IOHS BIOLOGY Notes Use for Week One

INTRODUCTION: THE NATURE OF SCIENCE AND BIOLOGY

Biology: The Science of Our Lives

Biology literally means "the study of life". Biology is such a broad field, covering the minute workings of chemical machines inside our cells, to broad scale concepts of ecosystems and global climate change. Biologists study intimate details of the human brain, the composition of our genes, and even the functioning of our reproductive system. Biologists recently all but completed the deciphering of the human genome, the sequence of deoxyribonucleic acid (DNA) bases that may determine much of our innate capabilities and predispositions to certain forms of behavior and illnesses. DNA sequences have played major roles in criminal cases (O.J. Simpson, as well as the reversal of death penalties for many wrongfully convicted individuals), as well as the impeachment of President Clinton (the stain at least did not lie). We are bombarded with headlines about possible health risks from favorite foods (Chinese, Mexican, hamburgers, etc.) as well as the potential benefits of eating other foods such as cooked tomatoes. Infomercials tout the benefits of metabolism-adjusting drugs for weight loss. Many Americans are turning to herbal remedies to ease arthritis pain, improve memory, as well as improve our moods.

Can a biology book give you the answers to these questions? No, but it will enable you learn how to sift through the biases of investigators, the press, and others in a quest to critically evaluate the question. To be honest, five years after you are through with this class it is doubtful you would remember all the details of metabolism. However, you will know where to look and maybe a little about the process of science that will allow you to make an informed decision. Will you be a scientist? Yes, in a way. You may not be formally trained as a science major, but you can think critically, solve problems, and have some idea about what science can and cannot do. I hope you will be able to tell the shoe from the shinola.

Science and the Scientific Method

Science is an objective, logical, and repeatable attempt to understand the principles and forces operating in the natural universe. Science is from the Latin word, *scientia*, to know. Good science is **not** dogmatic, but should be viewed as an ongoing process of testing and evaluation. One of the hoped-for benefits of students taking a biology course is that they will become more familiar with the process of science.

Humans seem innately interested in the world we live in. Young children drive their parents batty with constant "why" questions. Science is a means to get some of those whys answered. When we shop for groceries, we are conducting a kind of scientific experiment. If you like Brand X of soup, and Brand Y is on sale, perhaps you try Brand Y. If you like it you may buy it again, even when it is not on sale. If you did not like Brand Y, then no sale will get you to try it again.

In order to conduct science, one must know the rules of the game (imagine playing Monopoly and having to discover the rules as you play! Which is precisely what one does with some computer or videogames (before buying the cheatbook). The scientific method is to be used as a guide that can be modified. In some sciences, such as taxonomy and certain types of geology, laboratory experiments are not necessarily performed. Instead, after formulating a hypothesis, additional observations and/or collections are made from different localities.

Steps in the scientific method commonly include:

Observation: defining the problem you wish to explain.

Hypothesis: one or more falsifiable explanations for the observation.

Experimentation: Controlled attempts to test one or more hypotheses.

Conclusion: was the hypothesis supported or not? After this step the hypothesis is either modified or rejected, which causes a repeat of the steps above.

After a hypothesis has been repeatedly tested, a hierarchy of scientific thought develops. Hypothesis is the most common, with the lowest level of certainty. A theory is a hypothesis that has been repeatedly tested with little modification, e.g. The Theory of Evolution. A Law is one of the fundamental underlying principles of how the Universe is organized, e.g. The Laws of Thermodynamics, Newton's Law of Gravity. Science uses the word theory differently than it is used in the general population. Theory to most people, in general nonscientific use, is an untested idea. Scientists call this a hypothesis.

Scientific experiments are also concerned with isolating the variables. A good science experiment does not simultaneously test several variables, but rather a single variable that can be measured against a control. Scientific controlled experiments are situations where all factors are the same between two test subjects, except for the single experimental variable.

Consider a commonly conducted science fair experiment. Sandy wants to test the effect of gangsta rap music on pea plant growth. She plays loud rap music 24 hours a day to a series of pea plants grown under light, and watered every day. At the end of her experiment she concludes gangsta rap is conducive to plant growth. Her teacher grades her project very low, citing the lack of a control group for the experiment. Sandy returns to her experiment, but this time she has a separate group of plants under the same conditions as the rapping plants, but with soothing Led Zeppelin songs playing. She comes to the same conclusion as before, but now has a basis for comparison. Her teacher gives her project a better grade.

Theories Contributing to Modern Biology

Modern biology is based on several great ideas, or theories:

The Cell Theory

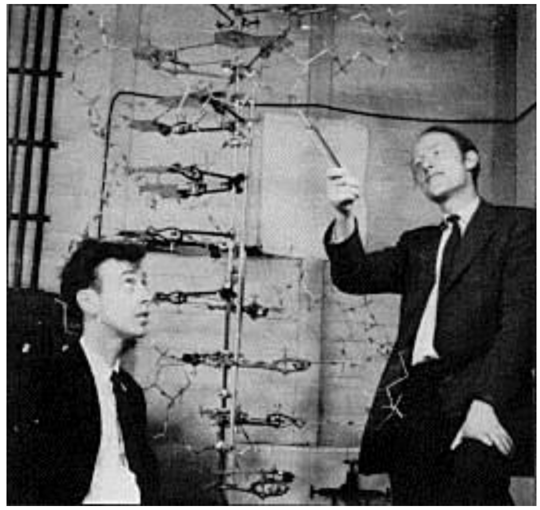
The Theory of Evolution by Natural Selection

Gene Theory

Homeostasis

Robert Hooke (1635-1703), one of the first scientists to use a microscope to examine pond water, cork and other things, referred to the cavities he saw in cork as "cells", Latin for chambers. Mattias Schleiden (in 1838) concluded all plant tissues consisted of cells. In 1839, Theodore Schwann came to a similar conclusion for animal tissues. Rudolf Virchow, in 1858, combined the two ideas and added that all cells come from pre-existing cells, formulating the Cell Theory. Thus there is a chain-of-existence extending from your cells back to the earliest cells, over 3.5 billion years ago. The cell theory states that all organisms are composed of one or more cells, and that those cells have arisen from pre-existing cells.

Figure 1. James Watson (L) and Francis Crick (R), and the model they built of the structure of deoxyribonucleic acid, DNA. While a model may seem a small thing, their development of the DNA model fostered increased understanding of how genes work. Image from the Internet.



In 1953, American scientist James Watson and British scientist Francis Crick developed the model for deoxyribonucleic acid (DNA), a chemical that had (then) recently been deduced to be the physical carrier of inheritance. Crick hypothesized the mechanism for DNA replication and further linked DNA to proteins, an idea since referred to as the central dogma. Information from DNA "language" is converted into RNA (ribonucleic acid) "language" and then to the "language" of proteins. The central dogma explains the influence of heredity (DNA) on the organism (proteins).

Homeostasis is the maintenance of a dynamic range of conditions within which the organism can function. Temperature, pH, and energy are major components of this concept. Thermodynamics is a field of study that covers the laws governing energy transfers, and thus the basis for life on earth. Two major laws are known: the conservation of matter and energy, and entropy. These will be discussed in more detail in a later chapter. The universe is composed of two things: matter (atoms, etc.) and energy.

These first three theories are very accepted by scientists and the general public. The theory of evolution is well accepted by scientists and most of the general public. However, it remains a lightning rod for school boards, politicians, and television preachers. Much of this confusion results from what the theory says and what it does not say.

Development of the Theory of Evolution

Modern biology is based on several unifying themes, such as the cell theory, genetics and inheritance, Francis Crick's central dogma of information flow, and Darwin and Wallace's theory of evolution by natural selection. In this first unit we will examine these themes and the nature of science.

The Ancient Greek philosopher Anaxiamander (611-547 B.C.) and the Roman philosopher Lucretius (99-55 B.C.) coined the concept that all living things were related and that they had changed over time. The classical science of their time was observational rather than experimental. Another ancient Greek philosopher, Aristotle developed his *Scala Naturae*, or Ladder of Life, to explain his concept of the advancement of living things from inanimate matter to plants, then animals and finally man. This concept of man as the "crown of creation" still plagues modern evolutionary biologists (See Gould, 1989, for a more detailed discussion).

