (right).

- **Ginkgos (Ginkgophyta):** This is the most unique gymnosperm, with only one surviving member: *Ginkgo bilboa* (AKA: maidenhair tree).

  Has flagellated sperm. This tree is deciduous, dioecious, and has leaves that do not possess a central vein but do have dichotomous venation. They are often used in decorations, but only the males because the females produce stinky seeds. TLDR: they are super weird.

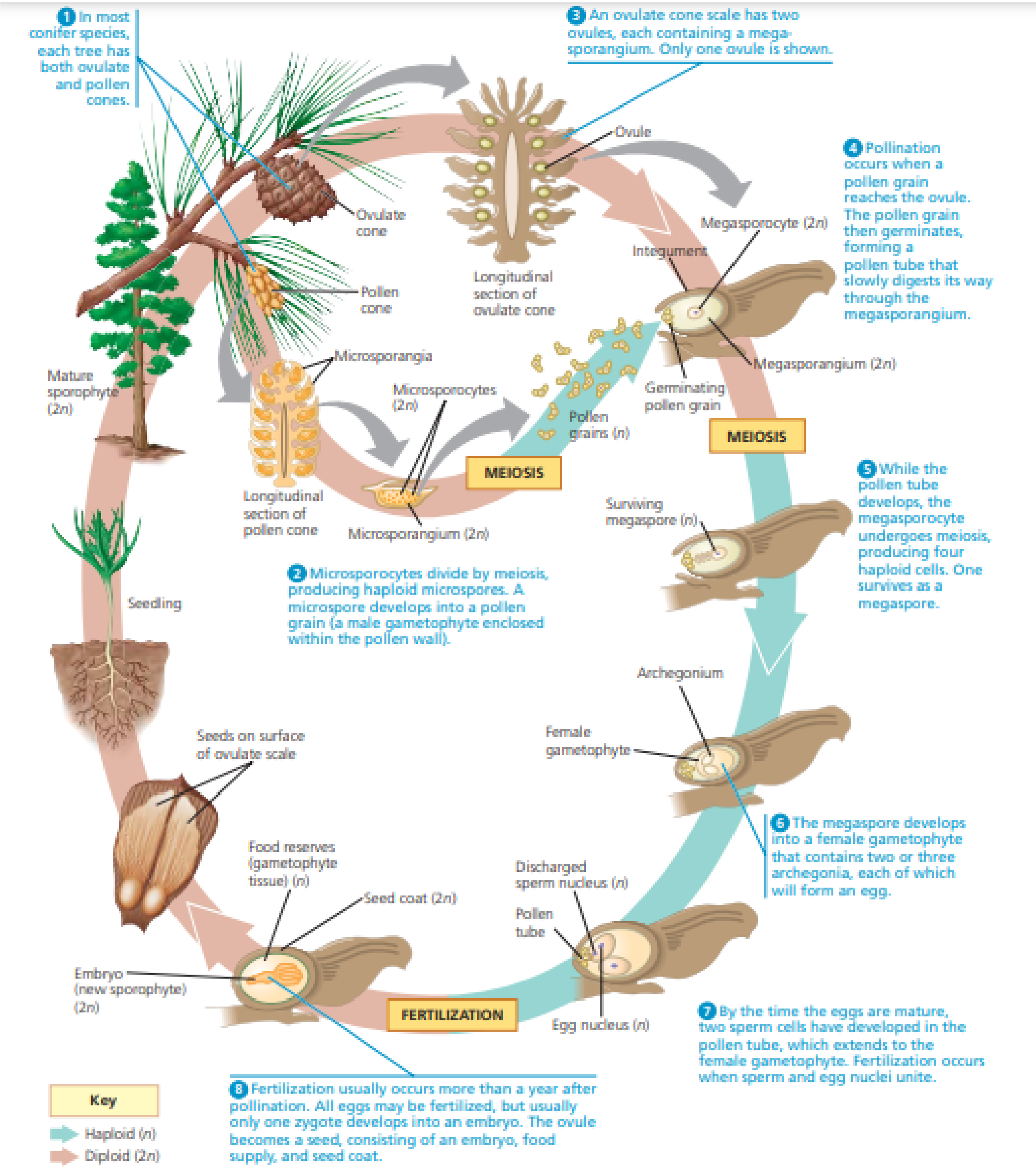



**Figure 37:** Life cycle of a gymnosperm.

### 7.4.2 Angiosperms (Anthophyta)

These are the flowering plants! If you ask someone to name a plant, it is very likely they are thinking of an angiosperm. Angiosperms are the most diverse and abundant of all plants coming into dominance at the end of the Mesozoic. They have flowers and fruits, which means that they practice **double fertilization** (some gymnosperms have double fertilization, but it results in 2 embryos so it doesn't really count as double fertilization). For more info on how angiosperms work, check out any of the handouts on plants!

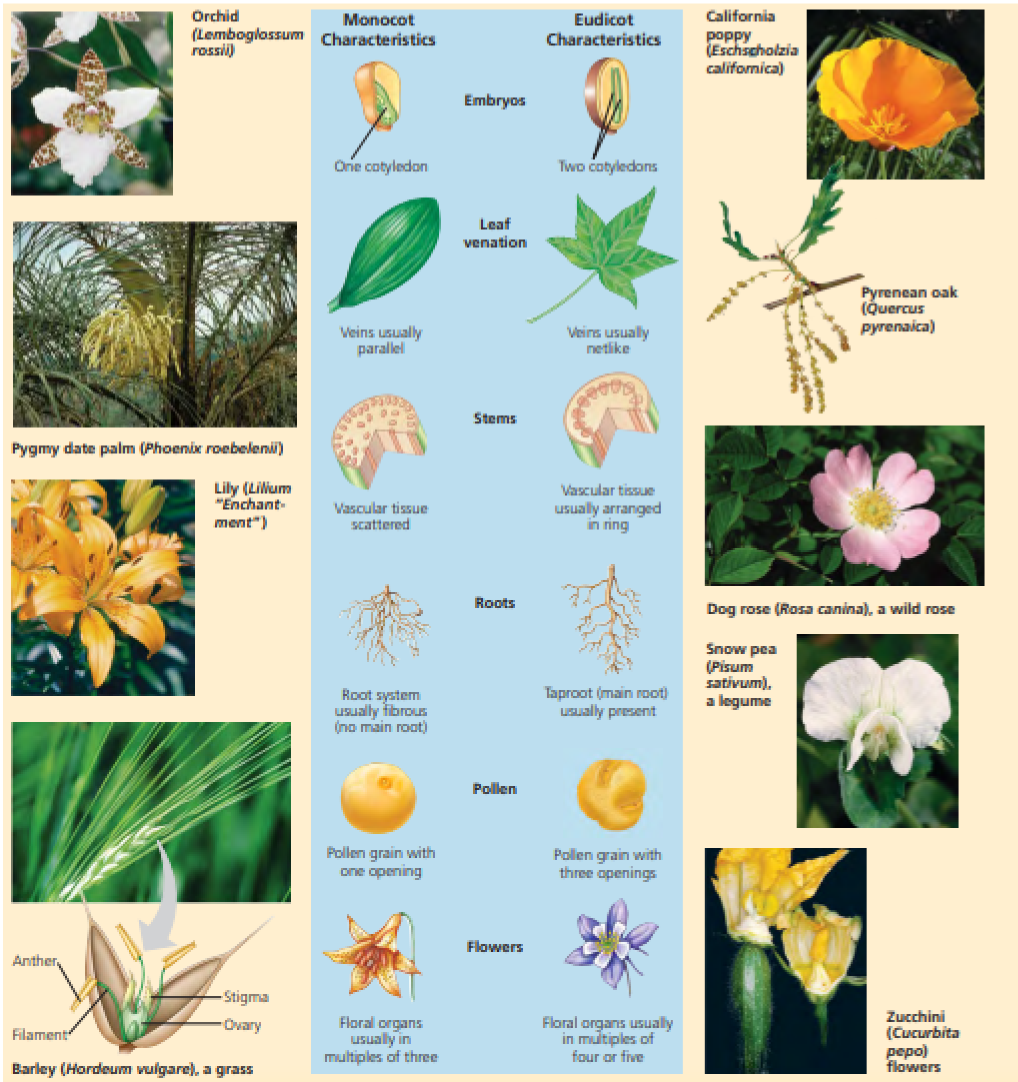
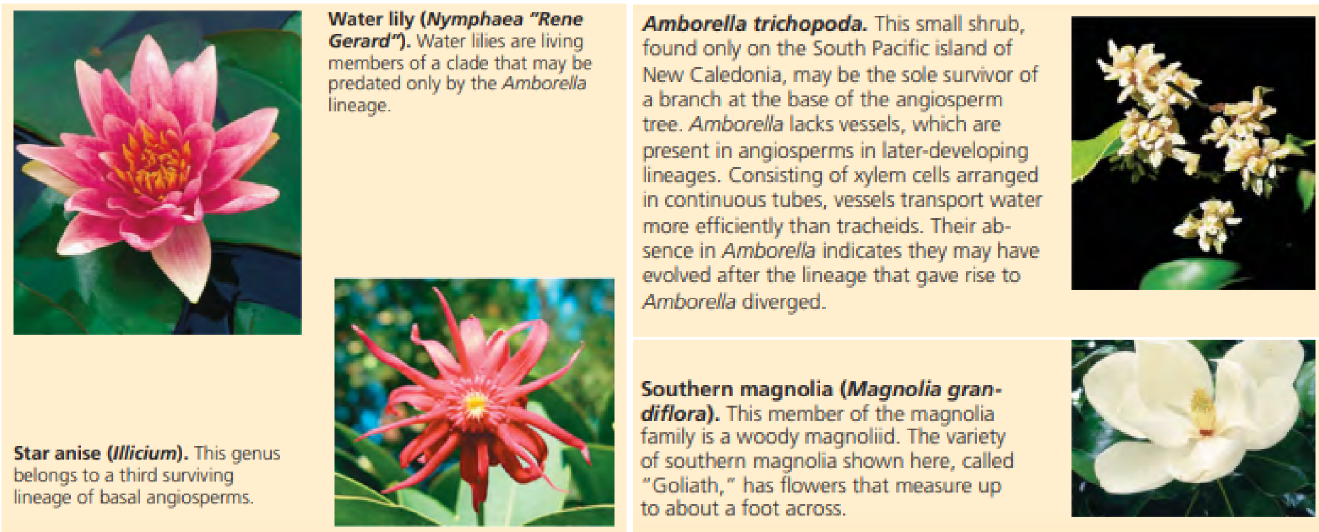



**Figure 38:** Chart comparing features of monocots and dicots, which you should memorize.

Angiosperms are mainly divided into **Monocots** and **Dicots**, whose traits are compared in the chart above. However, it was discovered that Dicots are not a true clade. Instead, they are split into three groups:

- **Eudicots:** These are the true dicots.
- **Basal Angiosperms:** These are the basal taxon, the first diverge from the rest of the angiosperms.
  - ***Amborella trichopoda* was technically the first to diverge
  - Water lilies
  - Star anises and their relatives

- **Magnoliids:** these organisms are very similar to the basal angiosperms. This clade contains both woody and herbaceous plants.



**Water lily (*Nymphaea* "Rene Gerard").** Water lilies are living members of a clade that may be predated only by the *Amborella* lineage.

**Star anise (*Illicium*).** This genus belongs to a third surviving lineage of basal angiosperms.

***Amborella trichopoda*.** This small shrub, found only on the South Pacific island of New Caledonia, may be the sole survivor of a branch at the base of the angiosperm tree. *Amborella* lacks vessels, which are present in angiosperms in later-developing lineages. Consisting of xylem cells arranged in continuous tubes, vessels transport water more efficiently than tracheids. Their absence in *Amborella* indicates they may have evolved after the lineage that gave rise to *Amborella* diverged.

**Southern magnolia (*Magnolia grandiflora*).** This member of the magnolia family is a woody magnoliid. The variety of southern magnolia shown here, called "Goliath," has flowers that measure up to about a foot across.

**Figure 39:** Examples of basal angiosperms and magnoliids.

**Example 7.1:** (USABO Opens 2016)

**34. Arrange the following genera from earliest to latest on the evolutionary time scale:**

**I. Amborella.**
**II. Pteridum.**
**III. Sphagnum.**
**IV. Gnetum.**
**V. Pisum.**

A. I, II, III, IV, V.
B. I, III, II, IV, V.
C. II, III, IV, V, I.
D. III, II, IV, I, V.
E. III, II, IV, V, I.

**Solution:** This question is difficult, as it tests knowledge on all groupings of plants. Amborella is a basal angiosperm. Pteridum refers to our pterophytes, so it's a fern. Sphagnum is refering to the Sphagnum moss that becomes peat. Remember that Gnetum is one of the weird gymnosperms. Finally, we have not talked about Pisum (Peas, an angiosperm), but you could have gotten far into the question without that knowledge. Generally, if you hear a plant name and it is not one of the ones discussed in this lesson, it is likely an angiosperm. We know that mosses, a nonvascular plant, came before ferns, a seedless vascular plant, came before gymnosperms, which came before angiosperms. Therefore, that gives us the answer Sphagnum, Pteridum, Gnetum, Amborella, Pisum, **which is D**.

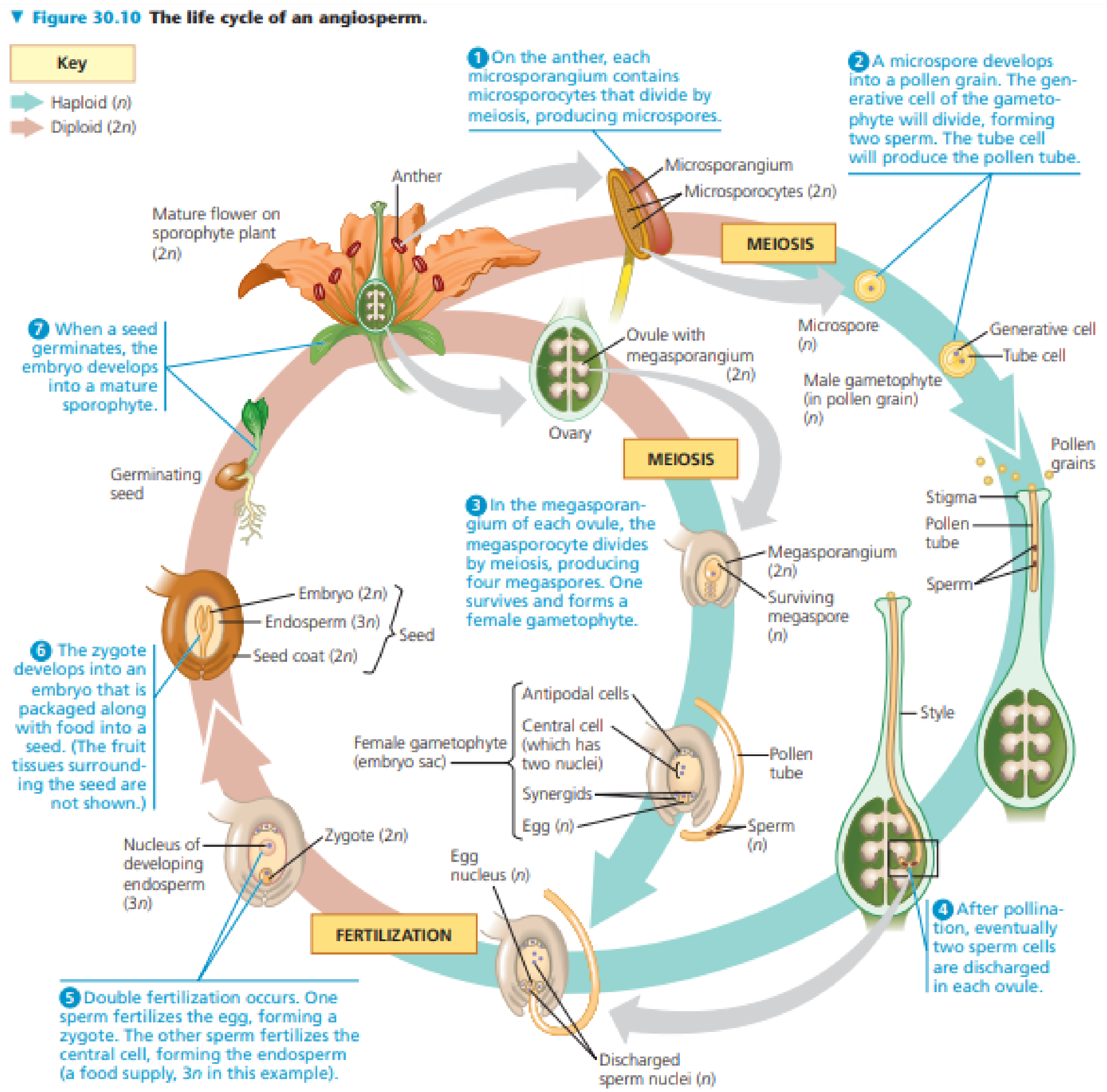



**Figure 40:** Life cycle of an angiosperm.

# 8 Fungi

People often believe that fungi look like plants, when in reality, they are much closer to animals. They don't perform photosynthesis and instead gain their nutrients through **saprophytic feeding**. They secrete digestive enzymes into their environment and then absorb the digested nutrients. For this reason, fungi act as decomposers, but they can also be parasite, or mutualistic symbionts. They form a crucial part of many ecosystesms, so its important to understand what fungi really are.

## 8.1 Features

Fungi can exist as single cells (**yeast**), or as multicellular filaments (**hyphae**). A mass of hyphae is called a **mycelium**. The hyphae can either be divided by **septa** (sorta like cell walls), or be a connected mass called a **coenocytic fungi**.