Post-Aristotlean "scientists" were constrained by the prevailing thought patterns of the Middle Ages -- the inerrancy of the biblical book of Genesis and the special creation of the world in a literal six days of the 24-hour variety. Archbishop James Ussher of Ireland, in the late 1600's calculated the age of the earth based on the genealogies from Adam and Eve listed in the biblical book of Genesis. According to Ussher's calculations, the earth was formed on October 22, 4004 B.C. These calculations were part of Ussher's book, History of the World. The chronology he developed was taken as factual, and was even printed in the front pages of bibles. Ussher's ideas were readily accepted, in part because they posed no threat to the social order of the times; comfortable ideas that would not upset the linked applecarts of church and state.

Figure 2. Archbishop James Ussher. Image from the Internet.

Often new ideas must "come out of left field", appearing as wild notions, but in many cases prompting investigation which may later reveal the "truth". Ussher's ideas were comfortable, the Bible was viewed as correct, and therefore the earth **must** be only 5000 years old.

Geologists had for some time doubted the "truth" of a 5,000 year old earth. Leonardo da Vinci (painter of the Last Supper, and the Mona Lisa, architect and engineer) calculated the sedimentation rates in the Po River of Italy. Da Vinci concluded it took 200,000 years to form some nearby rock deposits. Galileo, convicted heretic for his contention that the Earth was not the center of the Universe, studied fossils (evidence of past life) and concluded that they were real and not inanimate artifacts. James Hutton, regarded as the Father of modern geology, developed the Theory of Uniformitarianism, the basis of modern geology and paleontology. According to Hutton's work, certain geological processes operated in the past in much the same fashion as they do today, with minor exceptions of rates, etc. Thus many geological structures and processes cannot be explained if the earth was only a mere 5000 years old.

The Modern View of the Age of the Earth

Radiometric age assignments based on the rates of decay of radioactive isotopes, not discovered until the late 19th century, suggest the earth is over 4.5 billion years old. The Earth is thought older than 4.5 billion years, with the oldest known rocks being 3.96 billion years old. Geologic time divides into eons, eroas, and smaller units. An overview of geologic time may be obtained at http://www.ucmp.berkeley.edu/help/timeform.html.

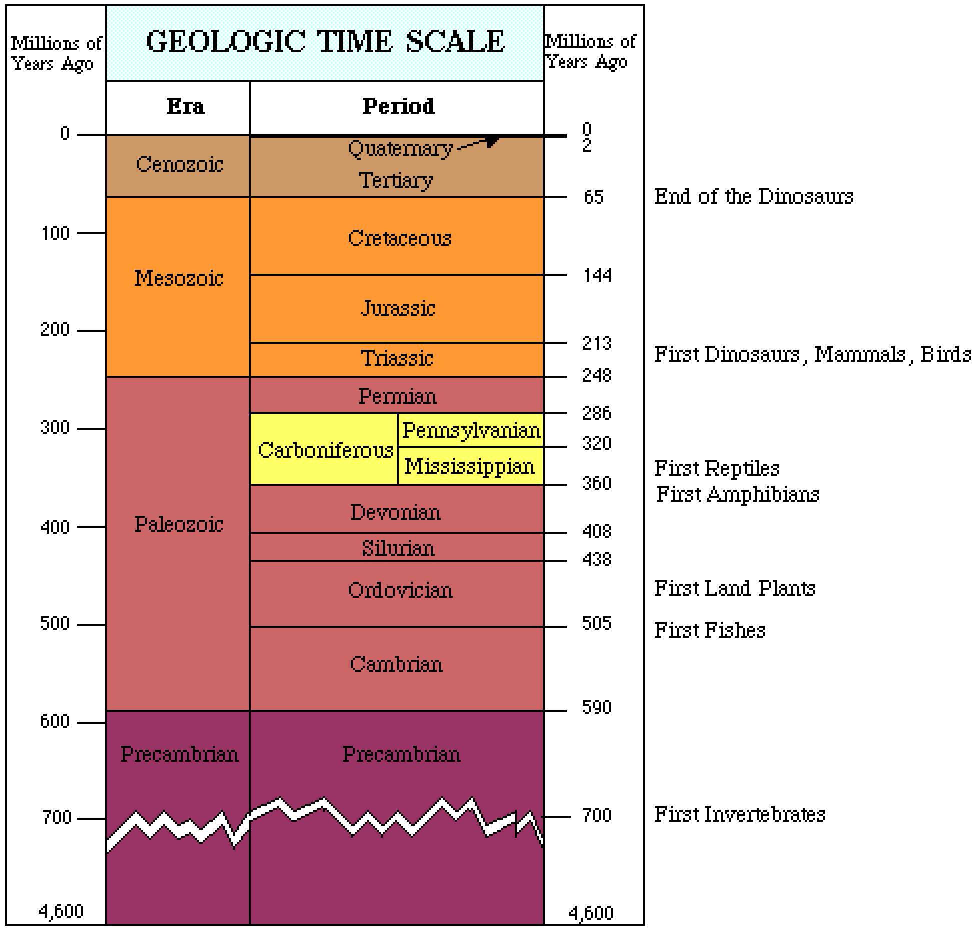


Figure 3. The geologic time scale, highlighting some of the firsts in the evolution of life. One way to represent geological time. Note the break during the Precambrian. If the vertical scale was truly to scale the Precambrian would account for 7/8 of the graphic. This image is from http://www.clearlight.com/~mhieb/WVFossils/GeolTimeScale.html.

Development of the modern view of Evolution

Erasmus Darwin (1731-1802; grandfather of Charles Darwin) a British physician and poet in the late 1700's, proposed that life had changed over time, although he did not present a mechanism. Georges-Louis Leclerc, Comte de Buffon (pronounced Bu-fone; 1707-1788) in the middle to late 1700's proposed that species could change. This was a major break from earlier concepts that species were created by a perfect creator and therefore could not change because they were perfect, etc.

Swedish botanist Carl Linne (more popularly known as Linneus, after the common practice of the day which was to latinize names of learned men), attempted to pigeon-hole all known species of his time (1753) into immutable categories. Many of these categories are still used in biology, although the underlying thought concept is now evolution and not immutability of species. Linnean hierarchical classification was based on the premise that the species was the smallest unit, and that each species (or taxon) belonged to a higher category.

Kingdom Animalia

Phylum (Division is used for plants) Chordata

Class Mammalia

Order Primates

Family Hominidae

Genus Homo

species sapiens

This image is from http://linnaeus.nrm.se/botany/fbo/welcome.html.en.

Linneus also developed the concept of binomial nomenclature, whereby scientists speaking and writing different languages could communicate clearly. For example Man in English is *Hombre* in Spanish, *Mensch* in German, and *Homo* in Latin. Linneus settled on Latin, which was the language of learned men at that time. If a scientist refers to *Homo*, all scientists know what he or she means.

William "Strata" Smith (1769-1839), employed by the English coal mining industry, developed the first accurate geologic map of England. He also, from his extensive travels, developed the Principle of Biological Succession. This idea states that each period of Earth history has its own unique assemblages of fossils. In essence Smith fathered the science of stratigraphy, the correlation of rock layers based on (among other things) their fossil contents. He also developed an idea that life had changed over time, but did not overtly state that.

Abraham Gottlob Werner and Baron Georges Cuvier (1769-1832) were among the foremost proponents of catastrophism, the theory that the earth and geological events had formed suddenly, as a result of some great catastrophe (such as Noah's flood). This view was a comfortable one for the times and thus was widely accepted. Cuvier eventually proposed that there had been several creations that occurred after catastrophies. Louis Agassiz (1807-1873) proposed 50-80 catastrophies and creations.

Jean Baptiste de Lamarck (1744-1829) developed one of the first theories on how species changed. He proposed the inheritance of acquired characteristics to explain, among other things, the length of the giraffe neck. The Lamarckian view is that modern giraffe's have long necks because their ancestors progressively gained longer necks due to stretching to reach food higher and higher in trees. According to the 19th century concept of use and disuse the stretching of necks resulted in their development, which was somehow passed on to their progeny. Today we realize that only bacteria are able to incorporate non-genetic (no heritable) traits. Lamarck's work was a theory that plainly stated that life had changed over time and provided (albeit an erroneous) mechanism of change.

Additional information about the biological thoughts of Lamarck is available by clicking here.

Darwinian evolution

Charles Darwin, former divinity student and former medical student, secured (through the intercession of his geology professor) an unpaid position as ship's naturalist on the British exploratory vessel H.M.S. Beagle. The voyage would provide Darwin a unique opportunity to study adaptation and gather a great deal of proof he would later incorporate into his theory of evolution. On his return to England in 1836, Darwin began (with the assistance of numerous specialists) to catalog his collections and ponder the seeming "fit" of organisms to their mode of existence. He eventually settled on four main points of a radical new hypothesis:

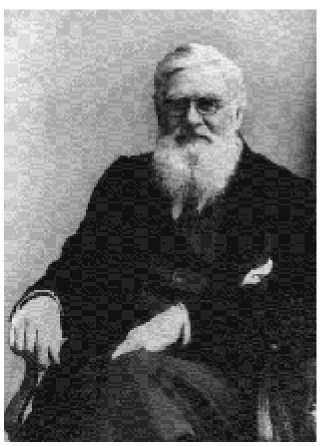
Adaptation: all organisms adapt to their environments.

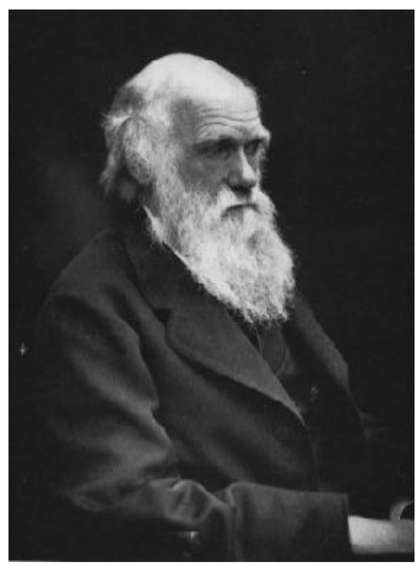
Variation: all organisms are variable in their traits.

Over-reproduction: all organisms tend to reproduce beyond their environment's capacity to support them (this is based on the work of Thomas Malthus, who studied how populations of organisms tended to grow geometrically until they encountered a limit on their population size).

Since not all organisms are equally well adapted to their environment, some will survive and reproduce better than others -- this is known as natural selection. Sometimes this is also referred to as "survival of the fittest". In reality this merely deals with the reproductive success of the organisms, not solely their relative strength or speed.

Figure 4. Charles Darwin (right) and Alfred Wallace (left), the co-developers of the theory of evolution by means of natural selection. Image of Charles Darwin from http://zebu.uoregon.edu/~js/glossary/darwinism.html.Image of A.R. Wallace (right) is modified from http://www.prs.k12.nj.us/schools/phs/science_Dept/APBio/Natural_Selection.html.





Unlike the upper-class Darwin, Alfred Russel Wallace (1823-1913) came from a different social class. Wallace spent many years in South America, publishing salvaged notes in **Travels on the Amazon and Rio Negro** in 1853. In 1854, Wallace left England to study the natural history of Indonesia, where he contracted malaria. During a fever Wallace managed to write down his ideas on natural selection.

In 1858, Darwin received a letter from Wallace, in which Darwin's as-yet-unpublished theory of evolution and adaptation was precisely detailed. Darwin arranged for Wallace's letter to be read at a scientific meeting, along with a synopsis of his own ideas. To be correct, we need to mention that both Darwin and Wallace developed the theory, although Darwin's major work was not published until 1859 (the book On the Origin of Species by Means of Natural Selection, considered by many as one of the most influential books written [follow the hyperlink to view an online version]). While there have been some changes to the theory since 1859, most notably the incorporation of genetics and DNA into what is termed the "Modern Synthesis" during the 1940's, most scientists today acknowledge evolution as the guiding theory for modern biology.

Recent revisions of biology curricula stressed the need for underlying themes. Evolution serves as such a universal theme. An excellent site devoted to Darwin's thoughts and work is available by clicking here. At that same site is a timeline showing many of the events mentioned above in their historical contexts.

The Diversity of Life

Evolutionary theory and the cell theory provide us with a basis for the interrelation of all living things. We also utilize Linneus' hierarchical classification system, adopting (generally) five kingdoms of living organisms. Viruses, as discussed later, are not considered living. Click here for a table summarizing the five kingdoms. Recent studies suggest that there might be a sixth Kingdom, the Archaea.

Figure 5. A simple phylogenetic representation of three domains of life" Archaea, Bacteria (Eubacteria), and Eukaryota (all eukaryotic groups: Protista, Plantae, Fungi, and Animalia). Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

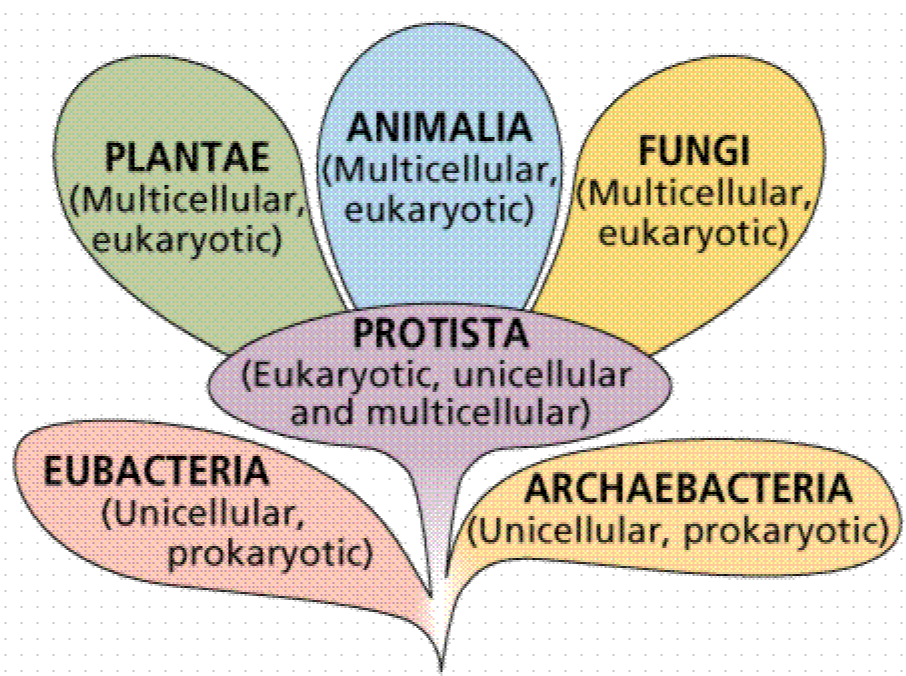


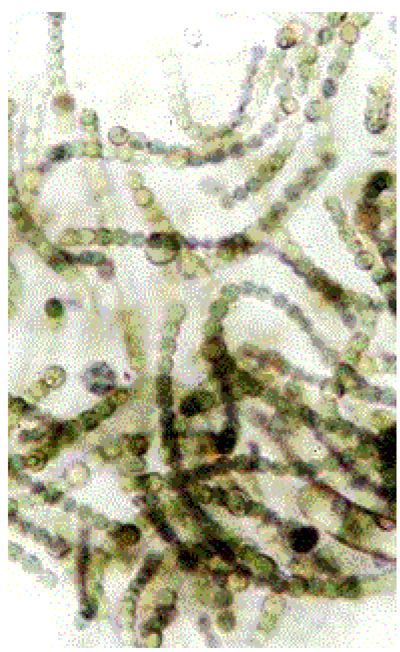
Table 1. The Five Kingdoms.

Kingdom	**Methods of Nutrition**	**Organization**	**Environmental Significance**	**Examples**
Monera (in the broadest sense, including organisms usually placed in the Domain Archaea).	Photosynthesis, chemosynthesis, decomposer, parasitic.	Single-celled, filament, or colony of cells; all prokaryotic.	Monerans play various roles in almost all food chains, including producer,consumer, and decomposer. Cyanobacteria are important oxygen producers. Many Monerans also produce nitrogen, vitamins, antibiotics, and are important compoents in human and animal intestines.	Bacteria (*E. coli*), cyanobacteria (*Oscillatoria*), methanogens, and thermacidophiles.
Protista	Photosynthesis, absorb food from environment, or trap/engulf smaller organisms.	Single-celled, filamentous, colonial, and multicelled; all eukaryotic.	Important producers in ocean/pond food chain. Source of food in some human cultures. Phytoplankton component that is one of the major producers of oxygen	Plankton (both phytoplankton and zooplankton), algae (kelp, diatoms, dinoflagellates),and Protozoa (*Amoeba*, *Paramecium*).
Fungi	Absorb food from a host or from their environment. All heterotrophic.	Single-celled, filamentous, to multicelled; all eukaryotic.	Decomposer, parasite, and consumer. Produce antibiotics,help make bread and alcohol. Crop parasites (Dutch Elm Disease, Karnal Bunt, Corn Smut, etc.).	Mushrooms (*Agaricus campestris*, the commercial mushroom), molds, mildews, rusts and smuts (plant parasites), yeasts (*Saccharomyces cerevisae*, the brewer's yeast).
Plantae	Almost all photosynthetic, although a few parasitic plants are known.	All multicelled, photosynthetic, autotrophs..	Food source, medicines and drugs, dyes, building material, fuel. Producer in most food chains.	Angiosperms (oaks, tulips, cacti),gymnosperms (pines, spuce, fir), mosses, ferns,liverworts, horsetails

				(*Equisetum*, the scouring rush)
Animalia	All heterotrophic.	Multicelled heterotrophs capable of movement at some stage during their life history (even couch potatoes).	Consumer level in most food chains (herbivores,carnivores,omnivores). Food source, beasts of burden and transportation, recreation, and companionship.	Sponges, worms,molluscs, insects, starfish,mammals, amphibians,fish, birds, reptiles, and dinosaurs, and people.