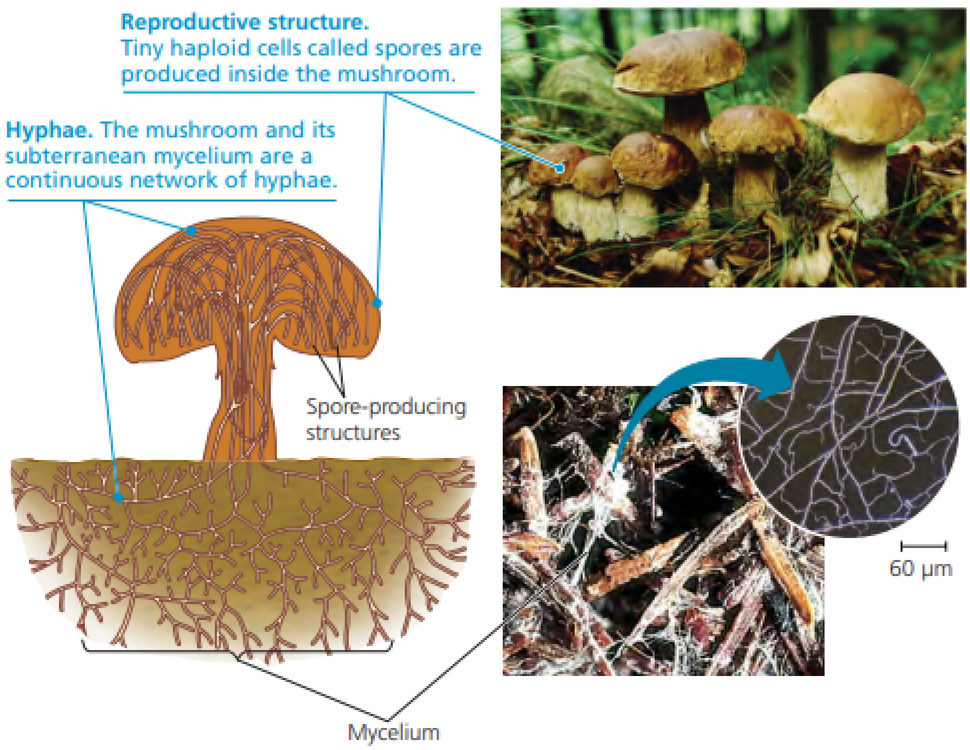



**Figure 41:** Fungi structure diagram. The mushrooms we see are part of a much larger organism.

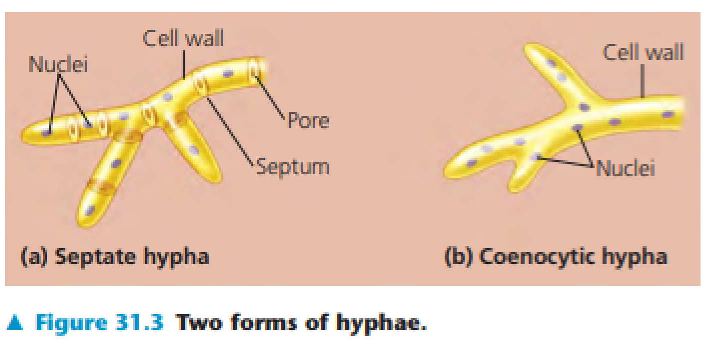



**Figure 42:** Types of hyphae.

The structure of fungi allows them to form unique connections with many organisms:

- **Haustoria** are specialized hyphae that fungi use to exchange nutrients with plants. This fungi/plant relationship is called **mycorrhizae**.
  - **Ectomycorrhizal fungi:** sheats of hyphae cover the plant roots.
  - **Arbuscular mycorrhizal fungi:** hyphae called arbuscules stick directly into plant cells **Arum** type mycorrhizae have the haustoria travel mainly between cell walls while **Paris** type mycorrhizae have the haustoria mainly inside the plant cells.

  - **Sym genes** are 3 special genes in flowering plants that allow them to form mycorrhizae.

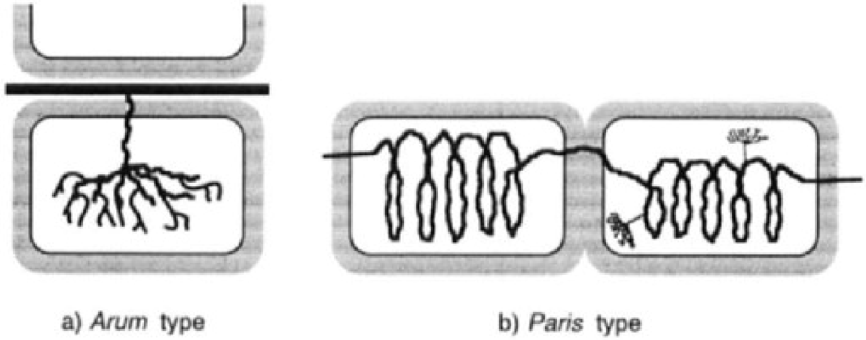



**Figure 43:** Types of arbuscular mycorrhizae. (Source: SienceDirect.com)

- **Endophytes:** symbiotic fungi that live *inside* plants without harming them. In fact, they help deter pathogens and herbivores. Most are ascomycetes.
- *Carpenter ants raise fungi farms! The ants bring leaves that they can't eat to the fungi. The fungi digest the leaves and get nutrients. Then, they make specialized hyphae where the tips are loaded with nutrients that the ants can munch on :)
- **Lichen:** A symbiotic relationship between a fungus (usually ascomycete but can also be mucoromycete or basidiomycete) and a photosynthetic microorganism (usually **cyanobacteria** or green algae). The symbiotic relationship is so close that the lichen is sometimes considered a species of its own. Lichem grow in three forms **crustose**, **foliose**, **fruticose**.

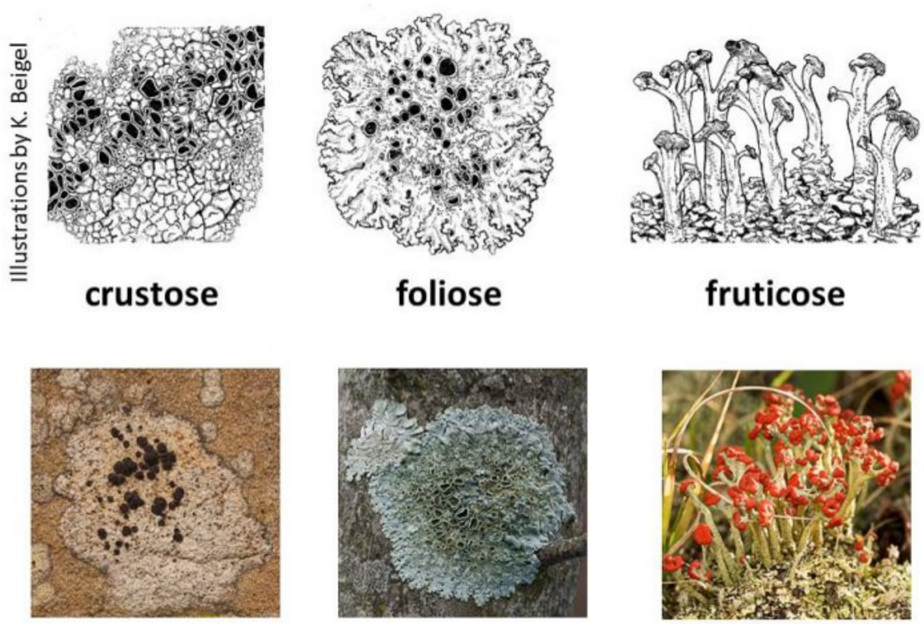



**Figure 44:** Types of lichen. (Source: Ohio Plants.org)

Lichen act as pioneer species, meaning they are the first to colonize new land. Lichen reproduce by having bits of them break of and form new lichen. This can happen in two ways:

– **Soredia:** are tiny, rounded, powdery balls of algae wrapped in hyphae.
– **Isidia:** are stalked outgrowths that are covered by a definite cortex.

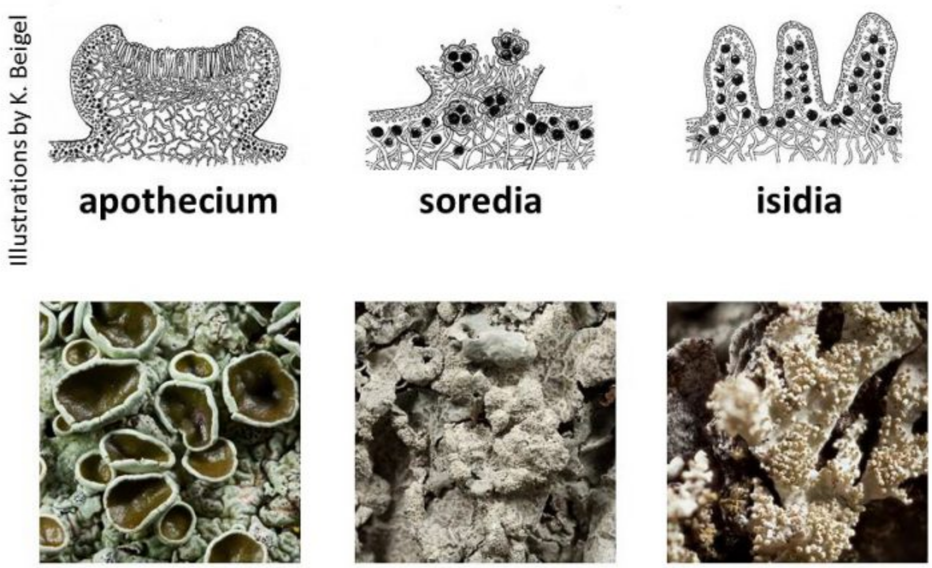
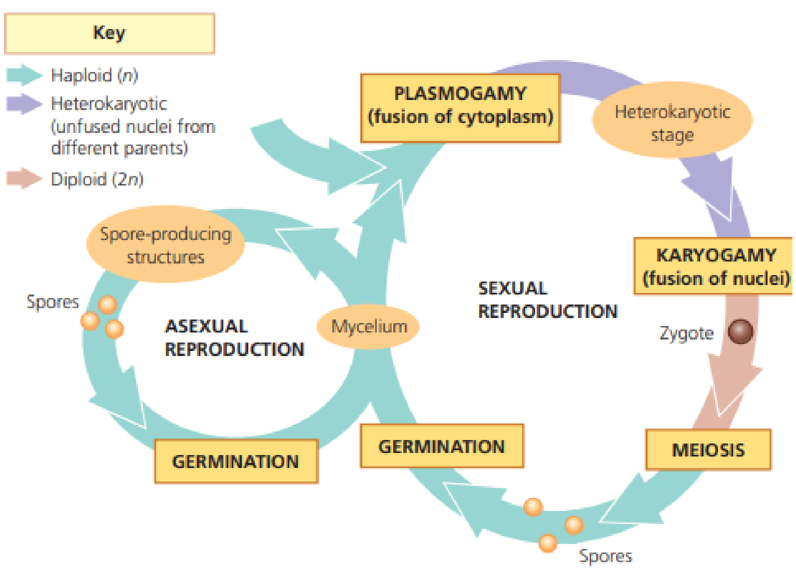



**Figure 45:** Different forms of reproduction for lichen. (Source: Ohio Plants.org)

Fungi use their hyphae to reproduce in a unique manner that results in a single cell having 2 nuclei! Fungi spend most of their time as a **haploid** organism. They can spread asexually through **spores**. The fungi that use spores are **molds**. The other option for asexual reproduction is as single celled yeasts.




▲ **Figure 31.5 Generalized life cycle of fungi.** Many—but not all—fungi reproduce both sexually and asexually. Some reproduce only sexually, others only asexually.

**Figure 46:** Life cycle of fungi.

Sexual reproduction begins when **pheromones** cause hyphae of two different mating types to attract. The two hyphae meet and fuse their cytoplasm. This is known as **Plasmogamy** (fusing of plasmas). Plasmogamy results in a cell with multiple nuclei, called a **heterokaryon** (different nucleus). If there are specifically 2 nuclei, then it is **dikaryotic**. After plasmogamy is **karyogamy** (fusing of nuclei). Karyogamy causes the two nuclei to fuse, making a zygote. The *diploid* zygote then undergoes meiosis to make spores. Any fungi that lack a means of sexual reproduction is lumped into the informal group **Deutero-mycetes**.

## 8.2 Basal fungi

Although most fungi lack flagella, many of the basal fungi have flagellated sperm. Thus, it is likely that fungi originated from a flagellated ancestor. There are three main basal groups of fungi:

- **Nucleariids:** This is the most basal group, and is often considered the closest living relative to fungi.
- **Cryptomycetes:** These are found in diverse environments. They are unicellular and have flagellated spores. Many of them are parasites of protists and other fungi:
  - *******Rozella allomycis*
- **Microsporidia:** This basal group is cool because its spores don't have flagella so instead they use harpoons to move. They possess reduced mitochondria and a small genome:
  - ***Encephalitozoon intestinalis* has only 2.3Mbp of DNA, which is the smallest genome of any eukaryote!

  Many microsporidia function as unicellular parasites of animals and protists. Although they are mostly harmless, there are some notable examples:
  - ***Nosema ceranae* causes **CCD (colony collapse disorder)** in honeybees.

## 8.3 Chytrids

Chytrids have flagellated **zoospores**. *The most notable chytrid is *Batrachochytrium dendrobatidis*, which poses a serious threat to killing nearly all amphibians.

## 8.4 Zoopagomycota

Zoopagomycota is full of mainly parasites (of protists and other fungi) or fungi that do commensalism with animals. Following plasmogamy, they form a special structure where karyogamy occurs. This structure is the **Zygosporangium** and is very resistant to the environment.

## 8.5 Mucoromycetes

Mucoromycetes includes fungi that form arbuscular mycorhizae and molds that grow quickly. They also form **Zygosporangium**.

## 8.6 Zygomycetes?

This clade used to be defined by organisms that formed a Zygosporangium and included many fast-growing molds of food. However, it turns out that this was paraphyletic.

- ***Rhizopus stolonifer* is black bread mold
- ***Pilobolus* can aim and shoot their sporangia towards light

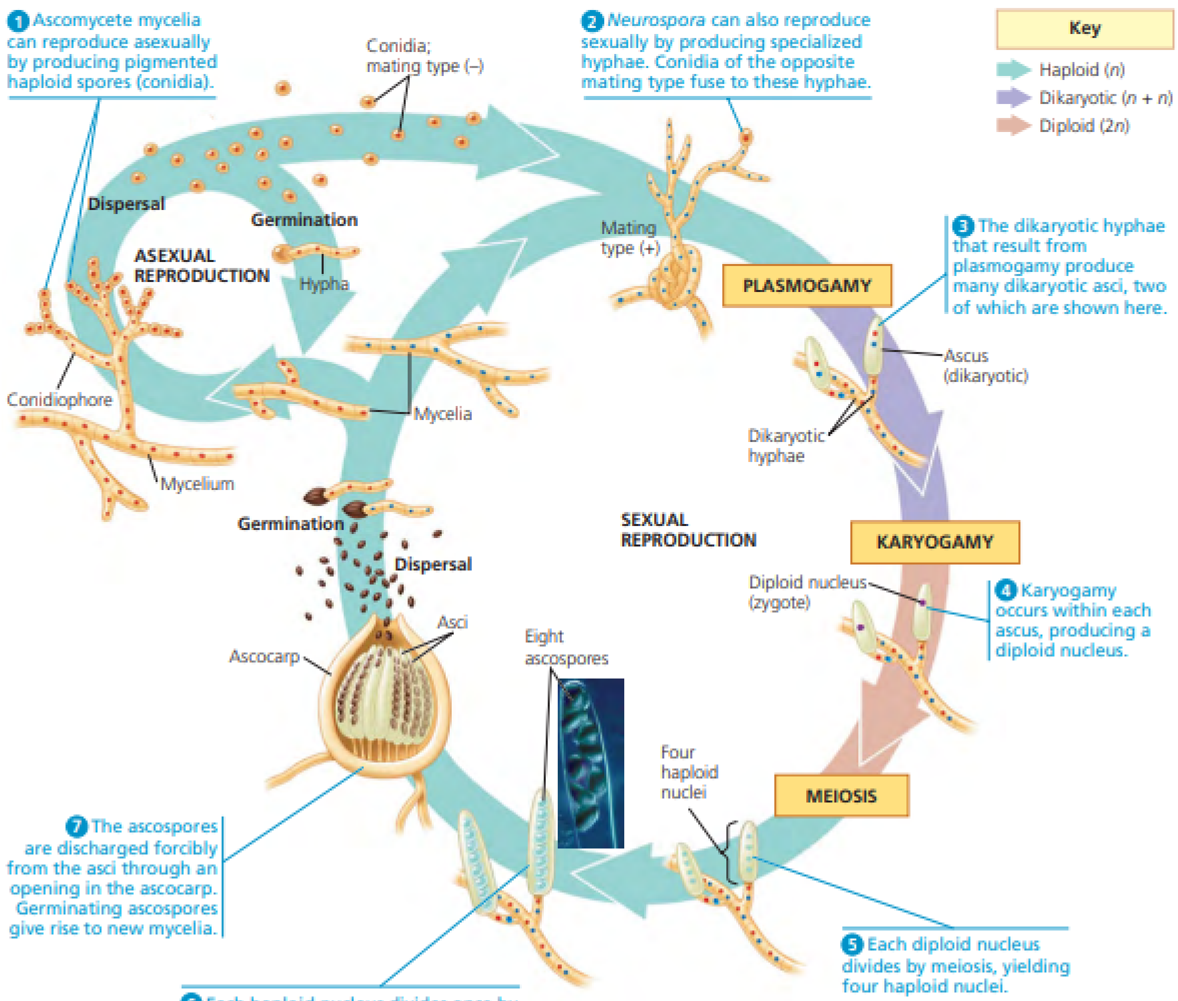
## 8.7 Glomeromycetes?

This clade used to include arbuscular fungi. The glomeromycetes and zygomycetes were incorporated with other fungi to form the new clades Zoopagomycota and Mucoromycetes.

## 8.8 Ascomycetes

These fungi are named after their fruiting body where sexual reproduction occurs, the **ascocarp**. The ascocarp contains **Asci**, a saclike structure that produces **8** spores at a time. **Conidia** produce spores from asexual reproduction.

The ascomycetes are the most common fungi that will show up (e.g. *Neurospora Crasa* is a model organism used in many famous experiments).




▲ **Figure 31.17 The life cycle of *Neurospora crassa*, an ascomycete.** *Neurospora* is a bread mold and research organism that also grows in the wild on burned vegetation.

**Figure 47:** Life cycle of an ascomycete.

## 8.9 Basidiomycetes

Ascomycetes and Basidiomycetes are the two main clades of fungi and they share many parallels. These fungi are named after their fruiting body where sexual reproduction occurs, the **Basidiocarp**. Spores are produced in the **Basidia**, which is located in the **gills** of the basidiocarp. The cell where karyogamy happens is the **Basidium** (The club shape of this structure is why the basidiomycetes are also called club fungi).

This clade includes your mushrooms, puffballs, shelf fungi, mutualists and plant parasites (rusts and smuts). Sometimes the mycelium grows from a central point. As nutrients in the center get used up, the mycelium expands in a ring shape, leaving behind dead mycelium in the center. On the surface, this ring-like growth is visible in the form of **fairy rings**, where mushrooms pop up on the surface in a ring shape.

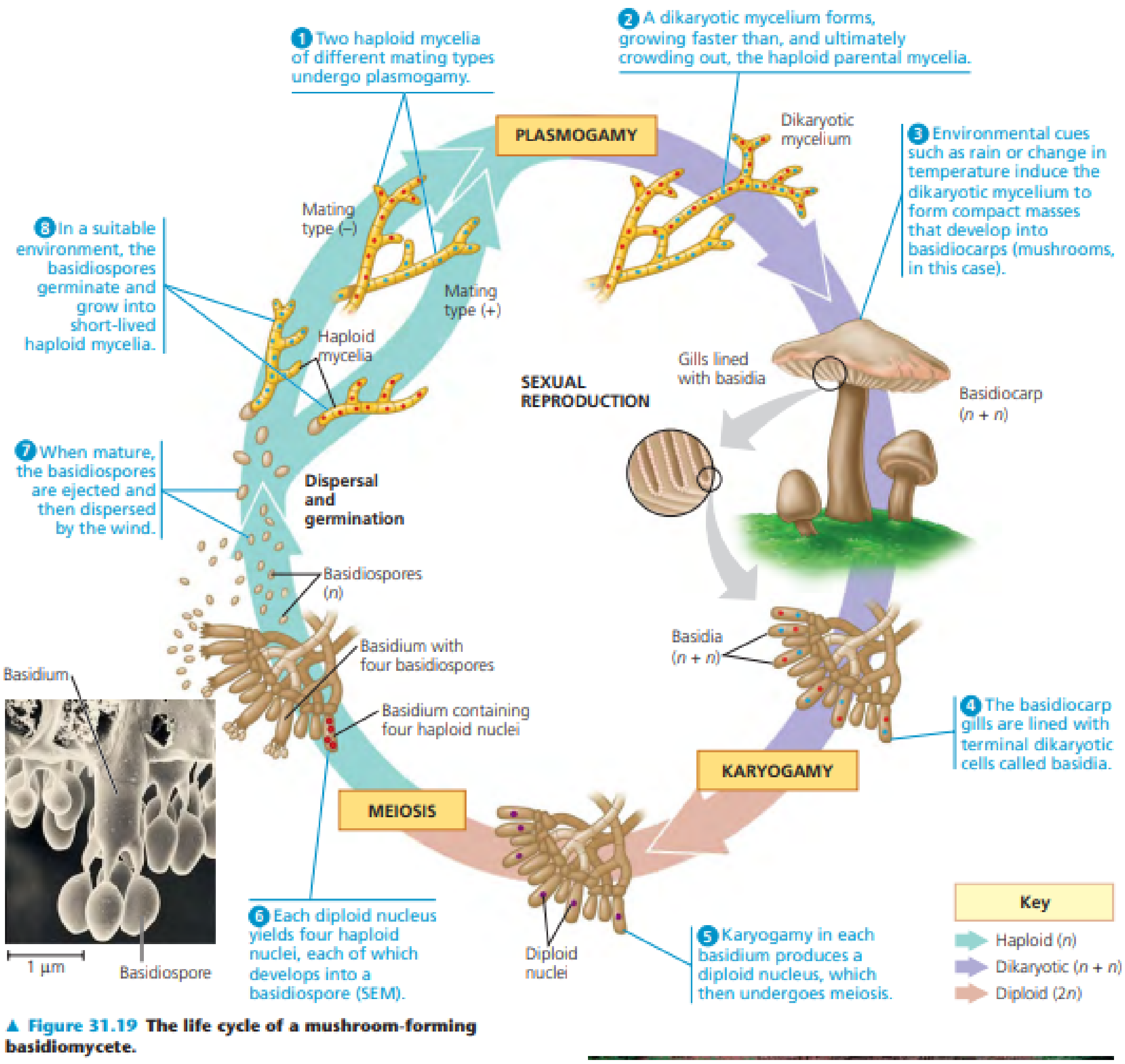



**Figure 48:** Life cycle of a basidiomycete.

# 9 Animals-Invertebrates

The earliest fossil evidence of animals is **Ediacaran biota**. During the Cambrian period, animals rapidly diversified and there was an explosion of new species, known as the **Cambrian explosion**! A lot of this diversification was due to the duplication of **Homeobox genes**, which are special genes that control the body plan of an organism. Extra copies of homeobox genes, specifically **Hox genes** in animals (which regulate the anterior-posterior axis), allowed for animals to develop new body structures. We shall see that major morphological changes in animal phyla are usually accomponied by duplications of Hox genes.

Compared to all of the other kingdoms, humans put a special emphasis on animalia, resulting in a LOT more important clades. Part of this is due to the easily visible differences resulting from genes duplicating, but part of it is also that since animals are so similar to us, we tend to focus on how they differ. Since there is so much to learn regarding animals, we will begin by only covering the **invertebrates**, which make up 95% of known animal species.

## 9.1 Features

**Collagen** is an important structure found only in animals. In fact, animal skeletons used to be made of collagen before they were made of bone. Animals obtain nutrients by ingesting food.

We can classify animals based on how they reproduce:

- **Oviparous:** lay eggs that hatch outside the mother (*e.g. Platypus)
- **Ovoviviparous:** eggs hatch within the mother *(e.g. Sharks)
- **Viviparous:** no egg shell. Instead, the embryo depends on the mother for nutrients (e.g. humans)

When understanding the structures of different animals, it can be helpful to know some basic terminology for direction:

- The Symmetry of the organism can either be **radial** (symmetric from any direction like a jellyfish) or **bilateral** (two sides are mirror images like a fish).
- **Anterior** refers to the front end (closer to mouth), while the **Posterior** refers to the back end (closer to anus)
- **Dorsal** refers to the top side, while **Ventral** refers to the bottom.
- **Cephalization** is a term that refers to how bilateral animals have evolved to have bigger heads.

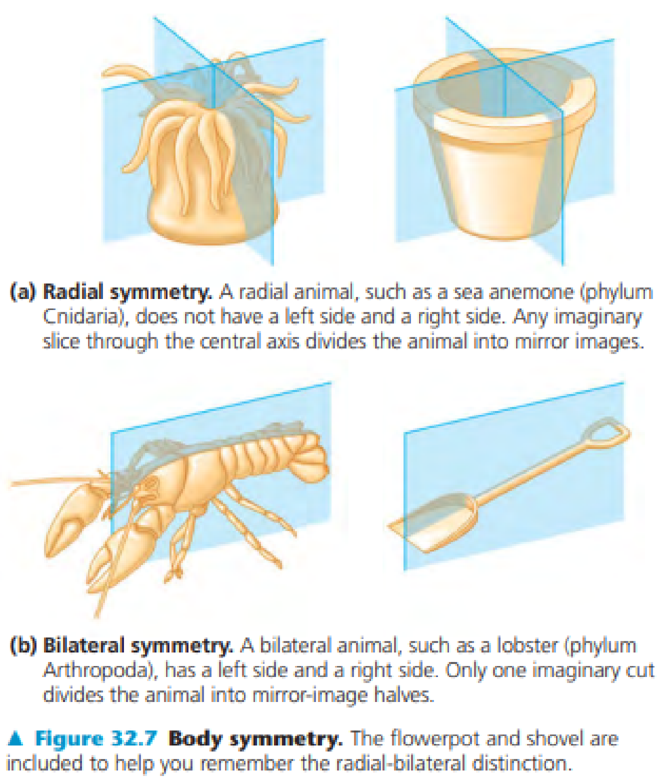



**Figure 49:** Types of symmetry in animals.

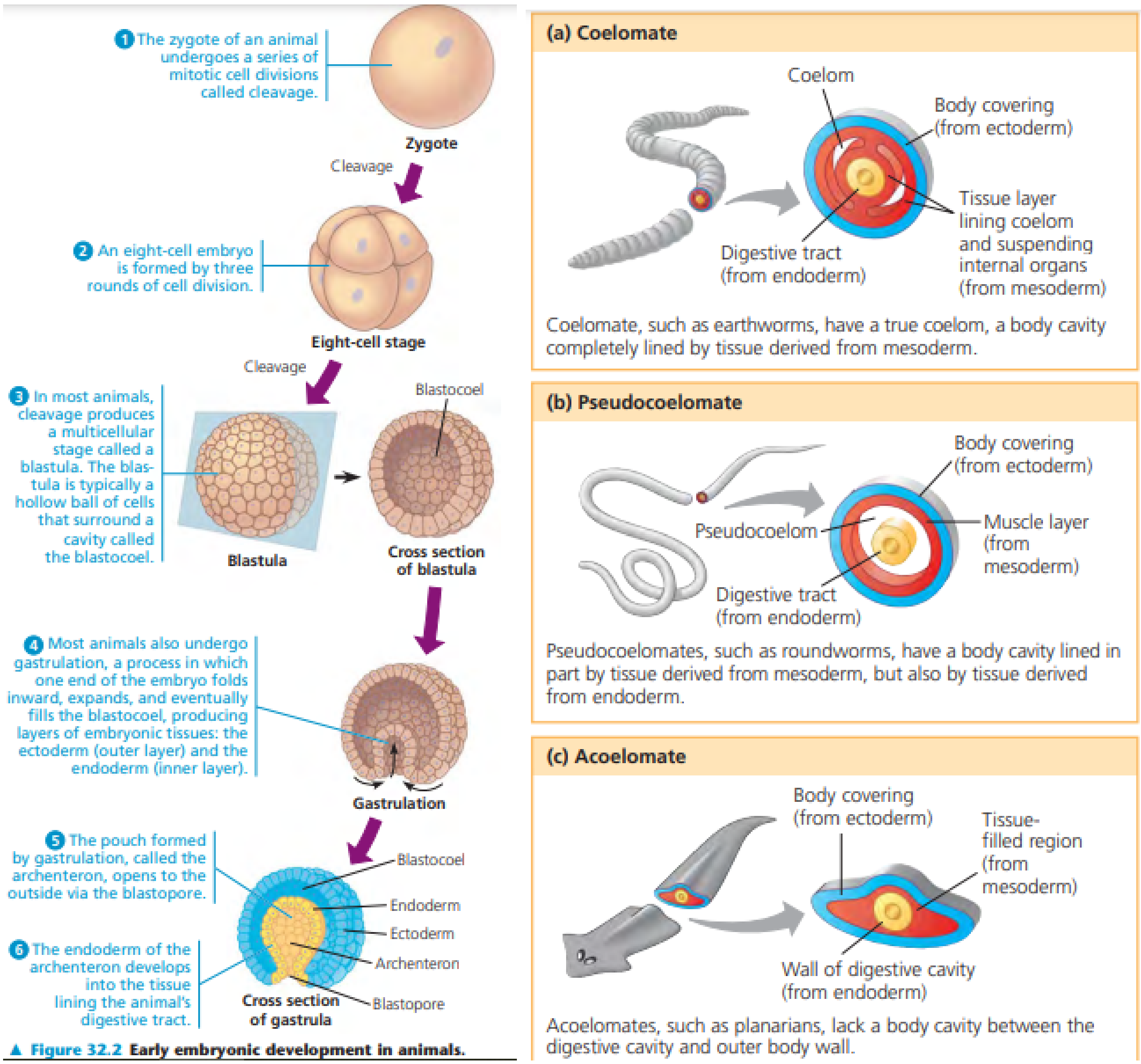



**Figure 50:** (left) Steps of gastrulation, (right) Types of coeloms.

Since surface structures can often be misleading in classification (analogous structures), biologists often turn to features of the animal during *development* while they are still an embryo. Therefore, to understand how we classify animals, I will briefly cover **gastrulation**: the formation of tissue layers.

1. After fertilization, the zygote cleaves into two **Blastomeres**.
2. More cell divisions happen until the zygote reaches the 16 cell stage, the **Morula**
3. After many more cell divisions, the embryo forms a hollow ball of cells. This ball is called the **blastula**. The cavity within is called the **blastocoel** coel means cavity, so the name means the cavity within the blastula.

4. After this point, **gastrulation** happens. The embryo folds into itself, making as inside layer (**endoderm**) and an outside layer **ectoderm**. Each of these tissue layers, will go on to form specific parts of the body:

   - The exoderm becomes outer covering (skin) and the nervous system. The endoderm becomes the digestive tract and related organs.
   - Animals with only these two layers are **diploblastic**. They include **Cnidarians** and **Comb jellies**. Some diploblasts actually do have a 3rd germ layer, but it is not well-developed enough to be considered mesoderm.
   - Other animals develop a middle layer (**mesoderm**) and are called **triploblastic**. All **bilaterians** are triploblastic. The mesoderm will go on to form all the muscles, bones, and all other organs between the endoderm and ectoderm.

     In the mesoderm, a body cavity called the **coelom** will form. We can classify triploblasts based on the presence of such a cavity.

     – **Coelomates** have the coelom develop solely from the mesoderm. This includes most triploblasts so it is often easier to remember which animals are *not* coelomates.
     – **Hemocoels** (formerly called **Pseudocoelomates**) are organisms where the coelom develops from mesoderm *and* endoderm. This includes **Nematodes** and **Rotifers**. The fluid inside a hemocoel is called **hemolymph**.
     – **Acoelomates** have no coelom. This includes diploblasts and **Platyhelminthes** (flatworms).
     – **Note:** It turns out the presence of a coelom isn't great at determining evolutionary relationships because coeloms and hemocoels have been gained and lost many times over history. *For example, mollusks and insects have a hemocoel with hemolymph, even though they are actually coelomates!

     The triploblasts can also be split into **protostomes** and **deuterostomes** depending on how they develop. Before we talk about them, you should know that during gastrulation, the opening hole where the embryo starts folding in on itself is the **blastopore**. The cavity that forms from this infolding is called the **archenteron**.

     Protostomes:

     – Includes **ecdysozoa**, **lophotrocozoa**, and **acoela**.
     – **Cleavage**: Protostomes are **spiral** and **determinate**. Spiral means that at the 8-cell stage, the cells spiral around a central axis. Determinate means that the fate of cells in this stage are already determined; if you take one out, it can not form an entire organism on its own.
     – **Coelom/mesoderm formation**: Random pockets just form.
     – **Blastopore**: In protostomes (proto = first, stome = mouth), the blastopore becomes the mouth

     Deuterostomes:

     – Includes **echinoderms** and **chordates**. ****Ectoprocts** and **Brachiopods** are often included as deuterostomes although they are part of lophotrocozoa.

- **Cleavage**: Deuterostomes are **radial** and **indeterminate**. Radial means that during the 8-cell stage, the cells are organized as 2 blocks of 4. Indeterminate means that you can take any of the cells from this stage, and it can divide to form an entire organism on its own.
- **Coelom/mesoderm formation**: pinches off from the archenteron.
- **Blastopore**: In deuterostomes (deutero = second, stome = mouth), the blastopore becomes the anus.

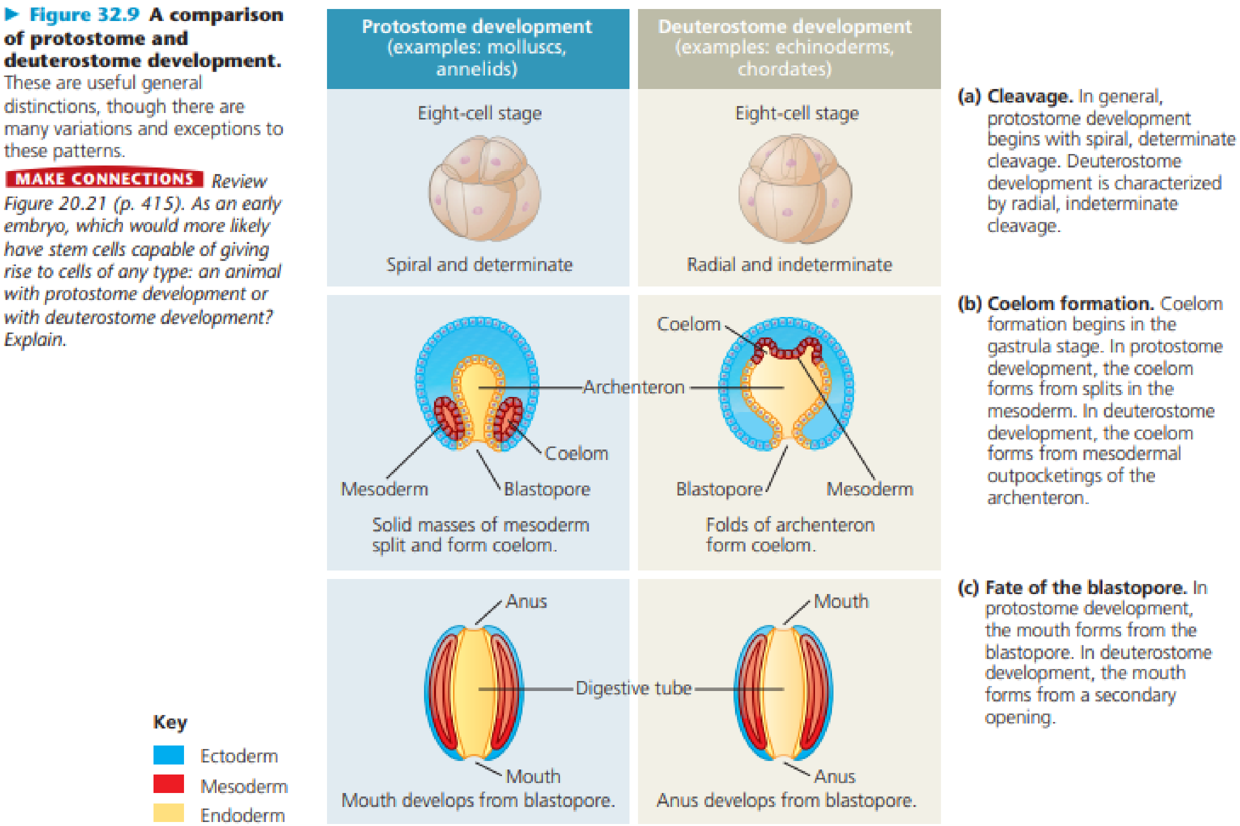



**Figure 51:** Diagram comparing the features of deuterostomes and protostomes.

**Example 9.1:** (USABO Opens 2016)

**50. Chef Grace is cooking up a stir fry. She wants to use a pseudocoelomate larva. Which of the following groups would NOT provide suitable larvae for her consumption? SELECT ALL THAT APPLY.**

A. Cestoda.
B. Aves.
C. Rotifera.
D. Mollusca.
E. Nematoda.

**Solution:** The only pseudocoelomates that matter are rotifers and nematodes! Therefore the answer is A, B, and D.

**Example 9.2:** (USABO Opens 2017)

**23. Select all of the following choices that correctly match the tissue to the embryonic germ layer from which it is primarily formed (*Select ALL that apply*):**

A. Ectoderm – spinal cord.
B. Mesoderm – heart.
C. Endoderm – thyroid.
D. Ectoderm – epidermis.
E. Endoderm – liver.

**Solution:** Remember that the ectoderm is outermost layer and responsible for the skin and nervous system. Therefore, A and D are true. The endoderm includes any organs related with the GI tract, so E is true. C is also true. The thyroid is essentially the only organ that the endoderm gives rise to that is not directly related to digestion. I suspect it is because the thyroid is located close to the esophagus, which is also derived from endoderm. Finally, mesoderm gives rise to all the major organs between the two, including the heart. Therefore, the **answer is all**.