Monera, the most primitive kingdom, contain living organisms remarkably similar to ancient fossils. Organisms in this group lack membrane-bound organelles associated with higher forms of life. Such organisms are known as prokaryotes. Bacteria (technically the Eubacteria) and blue-green bacteria (sometimes called blue-green algae, or cyanobacteria) are the major forms of life in this kingdom. The most primitive group, the archaebacteria, are today restricted to marginal habitats such as hot springs or areas of low oxygen concentration.

Figure 6. Representative photosynthetic cyanobacteria: *Oscillatoria* (left) and *Nostoc* (right). The left image is cropped from gopher://wiscinfo.wisc.edu:2070/I9/.image/.bot/.130/Cyanobacteria/Oscillatoria_130. The right image is cropped from gopher://wiscinfo.wisc.edu:2070/I9/.image/.bot/.130/Cyanobacteria/Nostoc_130.



Protista were the first of the eukaryotic kingdoms, these organisms and all others have membrane-bound organelles, which allow for compartmentalization and dedication of specific areas for specific functions. The chief importance of Protista is their role as a stem group for the remaining Kingdoms: Plants, Animals, and Fungi. Major groups within the Protista include the algae, euglenoids, ciliates, protozoa, and flagellates.

Figure 7. Scanning electron micrographs of diatoms (Protista).There are two basic types of diatoms: bilaterally symmetrical (left) and radially symmetrical (right). Images are from http://WWW.bgsu.edu/departments/biology/algae/index.html.

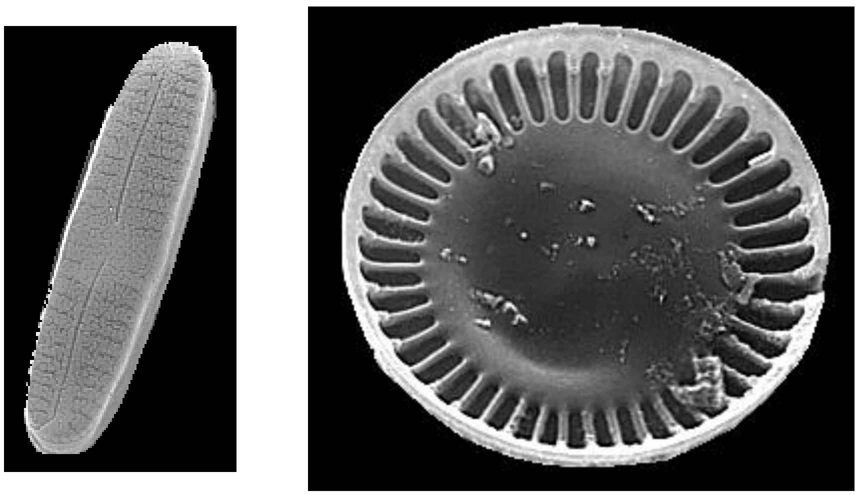


Figure 8. Light micrographs of some protistans. The images are Copyright 1994 by Charles J. O'Kelly and Tim Littlejohn, used by permission from: http://megasun.bch.umontreal.ca/protists/gallery.html.

Fungi are almost entirely multicellular (with yeast, *Saccharomyces cerviseae*, being a prominent unicellular fungus), heterotrophic (deriving their energy from another organism, whether alive or dead), and usually having some cells with two nuclei (multinucleate, as opposed to the more common one, or uninucleate) per cell. Ecologically this kingdom is important (along with certain bacteria) as decomposers and recyclers of nutrients. Economically, the Fungi provide us with food (mushrooms; Bleu cheese/Roquefort cheese; baking and brewing), antibiotics (the first of the wonder drugs, penicillin, was isolated from a fungus *Penicillium*), and crop parasites (doing several billion dollars per year of damage).

Figure 9. Examples of fungi. The images are from

http://www.cinenet.net/users/velosa/thumbnails.html.

Plantae include multicelled organisms that are all autotrophic (capable of making their own food by the process of photosynthesis, the conversion of sunlight energy into chemical energy). Ecologically, this kingdom is generally (along with photosynthetic organisms in Monera and Protista) termed the producers, and rest at the base of all food webs. A food web is an ecological concept to trace energy flow through an ecosystem. Economically, this kingdom is unparalleled, with agriculture providing billions of dollars to the economy (as well as the foundation of "civilization"). Food, building materials, paper, drugs (both legal and illegal), and roses, are plants or plant-derived products.

Figure 10. Examples of plants. The left image of species of *Equisetum* is cropped and reduced from gopher://wiscinfo.wisc.edu:2070/I9/.image/.bot/.130/Fern_Allies/Sphenophyta/Equisetum/E._arvense_and_E._laevigatum_KS. The center image of *Iris*, is reduced and cropped from gopher://wiscinfo.wisc.edu:2070/I9/.image/.bot/.401/Flowering_Plants/Monocots/Iridaceae/Iris/Iris_pumula_habit. The right image of *Pereskia* (Cactaceae) is reduced from gopher://wiscinfo.wisc.edu:2070/I9/.image/.bot/.401/Flowering_Plants/Dicots/Cactaceae/Pereskia/Pereskia_leafy_stem_RK.

Animalia consists entirely of multicelluar heterotrophs that are all capable (at some point during their life history) of mobility. Ecologically, this kingdom occupies the level of consumers, which can be subdivided into herbivore (eaters of plants) and carnivores (eaters of other animals). Humans, along with some other organisms, are omnivores (capable of functioning as herbivores or carnivores). Economically, animals provide meat, hides, beasts of burden, pleasure (pets), transportation, and scents (as used in some perfumes).

Figure 11. Examples of animals. The left image of a jellyfish is from http://www.smoky.org/~mtyler/bio/coelenterata.html. The center image of a tree frog is from http://frog.simplenet.com/froggy/images/wild28.gif. The right image of the chimpanzee is from http://www.selu.com/~bio/PrimateGallery/art/Copyright_Free02.html.

Characteristics of living things

Living things have a variety of common characteristics.

Organization. Living things exhibit a high level of organization, with multicellular organisms being subdivided into cells, and cells into organelles, and organelles into molecules, etc.

Homeostasis. Homeostasis is the maintenance of a constant (yet also dynamic) internal environment in terms of temperature, pH, water concentrations, etc. Much of our own metabolic energy goes toward keeping within our own homeostatic limits. If you run a high fever for long enough, the increased temperature will damage certain organs and impair your proper functioning. Swallowing of common household chemicals, many of which are outside the pH (acid/base) levels we can tolerate, will likewise negatively impact the human body's homeostatic regime. Muscular activity generates heat as a waste product. This heat is removed from our bodies by sweating. Some of this heat is used by warm-blooded animals, mammals and birds, to maintain their internal temperatures.

Adaptation. Living things are suited to their mode of existence. Charles Darwin began the recognition of the marvelous adaptations all life has that allow those organisms to exist in their environment.

Reproduction and heredity. Since all cells come from existing cells, they must have some way of reproducing, whether that involves asexual (no recombination of genetic material) or sexual (recombination of genetic material). Most living things use the chemical DNA (deoxyribonucleic acid) as the physical carrier of inheritance and the genetic information. Some organisms, such as retroviruses (of which HIV is a member), use RNA (ribonucleic acid) as the carrier. The variation that Darwin and

Wallace recognized as the wellspring of evolution and adaptation, is greatly increased by sexual reproduction.

Growth and development. Even single-celled organisms grow. When first formed by cell division, they are small, and must grow and develop into mature cells. Multicellular organisms pass through a more complicated process of differentiation and organogenesis (because they have so many more cells to develop).

Energy acquisition and release. One view of life is that it is a struggle to acquire energy (from sunlight, inorganic chemicals, or another organism), and release it in the process of forming ATP (adenosine triphosphate).

Detection and response to stimuli (both internal and external).

Interactions. Living things interact with their environment as well as each other. Organisms obtain raw materials and energy from the environment or another organism. The various types of symbioses (organismal interactions with each other) are examples of this.

Levels of Organization

Biosphere: The sum of all living things taken in conjunction with their environment. In essence, where life occurs, from the upper reaches of the atmosphere to the top few meters of soil, to the bottoms of the oceans. We divide the earth into atmosphere (air), lithosphere (earth), hydrosphere (water), and biosphere (life).

Ecosystem: The relationships of a smaller groups of organisms with each other and their environment. Scientists often speak of the interrelatedness of living things. Since, according to Darwin's theory, organisms adapt to their environment, they must also adapt to other organisms in that environment. We can discuss the flow of energy through an ecosystem from photosynthetic autotrophs to herbivores to carnivores.

Community: The relationships between groups of different species. For example, the desert communities consist of rabbits, coyotes, snakes, birds, mice and such plants as sahuaro cactus (*Carnegia gigantea*), Ocotillo, creosote bush, etc. Community structure can be disturbed by such things as fire, human activity, and over-population.

Species: Groups of similar individuals who tend to mate and produce viable, fertile offspring. We often find species described not by their reproduction (a biological species) but rather by their form (anatomical or form species).

Populations: Groups of similar individuals who tend to mate with each other in a limited geographic area. This can be as simple as a field of flowers, which is separated from another field by a hill or other area where none of these flowers occur.

Individuals: One or more cells characterized by a unique arrangement of DNA "information". These can be unicellular or multicellular. The multicellular individual exhibits specialization of cell types and division of labor into tissues, organs, and organ systems.

Organ System: (in multicellular organisms). A group of cells, tissues, and organs that perform a specific major function. For example: the cardiovascular system functions in circulation of blood.

Organ: (in multicellular organisms). A group of cells or tissues performing an overall function. For example: the heart is an organ that pumps blood within the cardiovascular system.

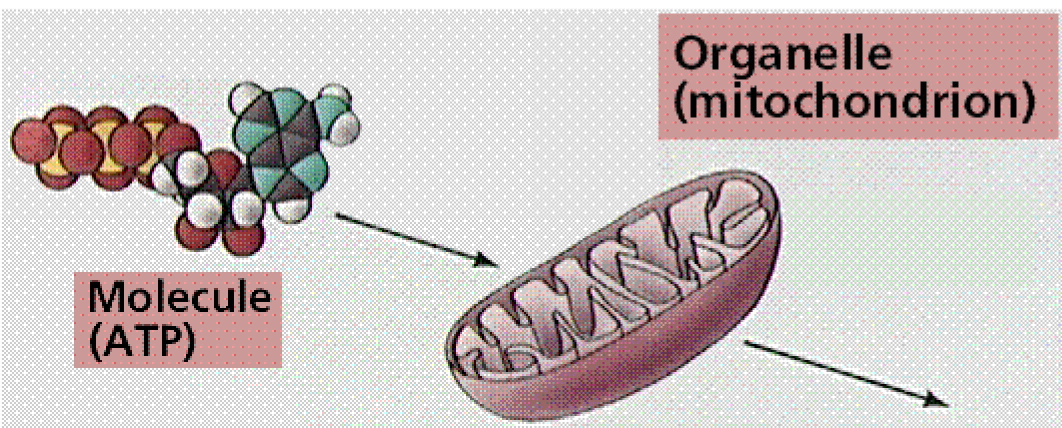
Tissue: (in multicellular organisms). A group of cells performing a specific function. For example heart muscle tissue is found in the heart and its unique contraction properties aid the heart's functioning as a pump. .

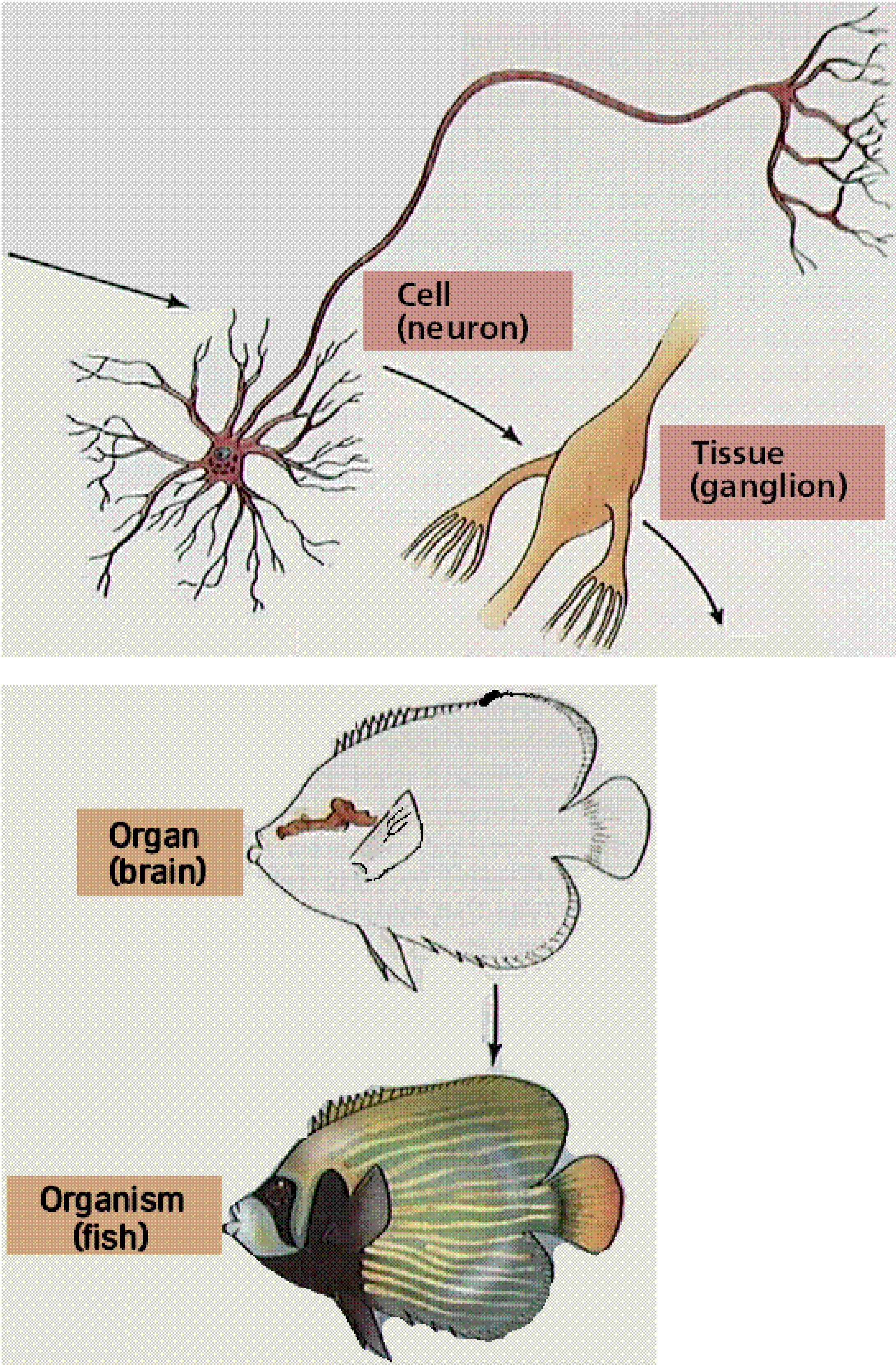
Cell: The fundamental unit of living things. Each cell has some sort of hereditary material (either DNA or more rarely RNA), energy acquiring chemicals, structures, etc. Living things, by definition, must have the metabolic chemicals plus a nucleic acid hereditary information molecule.