**Example 9.3:** (USABO Semifinals 2018)

**59. Which of the following are characteristic of deuterostomes?**

**I. Determinate cleavage**
**II. Schizocoelous**
**III. Radial cleavage**
**IV. An example is the Cephalopoda**

A. I, III
B. II, IV
C. II, III
D. III
E. III, IV

**Solution:** Remember that deuterostomes have radial and indeterminate cleavage, so I is wrong and III is true. II is not a term we have encountered before, but let's break down the roots to understand it. Schizo means split and coelous refers to a coelem, so schizocoelous means that the coelom forms from a split (not an infolding of the archenteron, which is called enterocoelous). Therefore, II is wrong. As we will see later, IV is wrong because cephalopoda is a type of mollusk, which is a protostome. The deuterostomes are echinoderms and chordates (and ectoprocts and brachiopods). Therefore the **answer is C**.

## 9.2 Porifera (Sponges)

Porifera is the basal taxon of animals, diverging nearly 700 mya. They are the only animals to lack true tissues. Instead, they are made up of just two layers of cells separated by a gelatinous region called the **mesohyl**. **Amoebocytes** are special cells that move through the mesohyl. They do lots of stuff and are totipotent, meaning they can become other types of cells if needed.

Sponges are suspension feeders, meaning that they take in water and filter it for food. Water is drawn into the inner cavity, called the **spongocoel**. Lining the spongocoel are **choanocytes**, special cells that eat food in the water. Then, the water leaves through an opening in the top called the **osculum**.

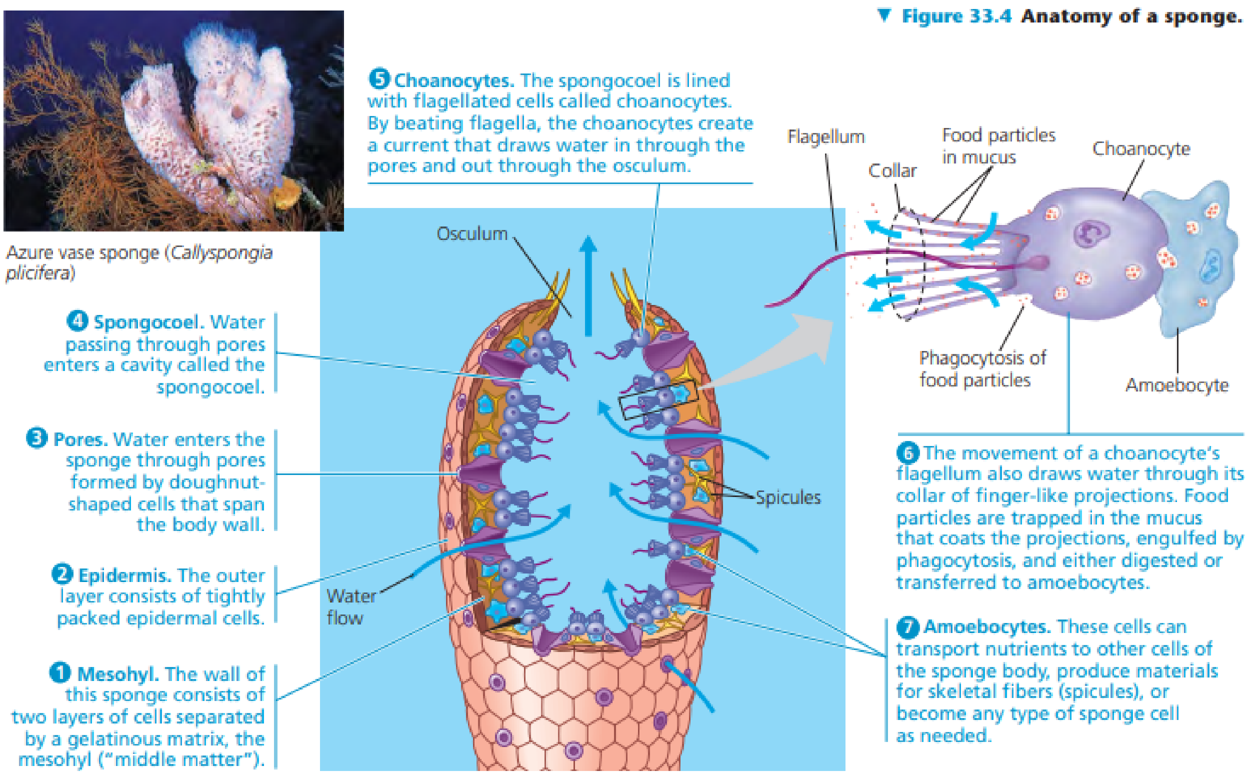



**Figure 52:** Diagram showing the components of a sponge.

The skeleton of sponges is made out of calcium carbonate and silica. However, they also have **spongin**, a special protein that makes their skeletons flexible. **Cribostatin is an antibiotic from sponges that we use to kill penicillin-resistant strains of *Streptococcus*.

Sponges are **hermaphrodites**, meaning that individual can make both eggs and sperm. This is common among immotile organisms since finding a mate happens so infrequently that having two separate sexes would be impractical. Some are **sequential** hermaphrodites, meaning they start off as one sex and switch to the other at some time.

## 9.3 Placozoa

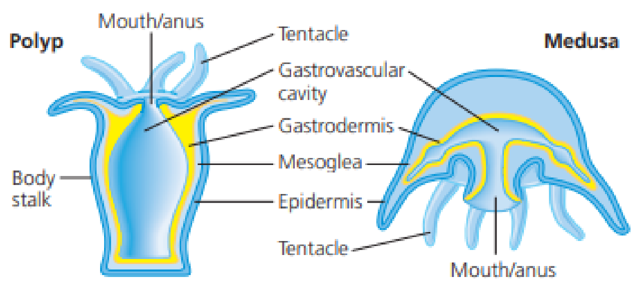
There is only 1 species, Trichoplax adherens, and it is just a simple bilayer of cells.

## 9.4 Ctenophora (Comb Jellies)

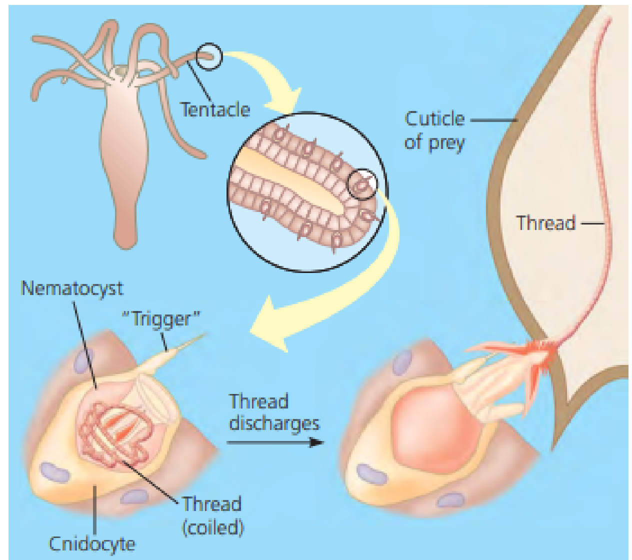
The comb jellies have 8 "combs" of cilia that allow them to move through water. They are very similar to cnideria.

## 9.5 Cnideria

Cnideria have a **gastrovascular cavity**, which means there is a single opening for food and everything else. Cnideria are named after their **cnidocytes**, which are specialized cells that *explode* on touch! **Nematocytes** are a subset of cnidocytes that sting prey (this is why jellyfish sting).




▲ **Figure 33.5 Polyp and medusa forms of cnidarians.** The body wall of a cnidarian has two layers of cells: an outer layer of epidermis (darker blue; derived from ectoderm) and an inner layer of gastrodermis (yellow; derived from endoderm). Digestion begins in the gastrovascular cavity and is completed inside food vacuoles in the gastrodermal cells. Flagella on the gastrodermal cells keep the contents of the gastrovascular cavity agitated and help distribute nutrients. Sandwiched between the epidermis and gastrodermis is a gelatinous layer, the mesoglea.




▲ **Figure 33.6 A cnidocyte of a hydra.** This type of cnidocyte contains a stinging capsule, the nematocyst, which contains a coiled thread. When a "trigger" is stimulated by touch or by certain chemicals, the thread shoots out, puncturing and injecting poison into prey.

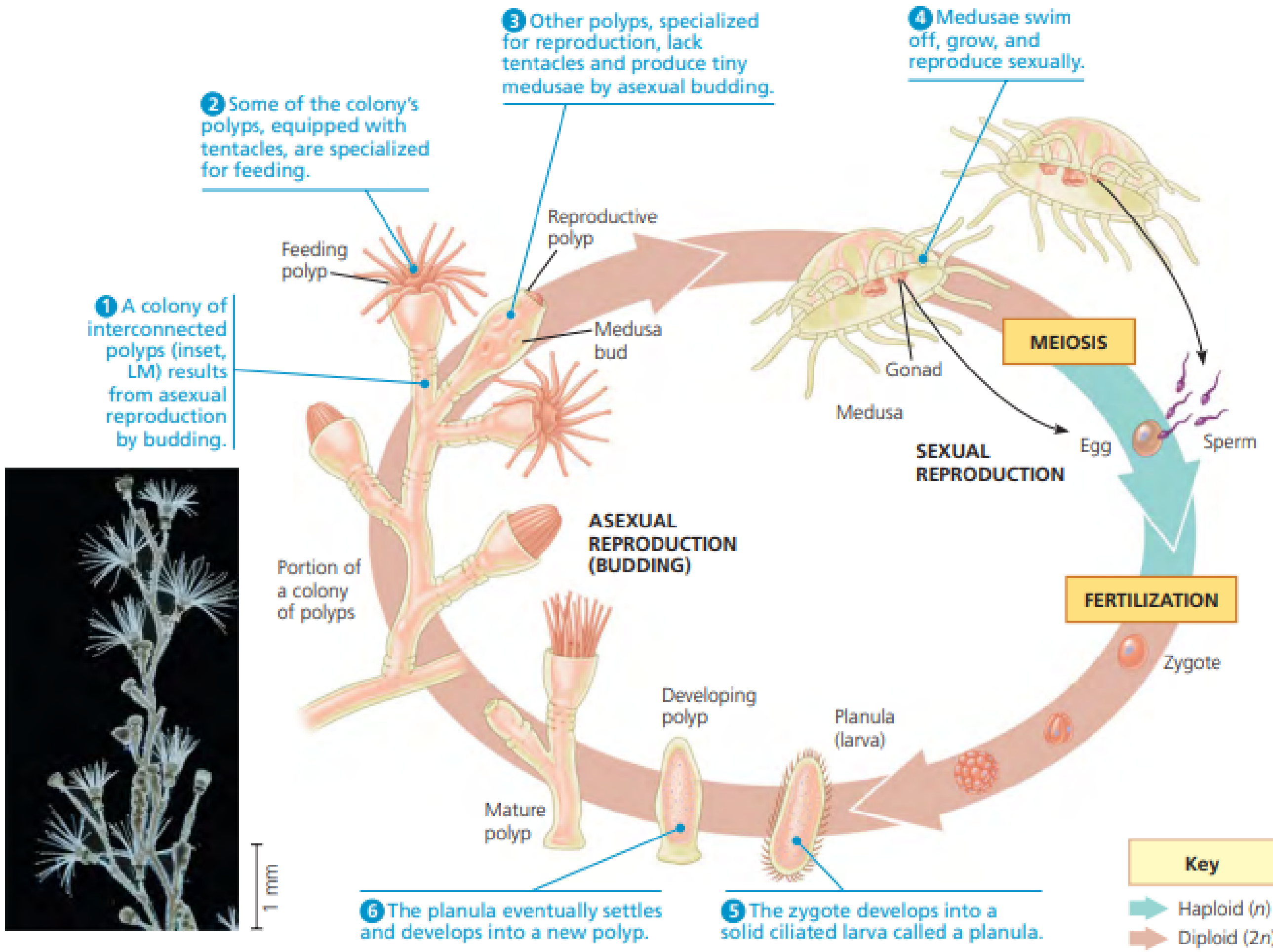
**Figure 53:** Diagrams showing the unique features of cnideria, including their polyp and medusa forms (left) and their specialized cnidocytes (right).

Cnideria can exist as either a **polyp** (sessile) or **medusa** (mobile) form. They are classified based on which of these forms is dominant:

- **Medusozoans:** The three groups in this clade used to each be their separate clade. However, they were later combined into Medusozoans, which are defined by a having a medusa stage at some point in their life.
  - **Hydrozoans:** Most alternate between their polyp and medusa form, **like *Obelia*. However, **Hydras** are freshwater hydrozoans that are unique because they only exist in polyp form. They reproduce asexually by budding.
  - **Scyphozoans:** The medusa is the dominant stage for these animals. Coastal scyphozoans have a small polyp phase while open ocean scyphozoans lack it completely. They include jellyfish!
  - **Cubozoans:** As the name suggests, cubozoans are defined by their box-shaped medusa. Since they look so similar to jellyfish, which are scyphozoans, they are called box jellyfish. A notable difference between them and jellyfish is that they have complex eyes. In fact, they come in 4 groups of 6, meaning that they have 24 eyes total! Box jellies are relatively strong swimmers.

  * **Some of them have really toxic cnidocytes, like the sea wasp (*Chironex fleckeri*), which is one of the deadliest organisms known. Despite that, they are no match for sea turtles, which eat them as snacks :)

- **Anthozoans:** Animals in this group have a polyp form only. You know them as sea anemones and corals. Yes, corals are living organisms. In fact, they are a symbiosis of organisms! **Zooxanthellae** are the photosynthetic symbionts that live in coral and provide them with food. However, warm or acidic water causes zooxanthellae to leave, resulting in the coral starving to death. This process is known as **coral bleaching** (since the corals lose their colorful zooxanthellae and die).




▲ **Figure 33.8 The life cycle of the hydrozoan *Obelia*.** The polyp is asexual, and the medusa is sexual, releasing eggs and sperm. These two stages alternate, one producing the other. Do not confuse this with the alternation of generations that occurs in plants and some algae: In *Obelia*, both the polyp and the medusa are diploid organisms. Typical of animals, only the single-celled gametes are haploid. By contrast, plants have a multicellular haploid generation and a multicellular diploid generation.

**WHAT IF?** *Suppose that* Obelia *medusae and gametes were haploid, but all other stages were diploid. What aspects of its actual life cycle would have to change for this to occur?*

**Figure 54:** Life cycle of a typical hydrozoan.

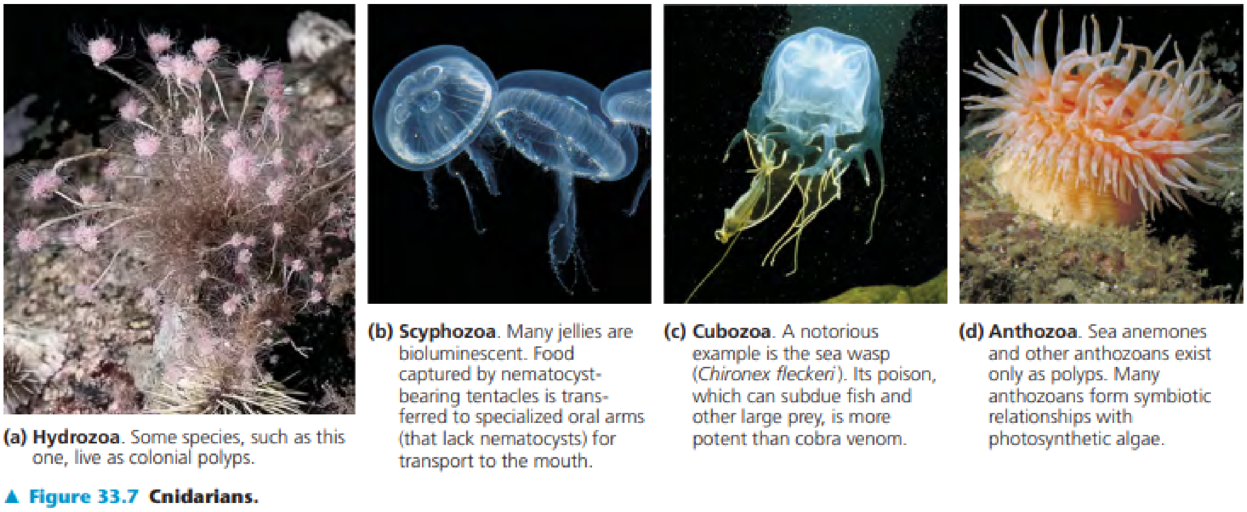



**Figure 55:** Types of cnideria.

## 9.6 Bilateria - Acoela

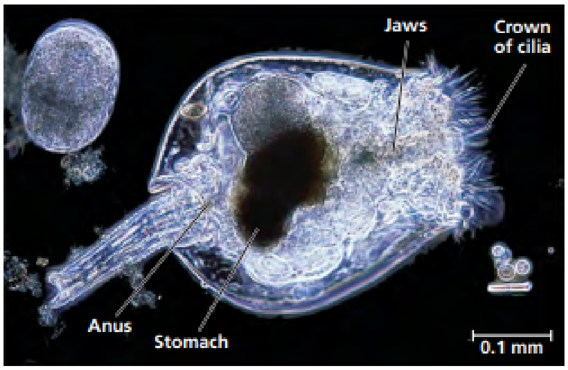
These are simple flatworms that lack a coelom. They used to be part of platyhelminthes but it turns out they are actually different.

## 9.7 Bilateria - Lophotrocozoa

The name of this group comes from the unique features that its members develop. Some members either have a **lophophore**, which is a crown of ciliated tentacles for feeding, or **trocophore larva**. This clade has 18 phyla, which is more than double any other bilaterian group.

- **Syndermata:** This group combines two that used to be separate.
  - **Rotifera:** Rotifers are filter feeders with an alimentary canal. They suck in water through the mouth, use jaws called **trophi** to grind the food, which then goes on to be digested.

    A special feature of rotifers is that they practice **Parthogenesis** (Partho = maiden, genesis = creation), which is a type of asexual reproduction where unfertilized eggs develop into adult females. In favorable conditions, some species do sexual reproduction and the fertilized eggs can grow into male or female adults. **However, some rotifer species like *Bdellodeia* have no males and only do parthogenesis. Yet, they still maintain genetic variation because desiccation creates cracks in their membrane. So, when they rehydrate, DNA from the environment can slip in through the cracks (a lot like bacterial transformation).
  - **Acanthocephala:** These are spiny-headed worms, named because they have hooks at the end of their proboscis (in this case, a proboscis is a long sucking organ on the head of worms). They are parasites and can even manipulate the host's behavior.




▲ **Figure 33.13 A rotifer.** These pseudocoelomates, smaller than many protists, are generally more anatomically complex than flatworms (LM).