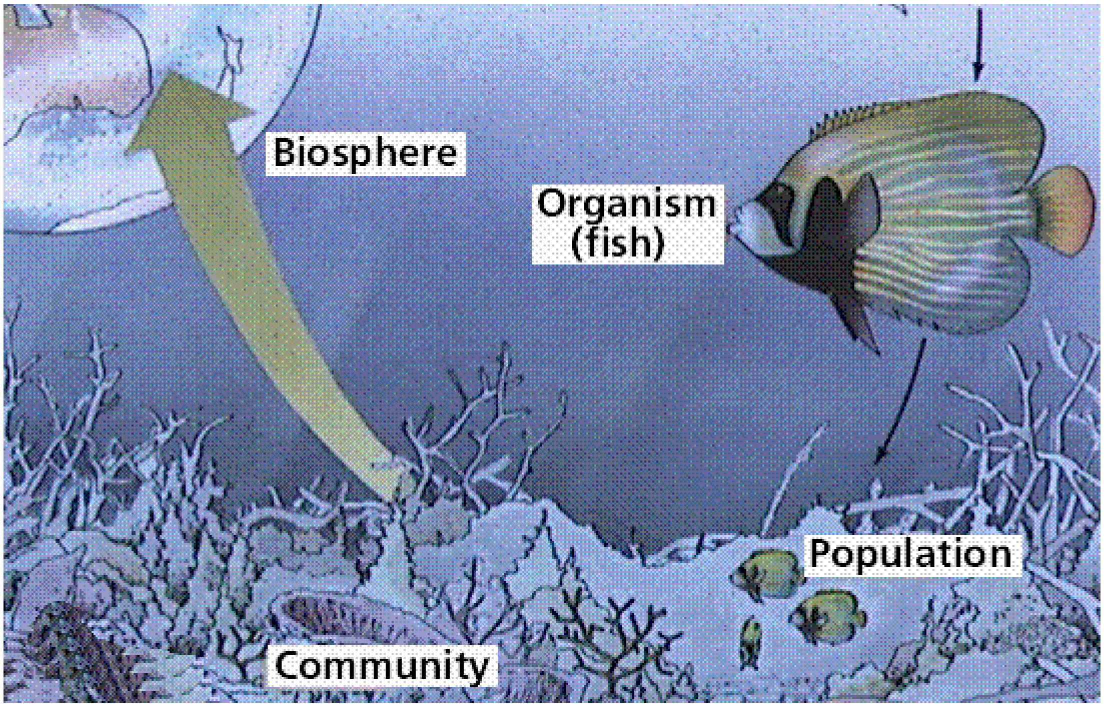
Organelle: A subunit of a cell, an organelle is involved in a specific subcellular function, for example the ribosome (the site of protein synthesis) or mitochondrion (the site of ATP generation in eukaryotes).

Molecules, atoms, and subatomic particles: The fundamental functional levels of biochemistry.

Figure 12. Organization levels of life, in a graphic format. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.




Cell
(neuron)
Tissue
(ganglion)
Organ
(brain)
Organism
(fish)



It is thus possible to study biology at many levels, from collections of organisms (communities), to the inner workings of a cell (organelle).

CELLS: ORIGINS

Origin of the Earth and Life

Scientific estimates place the origin of the Universe at between 10 and 20 billion years ago. The theory currently with the most acceptance is the Big Bang Theory, the idea that all matter in the Universe existed in a cosmic egg (smaller than the size of a modern hydrogen atom) that exploded, forming the Universe. Recent discoveries from the Space Telescope and other devices suggest this theory smay need some modification. Evidence for the Big Bang includes:

1) **The Red Shift**: when stars/galaxies are moving away from us the energy they emit is shifted to the red side of the visible-light spectrum. Those moving towards us are shifted to the violet side. This shift is an example of the Doppler effect. Similar effects are observed when listening to a train whistle-- it will sound higher (shorter wavelengths) approaching and lower (longer wavelengths) as it moves away. Likewise red wavelengths are longer than violet ones. Most galaxies appear to be moving away from ours.

2) **Background radiation**: two Bell Labs scientists discovered that in interstellar space there is a slight background radiation, thought to be the residual afterblast remnant of the Big Bang. Click here for additional information from sites dealing with the Big Bang, or here for a Powerpoint slideshow about the Big Bang.

Soon after the Big Bang the major forces (such as gravity, weak nuclear force, strong nuclear force, etc.) differentiated. While in the cosmic egg, scientists think that matter and energy as we understand them did not exist, but rather they formed soon after the bang. After 10 million to 1 billion years the universe became clumpy, with matter beginning to accumulate into solar systems. One of those solar systems, ours, began to form approximately 5 billion years ago, with a large "protostar" (that became our sun) in the center. The planets were in orbits some distance from the star, their increasing gravitational fields sweeping stray debris into larger and larger planetesimals that eventually formed planets.

The processes of radioactive decay and heat generated by the impact of planetesimals heated the Earth, which then began to differentiate into a "cooled" outer cooled crust (of silicon, oxygen and other relatively light elements) and increasingly hotter inner areas (composed of the heavier and denser elements such as iron and nickel). Impact (asteroid, comet, planetismals) and the beginnings of volcanism released water vapor, carbon dioxide, methane, ammonia and other gases into a developing atmosphere. Sometime "soon" after this, life on Earth began.

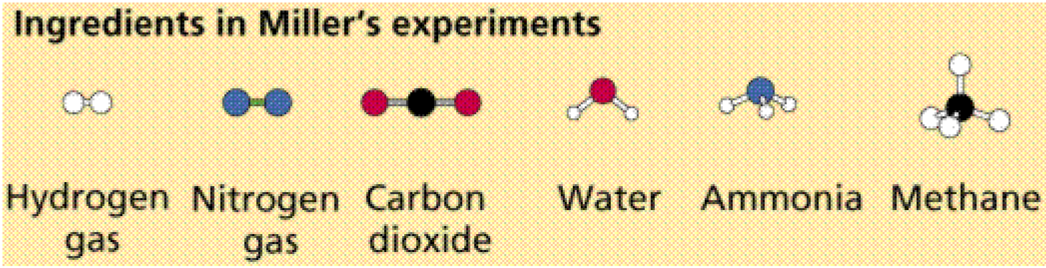
Where did life originate and how?

Extra-terrestrial: In 1969, a meteorite (left-over bits from the origin of the solar system) landed near Allende, Mexico. The Allende Meteorite (and others of its sort) have been analyzed and found to contain amino acids, the building blocks of proteins, one of the four organic molecule groups basic to all life. The idea of panspermia hypothesized that life originated out in space and came to Earth inside a meteorite. Recently, this idea has been revived as Cosmic Ancestry. The amino acids recovered from meteorites are in a group known as exotics: they do not occur in the chemical systems of living things. The ET theory is now not considered by most scientists to be correct, although the August 1996 discovery of the Martian meteorite and its possible fossils have revived thought of life elsewhere in the Solar System.

Supernatural: Since science is an attempt to measure and study the natural world, this theory is outside science (at least our current understanding of science). Science classes deal with science, and this idea is in the category of not-science.

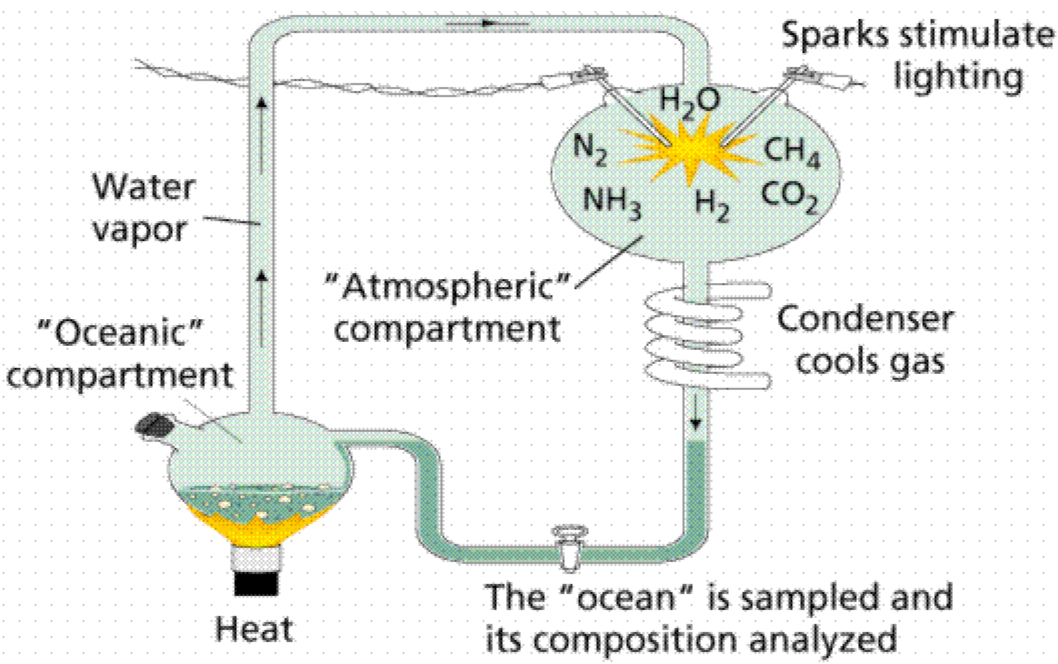
Organic Chemical Evolution: Until the mid-1800's scientists thought organic chemicals (those with a C-C skeleton) could only form by the actions of living things. A French scientist heated crystals of a mineral (a mineral is by definition inorganic), and discovered that they formed urea (an organic chemical) when they cooled. Russian scientist and academecian A.I. Oparin, in 1922, hypothesized that cellular life was preceeded by a period of chemical evolution. These chemicals, he argued, must have arisen spontaneously under conditions exisitng billions of years ago (and quite unlike current conditions).