▼ **Figure 33.10 Anatomy of a planarian.**

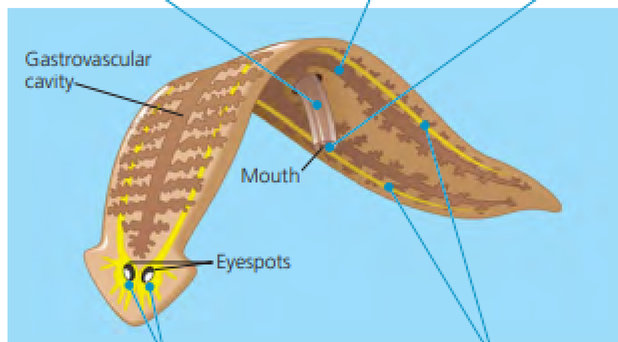



**Figure 56:** Diagrams of a rotifer (left) and planarian (right).

- **Cycliophora:** **This contains only 1 species, *Symbion pandora*. These animals live on the mothparts of lobsters and have an unusual reproductive cycle. The males impregnate the female fetus while it is still in the worm, so females are born pregnant.

- **Platyhelminthes (Flatworms):** Flatworms tend to live in wet places. Since they are so flat, they don't need a circulatory system because the cells can simply use diffusion across the skin.

  They have a special excretory system called **protonephridia**, which utilizes **flame bulbs** (check the excretory system handout for more info).

  Flatworms are split into two groups:

  - **Catenulida:** **Small clade of freshwater species that reproduce asexually by budding off the posterior end. they have earned the name "chain worms" because the buds can start budding before they even detach.

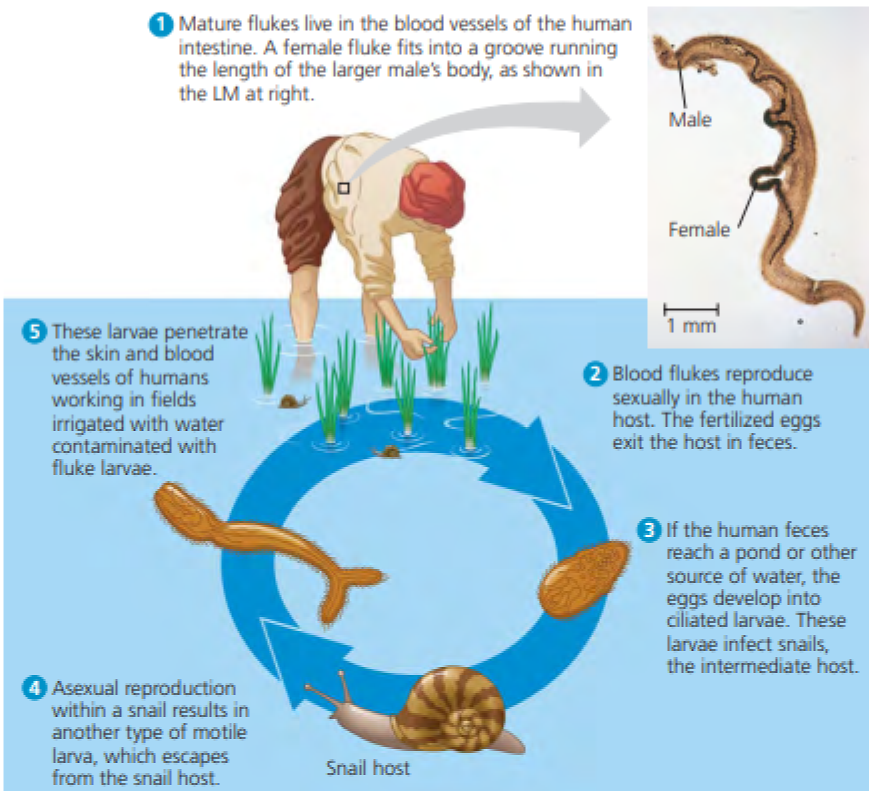
  - **Rhabditophora:** This includes free-living species, which are often predators or scavengers. This mainly includes **planarians** such as **Dugesia*. Planarians are hermaphrodites, however some reproduce asexually by splitting in half! They use **eyespots** to see. They move around by cilia on their ventral surface to glide along a film mucus.

    There are also parasitic species, which have suckers to get nutrients, a tough covering to protect from the host environment, and large reproductive organs that occupy most of the interior of their body. they fall into two main groups:

    * **Trematodes:** They have a complex life cycle with intermediate hosts. As a result, they need to be really good at evading immune systems.

· *Blood flukes (*Schistosoma*) cause **schistomiasis**. They have a snail and human host.

∗ **Tapeworms:** Humans contract tapeworms when eating contaminated undercooked meat. The tapeworm hides in the intestines of the host and absorbs nutrients across its surface. The anterior end of a tapeworm is called the **scolex**. After the scolex are sacs of sex organs called **proglottids**.




▲ **Figure 33.11 The life cycle of a blood fluke (*Schistosoma mansoni*), a trematode.**

**Figure 57:** Life cycle of a blood fluke.

- **Annelida:** These are the segmented worms (what you usually think of when you hear the word worm). The way annelids used to be classified relied on their morphology:
  - **Polychaeta:** Each segment has a pair of little feet called **parapodia**. Each parapodia had bristles of chitin called **chaetae**. These are richly supplied by blood vessels and thus can function as gills. The polychaeta are mostly marine worms.
  - **Oligochaeta:** These don't have a lot of chaetae. They included **earthworms** and **leeches**.

  It turns out that oligochaeta was actually a subgroup of polychaeta, so now annelids are split into two major groups:

  - **Errantia:** stuff that moves. **However, they have some immobile species like tube worm (recent model organism for neurobiology and development). Errantia has many of the species that used to be polychaeta.

- **Sedentaria:** stuff that are either sedentary or move slowly, **such as the Christmas tree worm and many other types of tube worms.
  * **Earthworms:** They improve soil quality by eating the soil. Earthworms are hermaphrodites. Two of them will pair up and exchange sperm. An organ called the **clitellum** makes a caccoon of mucus that slides along the earth worm and picks up eggs, and then picks up sperm at the end.
  * **Leeches:** leeches have several adaptations that make them amazingly effective parasites. They penetrate skin by slicing with bladelike jaws or digesting a hole with enzyemes. The anesthetics they release make the host oblivious as they feed on them. Leeches also produce **hirudin**, a special protein that prevents blood clotting and has medical uses.

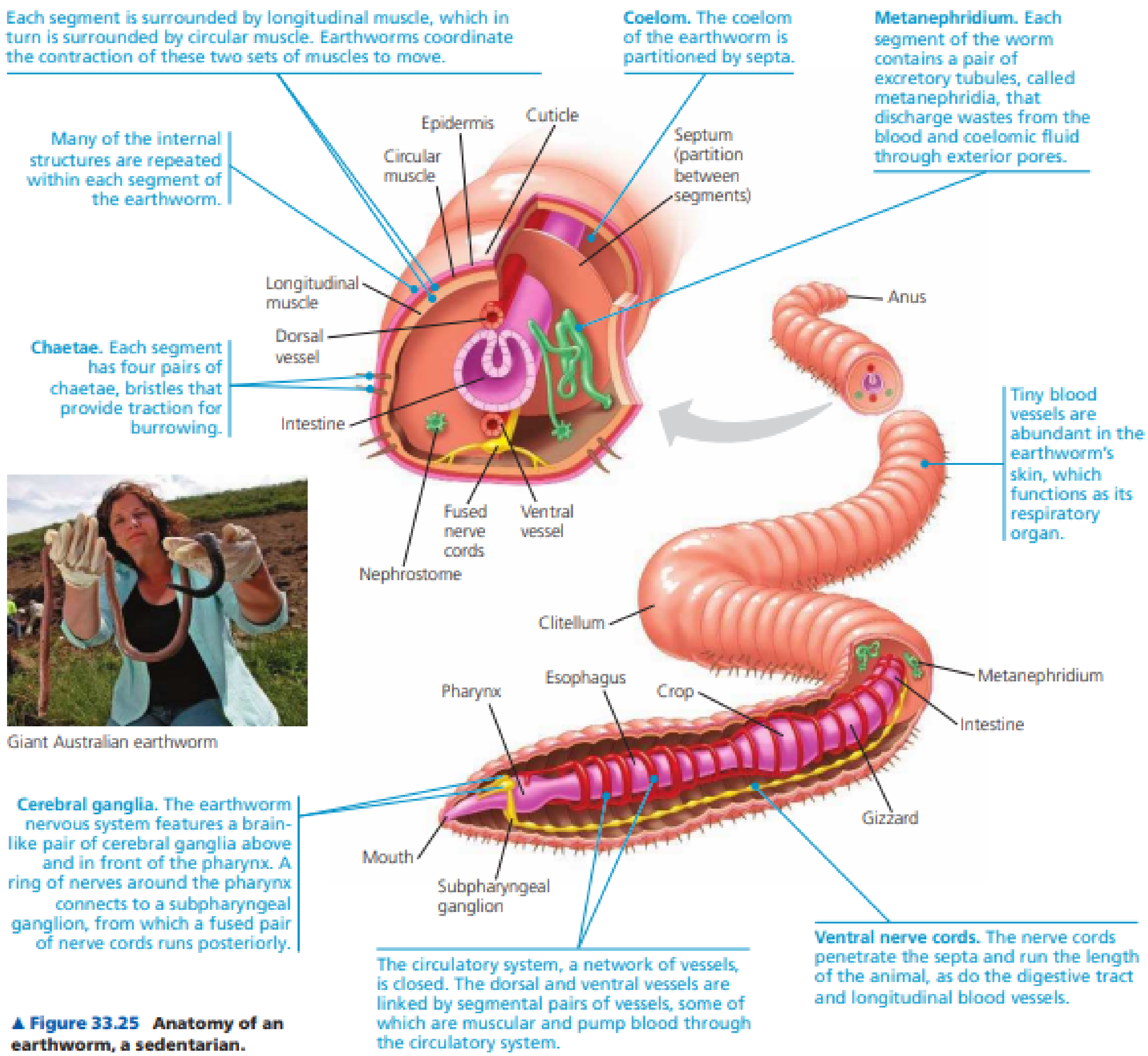
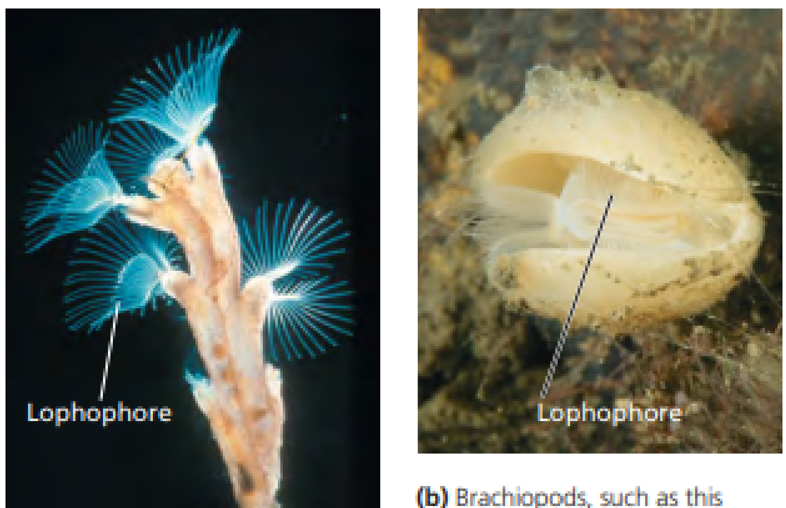



**Figure 58:** Diagram of an earthworm.

- **Nemertea (Proboscis/ribbon worm):** They swim through water and burrow in the sand, capturing any prey that strays nearby with their proboscis. They used to be part of platyhelminthes because they are acoelmates. Nemertea have an alimentary canal and closed circulatory system.

- **Brachiopoda (lamp shells):** This has a lophophore. They are marine organisms that look like clams and other mollusks. However, they are different because their shells are dorsal and ventral rather than lateral.
  - ***Lingula*

- **Ectoprocta:** Has a hard exoskeleton and lophophores stick out of pores. They are also called bryozoans because they look like clumps of moss (I don't see it). They are sessile, with many living in the ocean. **However, some species like *Pectinatella magnifica* lives in freshwater.



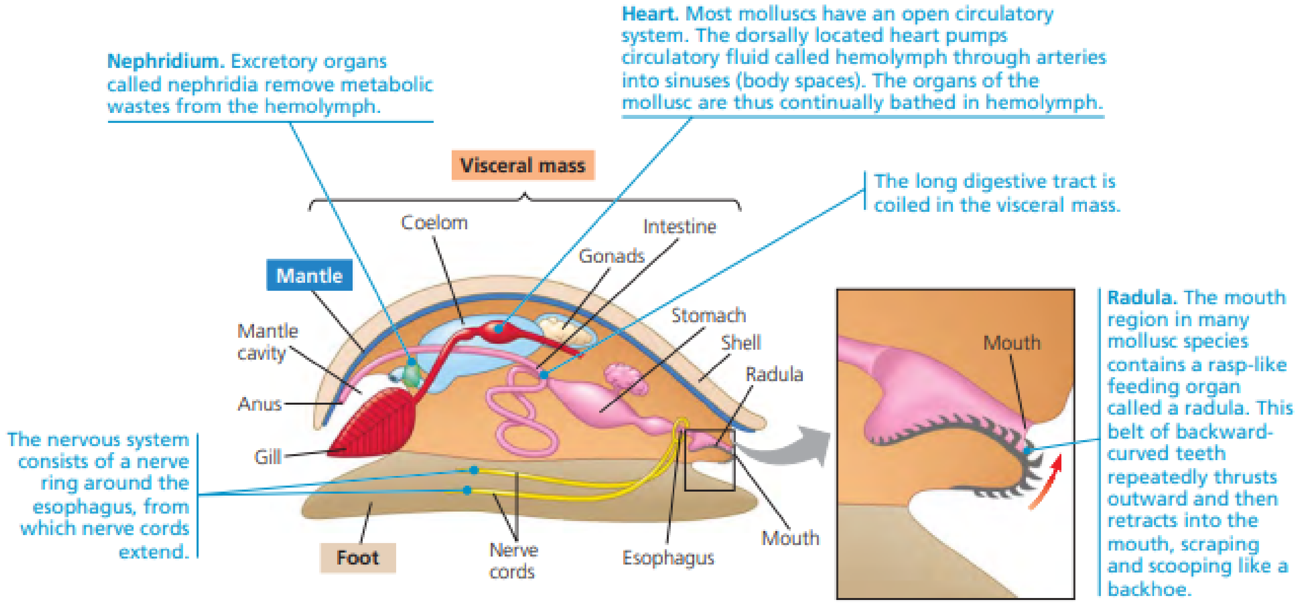

**(a)** Ectoprocts, such as this creeping bryozoan (*Plumatella repens*), are colonial lophophorates.

**(b)** Brachiopods, such as this lampshell (*Terebratulina retusa*), have a hinged shell. The two parts of the shell are dorsal and ventral.

▲ **Figure 33.14 Lophophorates.**

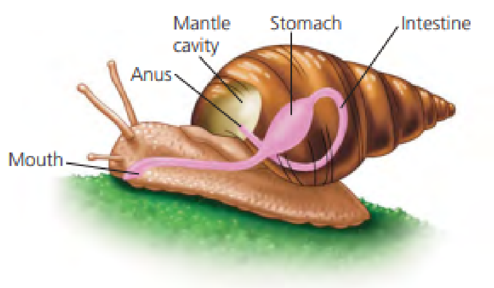
**Figure 59:** Example of ectoprocts (left) and brachiopods (right) displaying their lophophore.

- **Mollusca:** All molusks are soft bodied animals with calcium carbonate shells (except for slugs, squids, and octopuses). This is the 2nd most diverse phylum. However, they also make up 40% of all extinctions. Their body consists of three parts:
  - **Foot**: usually used for movement
  - **Visceral mass**: contains the internal organs
  - **Mantle:** secretes the shell. If the mantle extends beyond the visceral mass, then it creates a water-filled chamber called the mantle cavity.
  - They also have a **radula**, which scrapes up food.




▲ **Figure 33.15 The basic body plan of a mollusc.**

**Example 60:** Diagram of the parts of a mollusk.




▲ **Figure 33.18 The results of torsion in a gastropod.** Because of torsion (twisting of the visceral mass) during embryonic development, the digestive tract is coiled and the anus is near the anterior end of the animal.

▲ **Figure 33.19 A bivalve.** This scallop has many eyes (dark blue spots) lining each half of its hinged shell.

**Example 61:** Diagram of torsion in gastropods (left) and example of a bivalve (right).

Many have trocophore larva. Mollusks are sorted into the following four groups:

- **Chitons:** They have an oval shaped body covered by a shell with 8 plates. They can grip really hard to rocks and are often found on shore during low tide.
- **Gastropods:** Most are marine, but there are also freshwater and land species. Gastropods undergo a process as they grow called **torsion**, which is when their visceral mass flips 180°. This causes their butt to be directly above their head!
  - **In cone snails, the radula is turned into a very deadly poison dart.
- **Bivalves:** They are suspension feeders and are generally sessile **(some can use their foot to move. For example, scallops flap and clams can pull themeselves around a little).

– **Cephalopods:** These are the only mollusks with a *closed circulatory system*. *Octopuses have **3 hearts**: 1 for the body and 2 for the gills (one each). Cephalopods are predators; their tentacles grab, beak bites, their saliva contains immobilizing poison, and their foot has been replaced with excurrent siphon to shoot water jets and move! oh... and they're smart.

  * ***Ammonites** are fossils of ancient cephalopods.
  * **Some squid are really long, like *Architeuthis dux* and *Mesonychoteuthis hamiltoni*.