Figure 1. Ingredients used in Miller's experiments, simple molecules thought at the time to have existed on the Earth billions of years ago. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.



In 1950, then-graduate student Stanley Miller designed an experimental test for Oparin's hypothesis. Oparin's original hypothesis called for : 1) little or no free oxygen (oxygen not bonded to other elements); and 2) C H O and N in abundance. Studies of modern volcanic eruptions support inference of the existence of such an atmosphere. Miller discharged an electric spark into a mixture thought to resemble the primordial composition of the atmosphere. Miller's atmosphere contents are shown in Figure 1. From the water receptacle, designed to model an ancient ocean, Miller recovered amino acids. Subsequent modifications of the atmosphere have produced representatives or precursors of all four organic macromolecular classes. His experimental apparatus is shown in Figure 2.

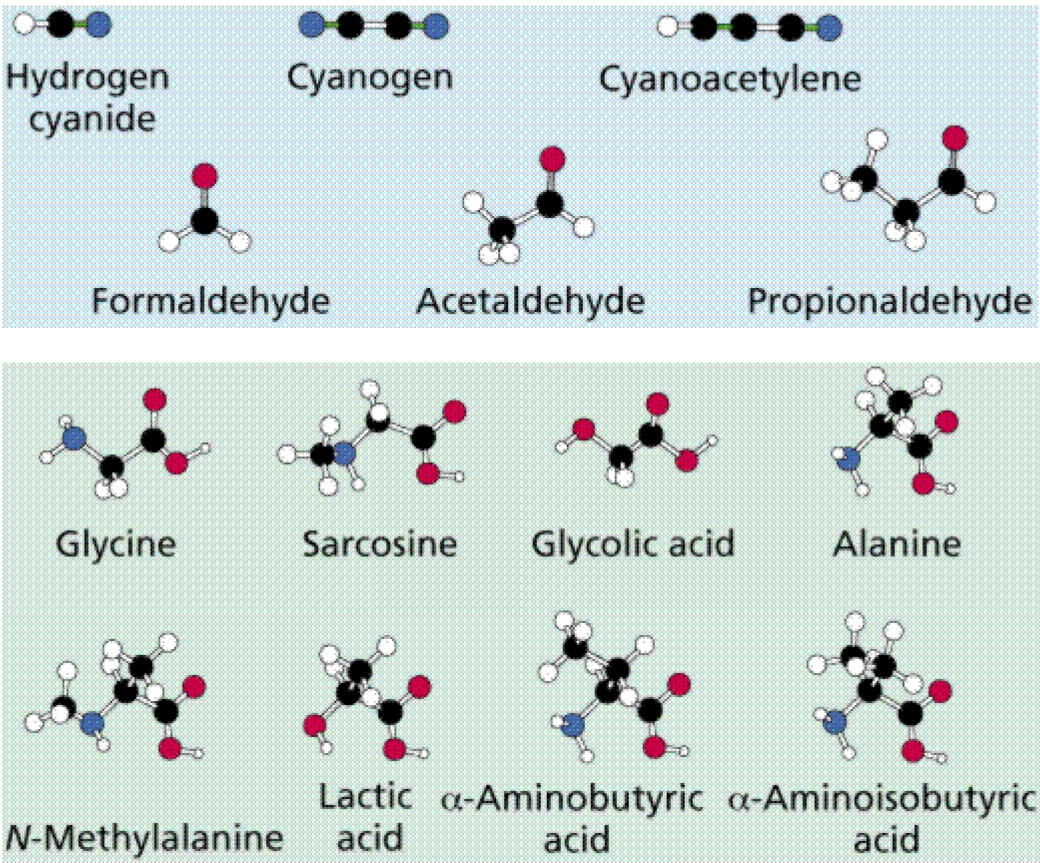
Figure 2. A diagrammatic representation of Miller's experimental apparatus. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

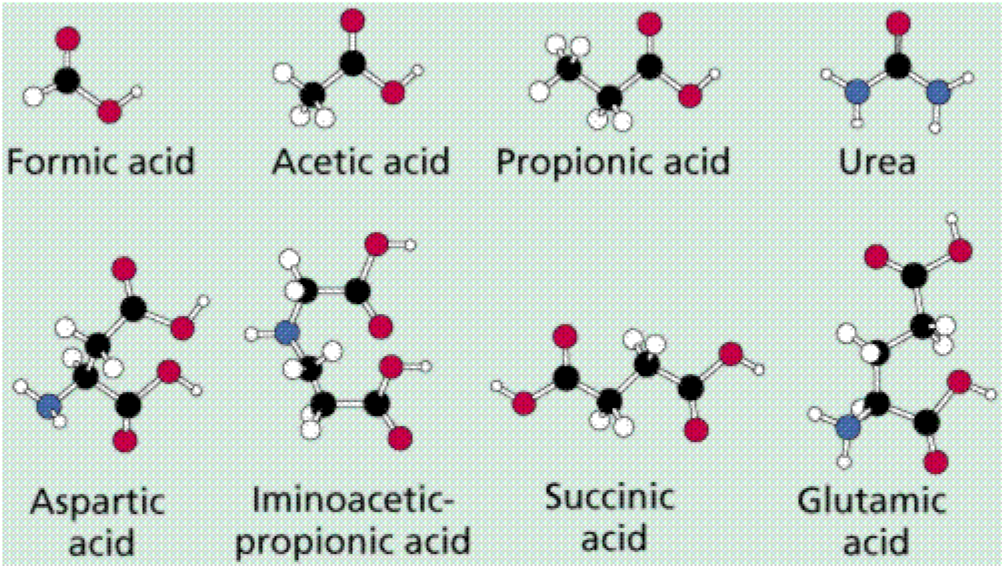


The primordial Earth was a very different place than today, with greater amounts of energy, stronger storms, etc. The oceans were a "soup" of organic compounds that formed by inorganic processes (although this soup would not taste umm ummm good). Miller's (and subsequent) experiments have **not** proven life originated in this way, only that conditions thought to have existed over 3 billion years ago were such that the spontaneous (inorganic) formation of organic macromolecules could have taken place.

The simple inorganic molecules that Miller placed into his apparatus, produced a variety of complex molecules, shown below in Figure 3.

Figure 3. Molecules recovered from Miller's and similar experiments. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.





The interactions of these molecules would have increased as their concentrations increased. Reactions would have led to the building of larger, more complex molecules. A pre-cellular life would have began with the formation of nucleic acids. Chemicals made by these nucleic acids would have remained in proximity to the nucleic acids. Eventually the pre-cells would have been enclosed in a lipid-protein membrane, which would have resulted in the first cells.

Biochemically, living systems are separated from other chemical systems by three things.