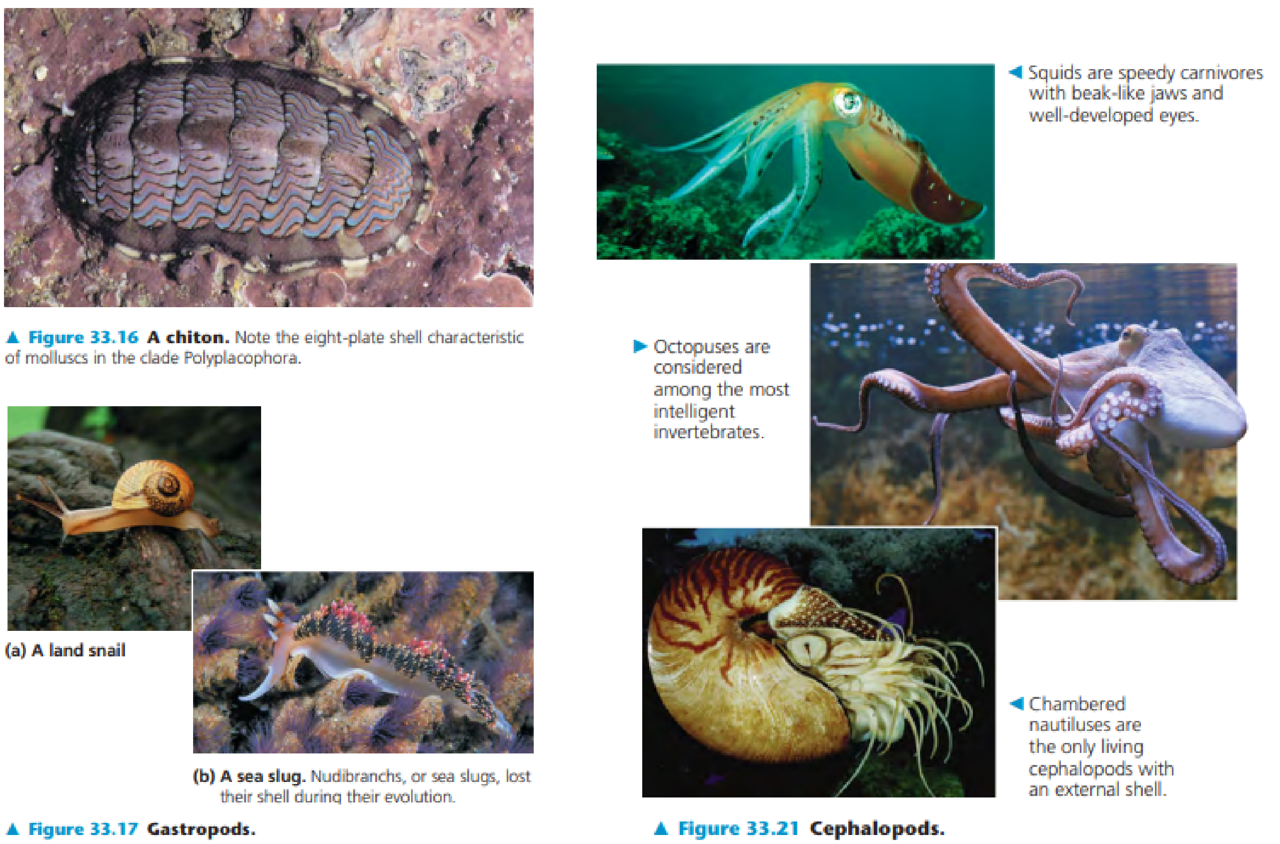



**Figure 62:** Examples of various mollusks.

## 9.8 Bilateria - Ecdyoszoa

Ecdyoszoa are named after the process **Ecdysis**, which is just molting!

- **Loricifera:** These organisms have a **lorica**, which is a pocket made by six plates surrounding the abdomen. They are able to telescope their head, neck, and thorax into the lorica!
- **Priapula (Penis worm):** The name says it all.
- **Onychophora (Velvet worms):** They live in humid forests. They have fleshy antennae and several dozen pairs of saclike legs.
- **Tardigrada (Water bears):** These guys are **OP**! They can survive essentially anywhere (even the vaccuum of space!) by dehydrating themselves.

- **Nematoda (roundworms):** Nematodes do a lot of stuff and are very important for the environment! It is said that if you removed *everything* from earth except nematodes, they would still preserve the structure/outline of the earth since they are so ubiquitous. Nematodes have an alimentary canal but no circulatory system. They are not segmented, with a blunt anterior end and a pointy posterior end. Their body wall muscles are all longitudinal, making a thrashing motion when they move. Also, they reproduce sexually by internal fertilization.
  - *Caenorhabditis elegans*: The model organism used for fate mapping and evelopment. As a result, we found that they have **exactly 959** cells and we *know* the history and future of every single one.
  - ** *Trichinella spiralis* causes **trichinosis**. People get it from eating contaminated uncooked meat.

**Example 9.4:** (USABO Opens 2017)

**19. Which of these systems cannot be found in *Caenorhabditis?***

A. Circulatory and excretory systems.
B. Circulatory and nervous systems.
C. Circulatory and respiratory systems.
D. Secretory, circulatory and respiratory systems.
E. Excretory and respiratory systems.

**Solution:** We should recognize that this organism is *C. elegans*, which is a nematode! Nematodes notably lack a circulatory system. In addition, they are complex enough to possess a normal system and the presence of a digestive system means they likely also contain secretory and excretory systems to digest food and excrete waste. Therefore, our **answer is C**.

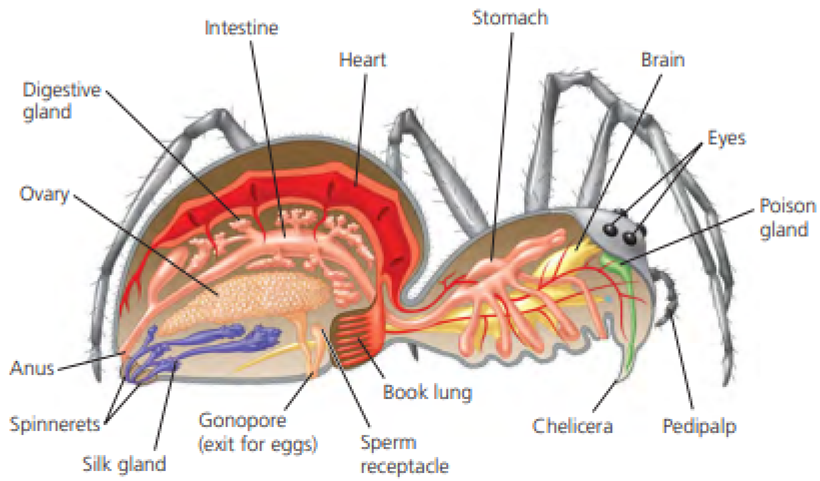
- **Arthropoda:** This is the biggest phylum ever! They have jointed appendages and a segmented hard exoskeleton made of **chitin**. **Lobopods** were an ancestral arthropod that had many identical segments and **Trilobites** were an ancestral arthropod that had segments with a little variation. Over time, segments fused together and became more varied. They have an open circulatory system with **hemolypmh** instead of blood.

  It was thought the duplication of the genes Ultrabithorax (Ubx) and abdominal-A (abd-A) may have resulted in arthropods. **However, this was proven false when it was discovered *Acanthokara kaputensis* had those duplicated genes.

  Arthropods are split into two main groups:

  - **Chelicerates: Chilcerae** are clawlike feeding appendages.
    * **Eurypetrids:** Water scorpions were the first chilcerates. However, all of the marine chelicerates are now extinct except for sea scorpions and horshoe crabs. Horseshoe crabs have blue blood!
    * Most chelicerates are **arachnids**! They have 6 pairs of apendages (chelicerae, **pedipalps** for sensing/feeding/sexual reproduction, and 4 pairs of walking legs).

· Scorpions
· Ticks, which are blood-sucking parasites.
· Mites
· Spiders! They make silk (Sericin and fibroin are the 2 proteins in spider silk), which can be used for catching prey, exchanging gifts, ballooning, and many other functions. Spiders have **book lungs** to breathe, which look like a stack of plates.



▲ Figure 33.33 **Anatomy of a spider.**

**Figure 63:** Diagram of spider anatomy.

– **Myriapods:** Myriapods have a pair of antennae and 3 pairs of modified mouthparts, including **mandibles**. The rest of their body has LOTS of legs. They are terrestial creatures and may have been the 1$^{st}$ animals on land! *The two most common myriapods are **Millipedes**, which are herbivores, and **Centipedes**, which are carnivores.

– **Pancrustaceans:** includes crustaceans and insects.

The **hexapods** include insects and are more species-rich than all other life forms combined! They evolved and diversified alongisde flowering plants. Hexapods have 2 pairs of wings (dragonflies were the first to get wings) and exhibit **metamorphosis**, a change in morphology as the young grows into an adult.

∗ **Incomplete metamorphosis:** the **nymph** is just a tiny version of the adult **(e.g. grasshoppers)).

∗ **Complete metamorphosis:** the **larva** eats a bunch and becomes a **pupa**, which transforms the larva into an adult.

Hexapods are split into the following groups:

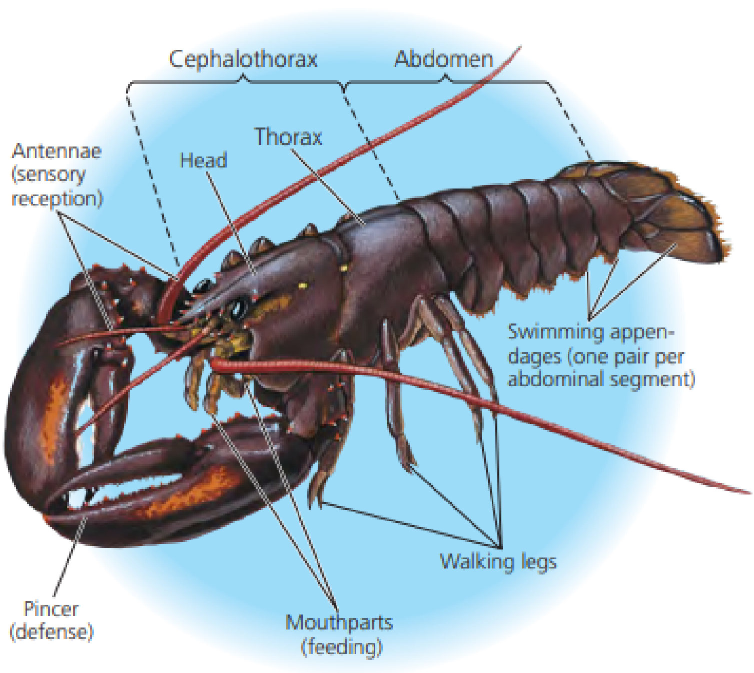
∗ **Archaeognatha (bristletails)**
∗ **Thysanura (silverfish)**
∗ **Winged insects:** These are sorted based on the type of metamorphosis they have. There are 4 groups that exhibit complete metamorphosis:
  · **Coleoptera:** This includes **beetles**. They have 2 pairs of wings: a flying membranous pair and the anterior thick, stiff pair for protection. They have *chewing* mouthparts.

    - **Diptera:** This includes **flies** and **mosquitoes**. In diptera, the second pair of wings became **halteres**, which are used for balance. They have *sucking* mouthparts.
    - **Hymenoptera:** This includes **ants**, **bees**, and **wasps**. They are **altruistic**. They have *chewing* or *sucking* mouthparts.
    - **Lepidoptera:** This includes **Butterlies** and **moths**. They have *sucking* mouthparts.

  There are 2 groups that exhibit incomplete metamorphosis:

    - **Hemiptera:** *These include true bugs. They have a membranous pair and leathery pair of wings. They have *sucking* mouthparts.
    - **Orthoptera:** *These include grasshoppers, crickets, and other similar insects. They are mostly herbivores.

- **Crustaceans:** They have lots of specialized appendages (2 pairs of antennae, 3 pairs of eating parts, walking lags, and other stuff). The main groups are:
  - **Isopods:** *These are your pill bugs
  - **Decapods:** These are your lobsters, crayfish, and crabs. They have a calcium carbonate exoskeleton.
  - **Copepods:** These are your krill and other abundant tiny animals.
  - **Barnacles:** They have a calcium carbonate exoskeleton.



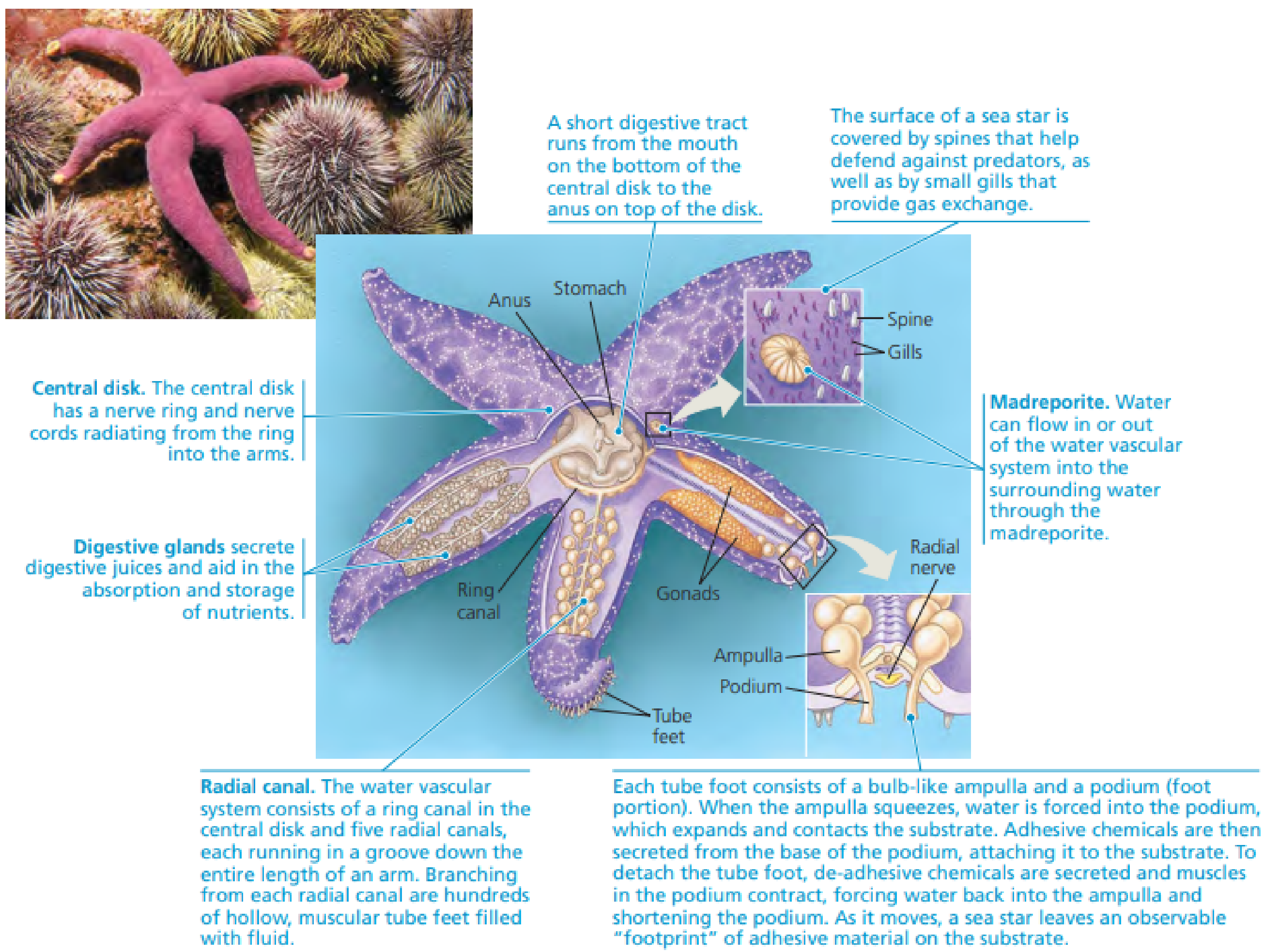

▲ **Figure 33.30 External anatomy of an arthropod.** Many of the distinctive features of arthropods are apparent in this dorsal view of a lobster, along with some uniquely crustacean characteristics. The body is segmented, but this characteristic is obvious only in the abdomen. The appendages (including antennae, pincers, mouthparts, walking legs, and swimming appendages) are jointed. The head bears a pair of compound (multilens) eyes, each situated on a movable stalk. The whole body, including appendages, is covered by an exoskeleton.

**Figure 64:** Diagram of arthropod anatomy.

## 9.9 Bilateria - Deuterostomia

This group contains the deuterostomes (keep in mind the only other deuterostomes are ectoprocts and brachiopods)! They are split into 3 main groups:

- **Hemichordata:** These are sort of like chordates, but not really. **Enteropneusts (acorn worms)** make up most of them.
- **Echinodermata:** Echinoderms have a **waster vascular system** in which they use water pressure to move their **tube feet**. It also allows for diffusion of oxygen. In addition, the tube feet contains **ampulla** that pump water into **podium**. The podium then expand and use adhesive chemicals to stick to substrates. This gives them an insanely strong grip! While the adults appear to be radial, their larvae are clearly bilateral. It turns out that the **madreporite**, which is the opening to the water vascular system, is slightly off center, making the adults bilateral.




▲ **Figure 33.40 Anatomy of a sea star, an echinoderm.**

**Figure 65:** Diagram displaying components of the water vascular system in echinoderms.

They are split into the following groups:

- **Asteroidea:** These include **sea stars** and **sea daisies.** Sea stars use chemical adhesives to stick onto surfaces, can stick their stomach inside out to eat prey, and have incredible regeneration!

  Sea daisies are the other part of asteroidea. Only 3 species are known, all of which live on submerged wood. They absorb nutrients (from decaying organisms) through a membrane surrounding their body.
- **Ophiuroidea:** These have a central disk with long, flexible arms.
- **Echinoidea:** These include **sea urchins** and **sand dollars**. The main difference between the two is that sea urchins are spherical while sand dollars are flat. They don't have arms, but their 5 rows of tube feet allow them to move slowly.
- **Crinoidea:** These include **sea lillies** and **feather stars**. Sea lillies attach to their substrate via a stalk. Feather stars have long, flexible arms. Crinoidea are suspension feeders that have changed little over evolution.
- **Holothuroidea:** These include **sea cucumbers**. While they don't look like other echinoderms, they still have many of the same features, such as 5 rows of tube feet.

• **Chordata:** That's what the next section is all about!

**Example 9.5:** (USABO Opens 2016)

**49. Which of the following classes would have members undergo radial and indeterminate cleavage during development? SELECT ALL THAT APPLY.**

A. Cephalopoda.
B. Holothuroidea.
C. Mammalia.
D. Scyphozoa.
E. Trematoda.

**Solution:** Radial and indeterminate cleavage means that we are talking about deuterostomes, which include chordates and echinoderms (and ectoprocts and brachiopods). A is an octopus. B is a sea cucumber, which we just saw are echinoderms. C is a mammal, which as we will see are chordates! D is jellyfish, which is cnidaria. E is trematodes, which are flatworms. Therefore, the **answer is B and C**.

**Example 9.6:** (USABO Semifinals 2018)

**58. You have found three new species, call them A, B, C. A has no coelom, a simple gut, and a simple nervous system; B also has no coelom and interestingly has protonephridia, and C is a pseudocoleomate with a cuticle and no circulatory system. Which of the following classifications is the most specific classification that still contains these three groups?**

A. Bilateria
B. Deuterostomia
C. Metazoa
D. Eukarya
E. Chordata

**Solution:** A refers to a simple acoelomate. B has protonephridia, which means it is likely a flatworm! C is a pseudocoelomate that lacks a circulatory system, which is indicative of a nematode. All 3 of these organisms are Bilateral, Metazoa (any organism with differentiated tissues, so basically all animals), and Eukarya. Out of these **A** is the most specific.

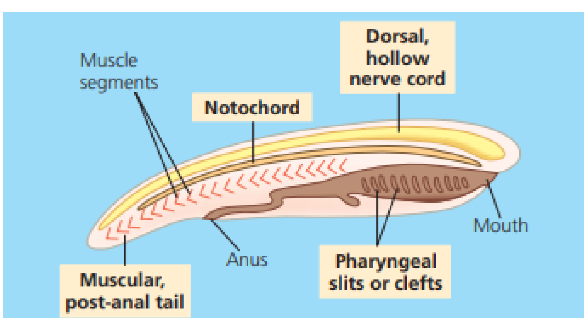
# 10 Animals-Vertebrates

This sections narrows down on what makes us human. As a result, each subsection will be a subset of the previous subsection.

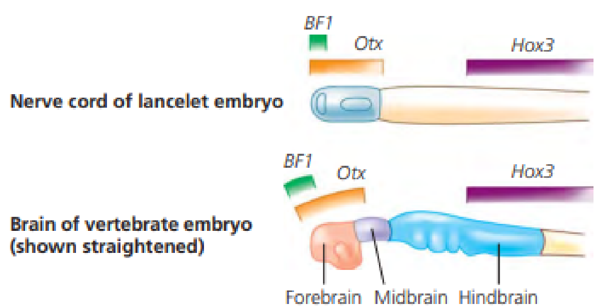
## 10.1 Features

All chordates share 4 traits:

1. **Notochord:** The notochord is a longitudinal, flexible rod along the back. It is important for directing the formation of the nerve cord. In humans, it has been reduced to **intervertebral disks.**
2. **Dorsal, hollow nerve cord:** The presence of the notochord helps direct the formation of the nerve cord. Some invertebrates have a *ventral* nerve cord.
3. **Pharyngeal Clefts/Slits:** Embryos have grooves along the side of the neck called pharyngeal clefts. These grooves can become gills, or parts of the ear and related regions.
4. **Muscular Post-anal tail**




▲ **Figure 34.3 Chordate characteristics.** All chordates possess the four highlighted structural trademarks at some point during their development.




▲ **Figure 34.6 Expression of developmental genes in lancelets and vertebrates.** *Hox* genes (including *BF1*, *Otx*, and *Hox3*) control the development of major regions of the vertebrate brain. These genes are expressed in the same anterior-to-posterior order in lancelets and vertebrates. Each colored bar is positioned above the portion of the brain whose development that gene controls.

**Figure 66:** Diagram displaying characteristics of chordates (left) and cephalization (right).

In addition, all chordates have **13 Hox genes** (except tunicates, which have 9 copies).

## 10.2 Historical chordates

Here is a list of important fossils of chordates. You will learn about the groups they represent in the subsequent subsections:

- *Haikouella*: fossil ancestor of chordates.
- *Myllokunmingia fengjiaoa*: fossil ancestor of craniates.
- **Conodonts:** fossil ancestor of vertebrates. They had well developed eyes. They impale their prey with barbed teeth. Then, the teeth farther back in the mouth grind the food.
- **Placoderms:** armored fossil ancestors of gnathostomes.
- **Acanthodians:** other fossil ancestors of gnathostomes around the same time.
- *Tiktaalik*: fossil ancestor of tetrapods. They show the transition from fish to tetrapods as they have many fish characteristics (fins, gills, lungs, and body covered in scales), but they also have many tetrapod characteristics (full set of ribs, head separated from body by neck, and fins had the tetrapod bone structuree of radius,ulna, and humerus).

## 10.3 Basal chordates

**Cephalocordata (lancelets):** They get their name from their bladelike shape. Lancelets retain many of the typical chordate traits as an adult, showing us what a "typical" chordate looks like. They burrow backwards into sand where they sit and filter feed. Instead of a brain, the only have a slightly swollen tip at the anterior end of the dorsal nerve cord (it still has the same genes that regulate brain development in all chordates).

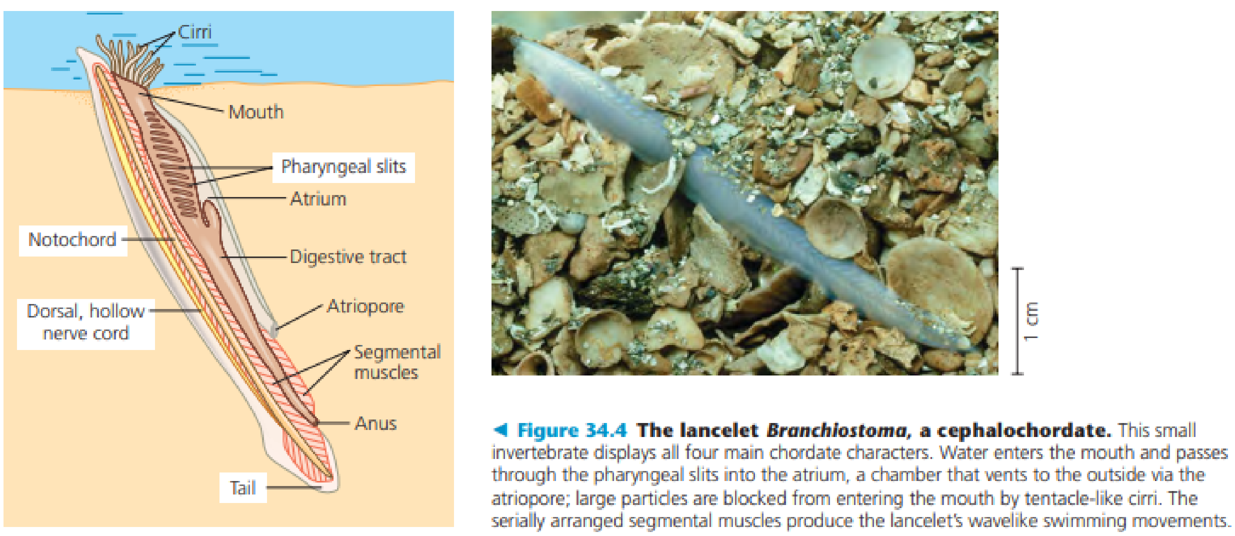
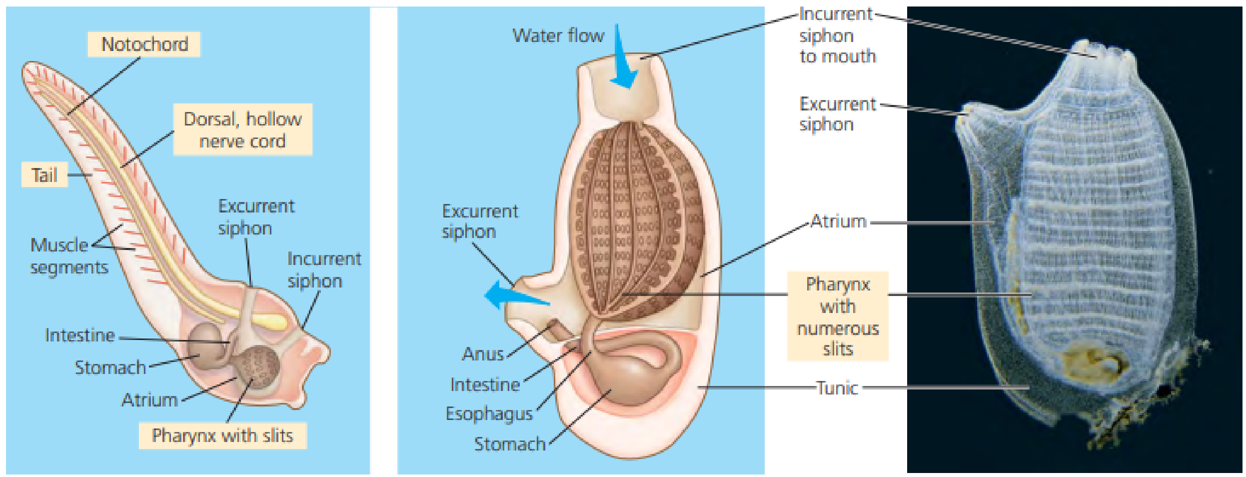



**Figure 67:** Diagram of adult lancelet, which retains the characteristic features of chordates.

**Urochordata (tunicates):** They look like a chordatewhile a larve. However, once it settles on a substrate, the tail and notochord are absorbed, the nervous system degenerates, and the remaining organs rotate 90°. As a result, the adult looks very different. As an adult, the tunicate sits there and filter feeds. **When attacked, some species shoot water out of an excurrent siphon, earning them the name "**sea squirts**".




**(a)** A tunicate larva is a free-swimming but nonfeeding "tadpole" in which all four main characters of chordates are evident.

**(b)** In the adult, prominent pharyngeal slits function in suspension feeding, but other chordate characters are not obvious.

**(c)** An adult tunicate, or sea squirt, is a sessile animal (photo is approximately life-sized).

▲ **Figure 34.5 A tunicate, a urochordate.**

**Figure 68:** Diagram contrasting the features of larva and adult tunicates.

As mentioned before, tunicates have only **9** Hox genes because they lost 4 of them during evolution. Tunicates also have embryonic cells that look sorta like neural crest cells even though only vertebrates have those.

**Example 10.1:** (USABO Semifinals 2018)

**60. You are discussing with your amazing biology teacher various biosystematics concepts. Which of the following are true statements?**

I. Porifera are basal metazoans
II. The Ediacara marked the appearance of the first eukaryotic organisms
III. The first organisms that existed and left a distinct record are the stromatolites
IV. Tunicates lack a notochord
V. Nematodes lack a circulatory system

A. I, IV, III
B. I, II, V
C. I, V
D. II, III, IV
E. II, V

**Solution:** I is true! Ediacara biota were the first animals, but far from the first eukaryotes, so II is false. I did not discuss **stromatolites**, but they were basically early colonies of photosynthetic cyanobacteria. Therefore, a stromatolite is a group of organisms and not an individual organism, so III is false. Tunicates are chordates, which means IV is false. V is a notable truth. Therefore, the **answer is C**.

Now, we will move on to the craniates!

## 10.4 Craniates

Craniates are chordates with a head. Craniates have 2 or more sets of Hox genes due to gene duplication, resulting in new features:

- In chordates, the presence of the notochord causes ectodermal cells near it to become the **neural plate**, which folds into a tube to become the dorsal nerve cord. In craniates, **neural crest cells** appear near the edge of the neural plate and migrate to other parts of the body to form many different structures (like bones in the skull).
- Gill slits now used for gas exchange instead of filter feeding
- Has more muscles, a heart with at least 2 chambers, red blood cells with hemoglobin, and kidneys.

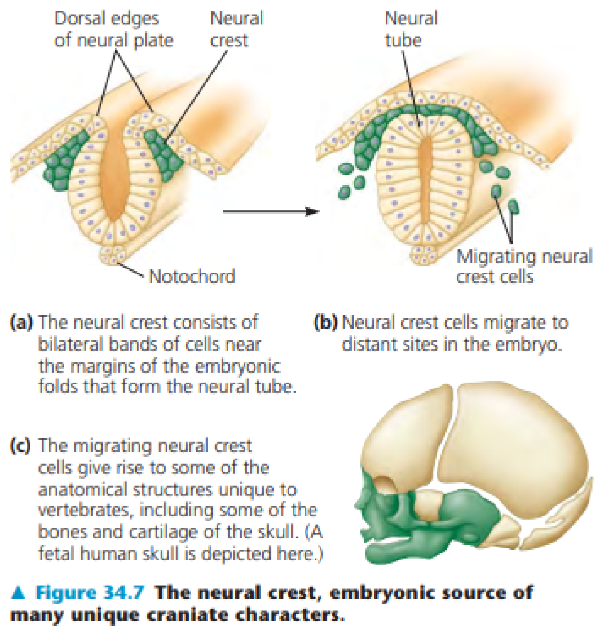



**Figure 69:** Diagram of neural crest cell migration.

Craniates are also called **vertebrates** because they have a backbone. The vertebrates also have a gene duplication of the *Dlx* family, allowing for a more extensive skull, backbone with vertebrae, and the aquatic vertebrates have fins. **Cyclostomes** are the living jawless vertebrates:

- **Myxini (hagfish):** Hagfish used to not be considered vertebrates because their vertebrae are so reduced its essentially nonexistent. Once it was discovered that hagfish are vertebrates, they were grouped together with lampreys, forming the group cyclostomes.


**Figure 70:** Hagfish! slimyyy

  Hagfish are marine scavengers with keratin teeth. They look like a snake and move like a snake. Most importantly, the cover themselves with *disgusting* slime that repulses other scavengers and suffocates any predators that try to eat it.

- **Pteromyzontida (lampreys):** As larva, lampreys live in freshwater streams and resemble lancelets. Once sexually mature, some species die within a few days while others go to the ocean and live out their life as parasites. They clamp onto the side of fish with their jawless mouth and then use their rasping tongue to borrow a hole and suck up blood. They have cartilage with no collagen. They have an inner ear with 2 semicircular canals for balance.

The vertebrates with jaws are Gnathostomes!

## 10.5 Gnathostomes

Gnathostomes are vertebrates with jaws. Their entire genome duplicated, so now they have 4 sets of Hox genes, resulting in unique features like the **lateral line system**. These are organs along the sides of fish that are sensitive to vibrations in water.

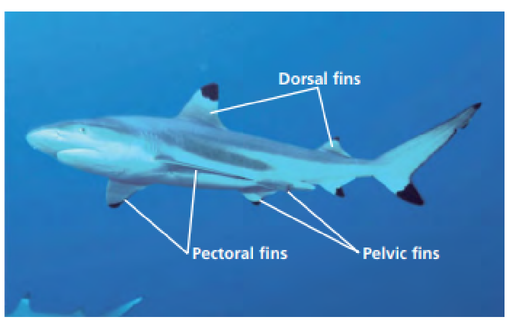
The gnathostomes are further devided based on what their skeleton is made of:

- **Chondrichthyans:** The chondrichthyans have cartilage skeletons (**chondroblasts** are cells that make cartilage). Like their ancestors, they have some bone, but it is restricted. They are separated into two main groups: the **Sharks**, **Rays**, and **skates**; then the **ratfish/chimaeras**.
  - **Sharks:** Sharks have some special compounds in them. They have high concentrations of urea in their tissue (see excretory system handout for why this is good for retaining water, but dangerously toxic), but prevent any damage because they have **TMAO (trimethylamine oxide)**.

    **Squalene** in shark liver helps with their buoyancy. However, sharks are still heavier than water so they need to keep on swimming to stay afloat. Sharks are swift swimmers but they can't maneuver well. When they swim, water goes through gills, allowing them to breathe (this is why some sharks swim even while asleep).

    The largest sharks are suspension feeders, but many are carnivores. As a result, they have a short digestive tract. However, a **corkscrew valve** helps increase the surface area for absorbing nutrients.

    Sharks have good vision, but can't distinguish colors. They have dead-end cup noses for smelling. Instead of eardrums, sharks have vibrations travel through the entire body to be transmitted to the inner ear, allowing them to hear. Sharks also have a **cloaca**, which is a single opening for everything (excretory and reproductive system).
  - **Rays:** Rays are bottom dwellers that feed on crustaceans and mollusks.




**(a) Blacktip reef shark (*Carcharhinus melanopterus*).** Sharks are fast swimmers with acute senses. Like all gnathosomes, they have paired pectoral and pelvic fins.

**(b) Southern stingray (*Dasyatis americana*).** Most rays are bottom-dwellers that feed on molluscs and crustaceans. Some rays cruise in open water and scoop food into their gaping mouth.

**Figure 71:** Examples of chondrichthyans. (Chimaera source: Wikipedia)

- **Osteichthyans (bony fishes):** The osteichthyans have bony skeletons ossified with **calcium phosphate**. They have new features like the **operculum**, which is a protective bony flap over the gills. They can also have a **swim bladder**, which exchanges gases with blood to control buoyancy. Lungs emerged in early osteichthyans. In some species, the lungs were modified into swim bladders.

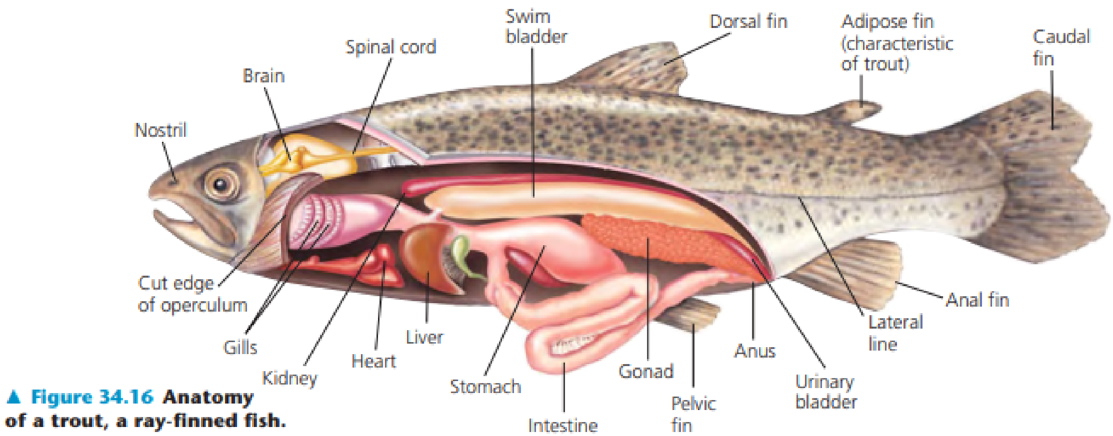



**Figure 72:** Diagram of ray-finned fish anatomy.

They are classified based on fin shape:

- **Actinopterygii (ray finned fishes):** They emerged during the Silurian.
- **Sarcopterygii (lobe finned fish):** They also emerged during the Silurian. Many lived in brackish water and "walked" on their lobe fins. However, by the end of the Devonian, only 3 lineages remained:
  * **Actinistia (Coelacanths):** These are the prime example of what a living fossil is. They were thought to be long extinct, until one was caught on the Comoros islands! Starting in the 1990s, they were caught in other places too.
  * **Dipnoi (lungfishes):** They originally evolved from the ocean, but now they only live in freshwater specifically, in stagnant ponds and swamps in the Southern Hemisphere. As the name suggests, these fish have both gills and lungs. Therefore, when water quality becomes poor, they can go up to the surface and gulp air!
  * **Tetrapod:** this is what the next subsection is about!

## 10.6 Tetrapod

Tetrapods are gnathostomes that have limbs with digits to suppor the body on land. In addition, they have a head that is separated from the body by the neck. The 1$^{st}$ vertebrae is called the **atlas** and allows for up and down movement of the head. The 2$^{nd}$ vertebrae is called the **axis** and allows for side to side movement of the head. Here are the tetrapods:

- **Amphibians:** amphibians can live on both land and water. They live in moist environments because they typically need to return to water to reproduce. As mentioned in the fungi section, their existence is threatened by a species of chytrid. There are 3 main groups of amphibians:
  - **Urodela (salamanders):** The name means "with tail". Salamanders have a tail and walk with a side to side bending motion. Both the adults and juveniles are carnivorous. Salamanders are unique because they exhibit **paedomorphosis**, where the fully grown adult still looks like a juvenile.

- **Anura (frogs):** The name means "no tail". The *tadpole* looks very different from the adult for a frog (for starters, the tadpole has a tail and but no limbs). Toads are just frogs with leathery skin or other adaptations for life on land. Check the respiratory system handout to understand their positive pressure breathing, check the cardiovascular handout to see how their heart works, and check the reproduction handout to see how they develop.
- **Apoda (caecillians):** The name means "no feet". Caecillians look like earthworms, making them legless and nearly blind. They are also the only venomous amphibians. When a baby caaecillian is born, they eat the skin of their mother!

• **Amniotes:** the rest of tetrapods have an egg adapted for terrestial life. The amniotic egg has **4 extraembryonic membranes**:

1. **Amnion:** protects the embryo in a cushioning fluid.
2. **Chorion:** performs gas exchange.
3. **Yolk sac:** provides nutrients for the developing embryo. **Lecithin** is an important lipid in egg yolk. **Albumin** is an important protein in egg whites.
4. **Allantois:** desposes wastes. This means it also helps with gas exchange ($CO_2$ is a waste).

While these structures remain the same for all amniotes, what the egg shell is composed of actually differs:

- Birds have calcareous shells.
- Reptiles have leathery shells.
- Mammals have no shell at all since it develops inside the mother.


**Figure 73:** Examples of amphibians.

**Example 10.2:** (USABO Opens 2016)

**25. Which of the following amniotic membranes can be involved in the respiratory exchange of gases in a snake embryo? SELECT ALL THAT APPLY.**

A. Amnion.
B. Chorion.
C. Respiratory lamina propria.
D. Allantois.
E. Yolk sac.

**Solution:** The chorion performs gas exchange. Since $CO_2$ is a waste, the allantois also deals with gas exchange. C is a random thing that is not one of the 4 extraembryonic membranes. Therefore, the **answer is A and D**.

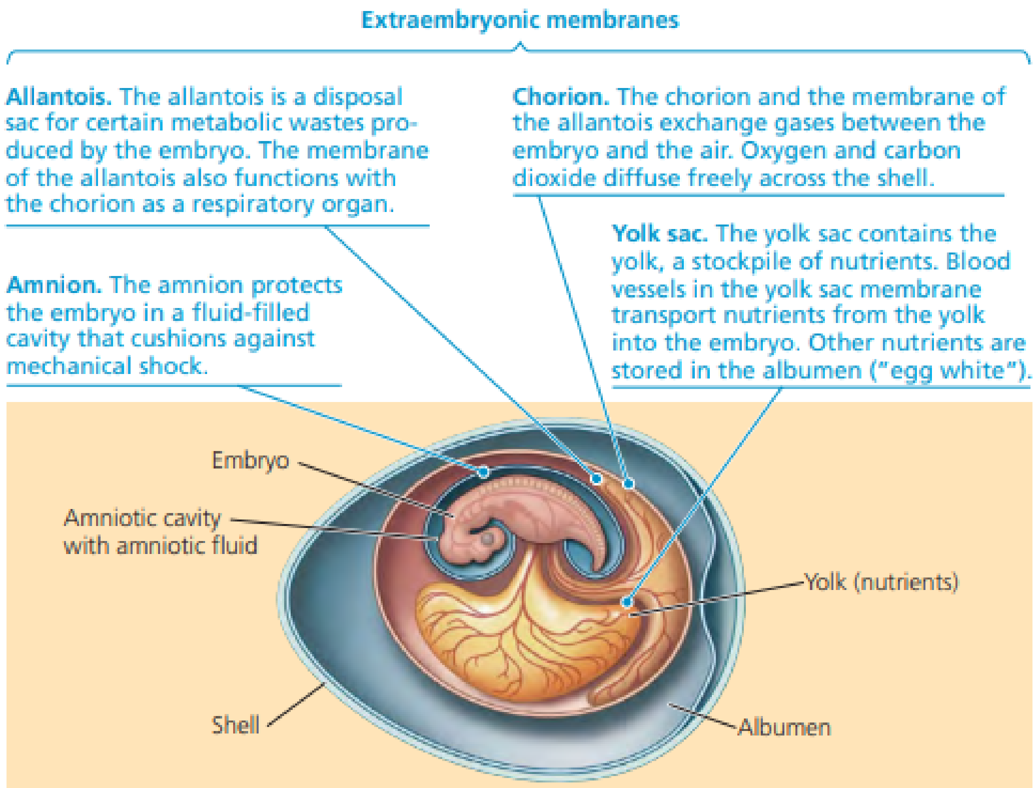



**Figure 74:** Diagram of components of amniotic egg.

The amniotes are further classified as either reptiles or mammals:

**Reptiles:** They have scales made of keratin. Many of them are **ectothermic**, relying on heat from their environment to regulate body temperatures. However, some, like birds, are **endothermic** and can regulate their temperature internaly. The reptiles are split into the following groups:

- **Parareptiles:** Large stocky quadrupedal herbivores that had plates for protection. They died out by the end of the Triassic.
- **Turtles:** They have an upper and lower shell fused to their vertebrae, clavicle, and ribs (you can **not** take a turtle out of its shell). Turtles are classified as either side-necked or vertical-necked based on how they retract their head.
  - **The Leatherback is the largest turtle.
- **Diapsids:** These animals have a hole behind their eye socket where muscles go through to attach to the jaw. They include:
  - **Lepidosaurs:** Includes lizards, snakes, and similar reptiles.
    - **Tuatras:** Sort of like lizards. **Rats are invasive species brought on boats that eat tuatara eggs and caused most species of tuatara to die out. As a result, Only 2 species exist and they live on New Zealand. Tuataras have a **third eye**, which is actually a pineal gland (part of the brain) that detects day/night cycles.
    - **Squamates:** *These include **lizards** and **snakes**. They come in all sizes:

- · **Jaragua lizard** is a super small lizard.
- · *Komodo dragon** is the largest and deadliest lizard. It has an incredibly venomous bite.

Some snakes have a vestigial pelvis. They move in waves of lateral bending, pushing against objects or gripping the ground with belly scales.

- **Archosaurs:** Includes:
  - ∗ **Crocodilians:** These include crocodiles, alligators, and gharials.
  - ∗ **Pterosaurs:** These animals essentially filled the ecological roles that birds do now (predators that dominate the sky). However, they died out by the end of the Cretaceous. They had very unique wings that stretched from arm to leg. Their wings had muscles, blood vessels, and nerves, allowing pterosaurs to dynamically adjust their wings while flying!
  - ∗ **Dinosaurs:** These reptiles on land diversified to fill many roles:
    - · **Ornithiscians:** These dinosaurs were herbivores with elaborate defenses, such as club tails and horned crests.
    - · **Saurishchians:** *These included the long-necked giants along with **Theropods:**
    - · → **Some theropods were bipedal carnivores, such as the *T. rex*
    - · → *Theropods also contained *Archaeopteryx*, the ancestor of birds.
    - · → **Birds:** These animals are well adapted for flight. They have many features to make them lightweight, such as lacking teeth, a urinary bladder, and having small gonads when it isn't breeding season. Their feathers are made of B-keratin. Birds can display complex behavior, especially during brooding season. Here are some notable birds:
    - · →→ ****Struthioniformes (Ratites):** This includes the ostrich, rhea, kiwi, cassowary, and emu.
    - · →→ ****Sphenisciformes (penguins)**
    - · →→ **Hummingbirds are the only birds that can hover and fly backwards.

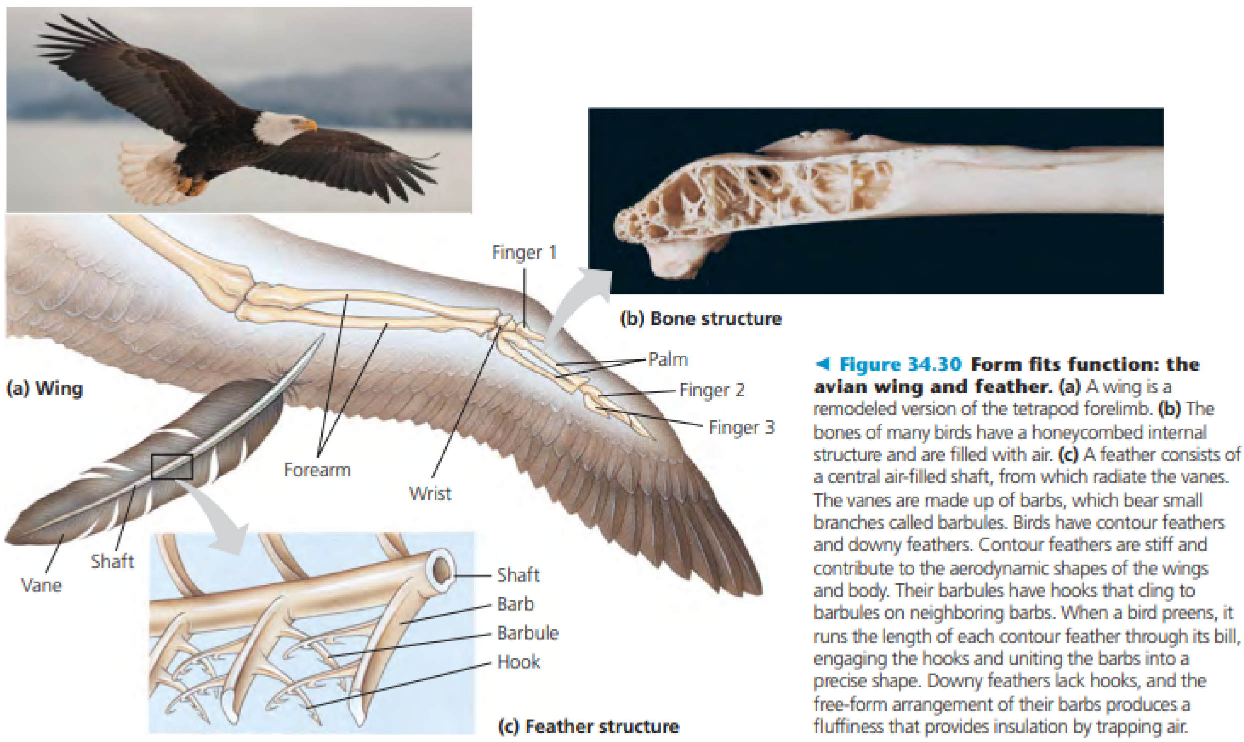



**Figure 75:** Diagram of a bird feather.

**Synapsids (Mammals):** This is what the next subsection is about!

## 10.7 Synapsids

The synapsids are amniotes that can produce milk. They have mammary glands (that make milk), hair, and differentiated teeth. The synapsids suffered heavy losses during the Permian-Triassic extinction but survived as mammals during the Cretaceous. As a result, the only existing synapsids today are mammals. We classify mammals based on how their young are born:

- **Monotremes:** These are mammals that lay eggs. They include 1 species of **platypus** and 4 species of **echidnas** (spiny anteaters). Monotremes lack nipples, so instead, their young must suck wet hair near the mammary glands to drink milk.
- **Marsupials:** The young are born premature, crawling out of the reproductive tract and directly into the **marsupium**, a special pouch on the adult where the young will stay. **Most animals have the marsupium on the front. Bandicoots, however, have their marsupium on their back so that the young are protected while the mother digs through dirt. Marsupials are found only in Australia and the Americas, with only 3 families of marsupials living outside of Australia. **The **opossum** is the only marsupial found naturally in North America.
- **Eutherians:** In these mammals, the young completes development in the uterus. Below is a list of the common Eutherian orders:


**Figure 76:** Orders within Synapsids.

It is important to know the difference between **even** and **odd-toed ungulates**. These are animals with hooves, and they are split into either group based on the number of toes on each hoove. I remember the odd toed ungulates as **Red Hot Takis** (**R**hinos, **H**orses and Zebras, and **T**apirs)! You should also know that **Cetaceans** (dolphins and whales) are closely related to the even-toed ungulates.

We are part of the order **Primates**. All primates have an **opposable thumb**, which is great for grabbing things. In addition, all primates (except humans) have opoosable toes. The hands and feet are built for grasping and have flat nails to facilitate it. However, primates are probably most well known for their highly social behavior, big brains, and short jaws (which creates a flat face with the eyes on the front). Primates are split into the following groups:

– **Lemurs**, **lorises**, and **bush babies:** These resemble early arboreal (tree dwelling) primates.

– **Tarsiers:** Live in Southeast Asia.

– **Anthropoids:** This group includes **Monkeys**, which were tree-dwellers originally from Africa. They are diurnal and live in bands. Monkeys are classified as **New World monkeys**, which include only arboreal species, or **Old World monkeys**, which include arboreal and ground-walking species.

  **Apes** is the other part of anthropoids and they diverged from the Old World monkeys:

  ∗ ** *Hylobates*: gibbons
  ∗ ** *Pongo*: orangutans
  ∗ ** *Gorilla*: gorillas
  ∗ ** *Pan*: chimpanzees and bonobos
  ∗ ** *Homo*: humans. The next subsection focuses on **hominins**, the animals in the genus **Homo** and other animals closely related to humans.

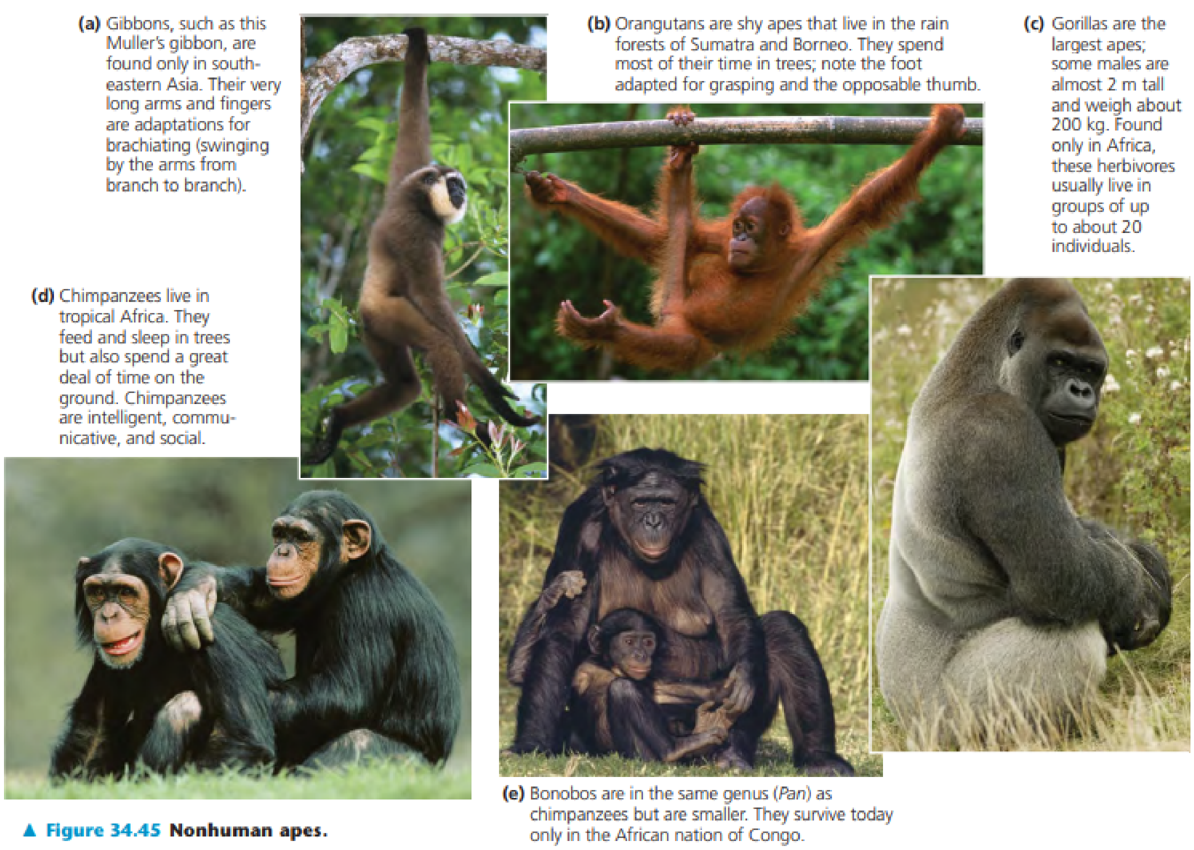



**Figure 77:** Common types of apes.

**Example 10.3:** (USABO Opens 2017)

**49. You are pleasantly enjoying your afternoon in Bali, Indonesia, when you stumble upon a street stand that has a conspicuous "DO NOT TOUCH" sign. Below the sign, there are two bats. This scary tourist trap owes its existence to which mammalian order?**

A. Monotremata.
B. Chiroptera.
C. Rodentia.
D. Lagomorpha.
E. Sirenia.

**Solution:** Chiroptera (Bats) is one of the mammal orders that is more commonly asked about. The **answer is B**.

**Example 10.4:** (USABO Opens 2017)

**50. Chef Grace is trying to experience the taste of dolphin without actually eating dolphin. She presumes that taste is evolutionary and changes much the same way genes do. Which of the following organisms should she eat based on this hypothesis?**

A. Elephant
B. Bighorn Sheep
C. Manatee
D. Lemur
E. Koala

**Solution:** Cetaceans, which include dolphins, are closely related to the even-toed ungulates. The only animal here that is an **ungulate (has hooves) is B**.

## 10.8 Hominins

**Paleoanthropology** is the study of human origins. Through it, we have found fossils of many species that resemble early humans:

- ******Sahelanthropus tchadensis*: one of the oldest species. We believe they are related to humans since their formane magnum was in the right place to let the head by upright.
- ******Ardipithecus ramidus*: another really old fossil. The leg bones show some bipedalism.
- ******Australopithecus africanus*: these fossils were bipedal.
- ******Australopithecus afarensis*: this species belongs to **Lucy**, one of the most famous hominid fossils.
- ******Paranthropus boisei*: these early humans were very robust.
- ******Australopithecus ghari*: these were possibly the first to use stone tools.
- ******Homo habilis*: These hominids had a shorter haw, bigger brain, and sharper toolers than previous fossils.

- ***Homo ergaster*: These hominids developed the traits of *homo habilis* even further. They were extremely bipedal, were the first to cook their food, and had a reduced sexual dimorphism.

- **Homo erectus*: These hominids were the first to migrate out of Africa.

- **Homo neanderthalensis*: these hominids are separate from our lineage. They had a stronger body than our ancestors, yet they still displayed culture such as burying their dead. Sadly, the neanderthals died out (possibly because of competition with our ancestors?)

  **The **Denisovans** are a unique species of hominid because they are believed to have interbred with neanderthals and maybe even humans. In 2018, the bones of a woman that had mixed denisovan and neanderthal parents was discovered!

- ***Homo floresiensis*: These hominids are separate from our lineage. They were like humans, but much smaller and they lived on a secluded island. As a result, their existence was a fairly recent discovery.

- ***Homo sapiens*: That's us!

# 11 Conclusion

Thank you for reading all the way to the end! As you have seen, there is plenty of diversity in life. Whether it is the predatory attacks of bdellovibrio, the mutualistic anomaly that is lichen, or the *unique* reproductive cycle of Cycliophora, if any of these organisms caught your interest, I highly recommend learning more about them! There are plenty of pictures of them online and videos highlighting the quirky behavior of organisms. It is these special features that will leave a lasting impact in your memory.