The capacity for replication from one generation to another. Most organisms today use DNA as the hereditary material, although recent evidence (ribozymes) suggests that RNA may have been the first nucleic acid system to have formed. Nobel laureate Walter Gilbert refers to this as the RNA world. Recent studies suggest a molecular

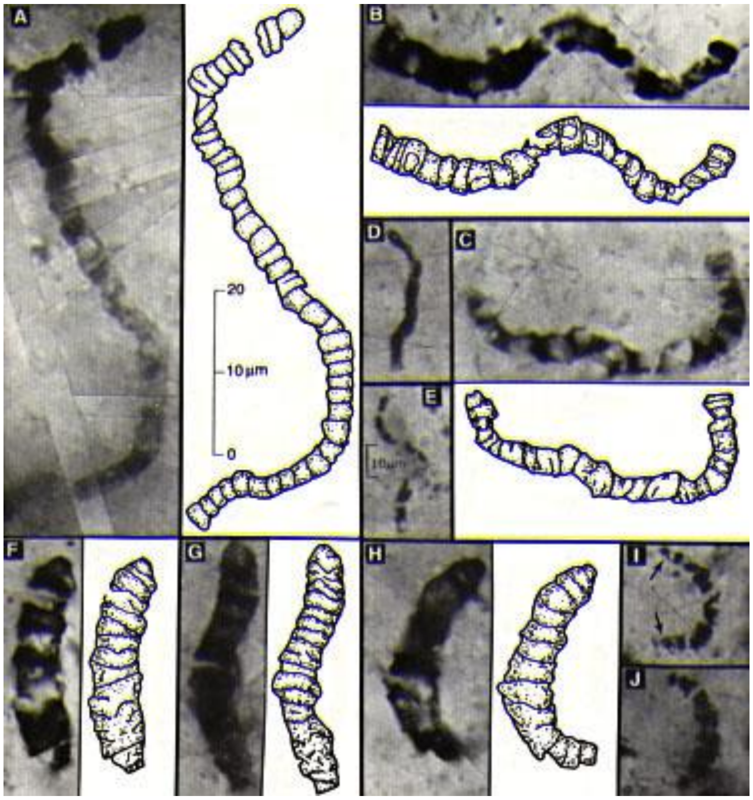
The presence of enzymes and other complex molecules essential to the processes needed by living systems. Miller's experiment showed how these could possibly form.

A membrane that separates the internal chemicals from the external chemical environment. This also delimits the cell from not-cell areas. The work of Sidney W. Fox has produced proteinoid spheres, which while not cells, suggest a possible route from chemical to cellular life.

Fossil evidence supports the origins of life on Earth earlier than 3.5 billion years ago. The North Pole microfossils from Australia, illustrated in Figure 4, are complex enough that more primitive cells must have existed earlier. From rocks of the Ishua Super Group in Greenland come possibly the earliest cells, as much as 3.8 billion years old. The oldest known rocks on Earth are 3.96 billion years old and are from Arctic Canada. Thus, life appears to have begun soon after the cooling of the Earth and formation of the atmosphere and oceans.

Figure 4. Microfossils from the Apex Chert, North Pole, Australia. These organisms are Archean in age, approximately 3.465 billion years old, and resemble filamentous cyanobacteria. Image from

http://www.astrobiology.ucla.edu/ESS116/L15/1515%20Apex%20Chert.jpg.



These ancient fossils occur in marine rocks, such as limestones and sandstones, that formed in ancient oceans. The organisms living today that are most similar to ancient life forms are the archaebacteria. This group is today restricted to marginal environments. Recent discoveries of bacteria at mid-ocean ridges add yet another possible origin for life: at these mid-ocean ridges where heat and molten rock rise to the Earth's surface.

Archaea and Eubacteria are similar in size and shape. When we do recover "bacteria" as fossils those are the two features we will usually see: size and shape. How can we distinguish between the two groups: the use of molecular fossils that will point to either (but not both) groups. Such a chemical fossil has been found and its presence in the Ishua rocks of Greenland (3.8 billion years old) suggests that the archeans were present at that time.

Is there life on Mars, Venus, anywhere else?

The proximity of the Earth to the sun, the make-up of the Earth's crust (silicate mixtures, presence of water, etc.) and the size of the Earth suggest we may be unique in our own solar system, at least. Mars is smaller, farther from the sun, has a lower gravitational field (which would keep the atmosphere from escaping into space) and does show evidence of running water sometime in its past. If life did start on Mars, however, there appears to be no life (as we know it) today. Venus, the second planet, is closer to the sun, and appears similar to Earth in many respects. Carbon dioxide build-up has resulted in a "greenhouse planet" with strong storms and strongly acidic rain. Of all planets in the solar system, Venus is most likely to have some form of carbon-based life. The outer planets are as yet too poorly understood, although it seems unlikely that Jupiter or Saturn harbor life as we know it. Like Goldilocks would say "Venus is too hot, Mars is too cold, the Earth is just right!"

Mars: In August 1996, evidence of life on Mars (or at least the chemistry of life), was announced. Click here to view that article and related ones. The results of years of study are inconclusive at best. The purported bacteria are much smaller than any known bacteria on Earth, were not hollow, and most could possibly have been mineral in origin. However, many scientists consider that the chemistry of life appears to have been established on Mars. Search for martian life (or its remains) continues.

Terms applied to cells

Heterotroph (other-feeder): an organism that obtains its energy from another organism. Animals, fungi, bacteria, and mant protistans are heterotrophs.

Autotroph (self-feeder): an organism that makes its own food, it converts energy from an inorganic source in one of two ways. Photosynthesis is the conversion of sunlight energy into C-C covalent bonds of a carbohydrate, the process by which the vast majority of autotrophs obtain their energy. Chemosynthesis is the capture of energy released by certain inorganic chemical reactions. This is common in certain groups of likely that chemosynthesis predates photosynthesis. At mid-ocean ridges, scientists have discovered black smokers, vents that release chemicals into the water. These chemical reactions could have powered early ecosystems prior to the development of an ozone layer that would have permitted life to occupy the shallower parts of the ocean. Evidence of the antiquity of photosynthesis includes: a) biochemical precursors to photosynthesis chemicals have been synthesized in experiments; and b) when placed in light, these chemicals undergo chemical reactions similar to some that occur in primitive photosynthetic bacteria.

Prokaryotes are among the most primitive forms of life on Earth. Remember that primitive does not necessarily equate to outdated and unworkable in an evolutionary sense, since primitive bacteria seem little changed, and thus may be viewed as well adapted, for over 3.5 Ga. Prokaryote (pro=before, karyo=nucleus): these organisms lack membrane-bound organelles, as seen in Figures 5 and 6. Some internal membrane organization is observable in a few prokaryotic autotrophs, such as the photosynthetic membranes associated with the photosynthetic chemicals in the photosynthetic bacterium *Prochloron*. A transmission electron micrograph of *Prochloron* is shown in Figure 5.

Figure 5 Prochloron, an extant prokaryote thought related to the ancestors of some eukarypote chloroplasts. Image fom http://tidepool.st.usm.edu/pix/prochloron.gif.

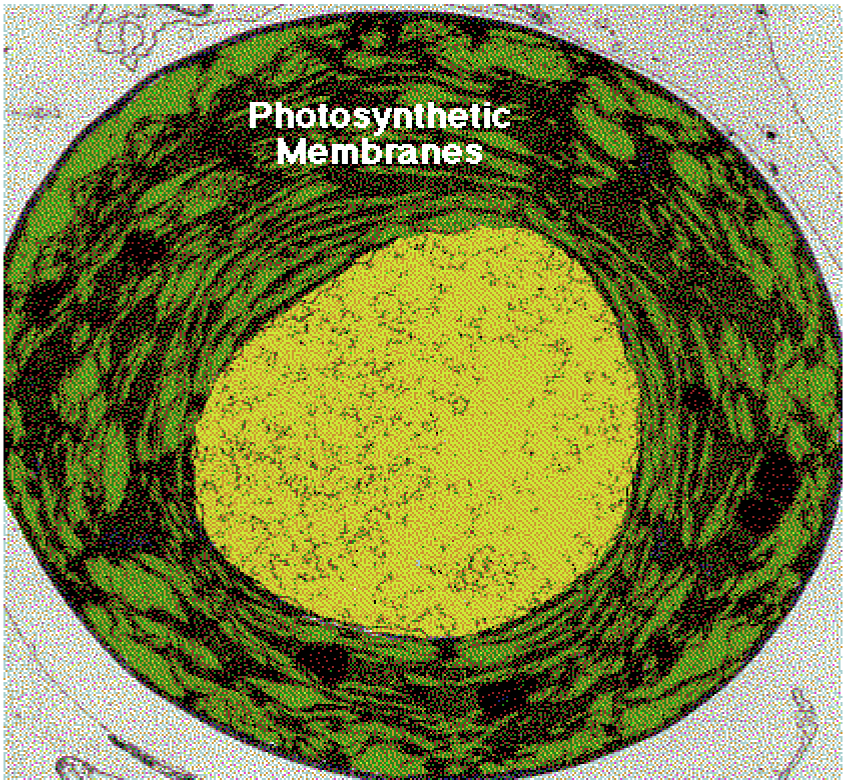
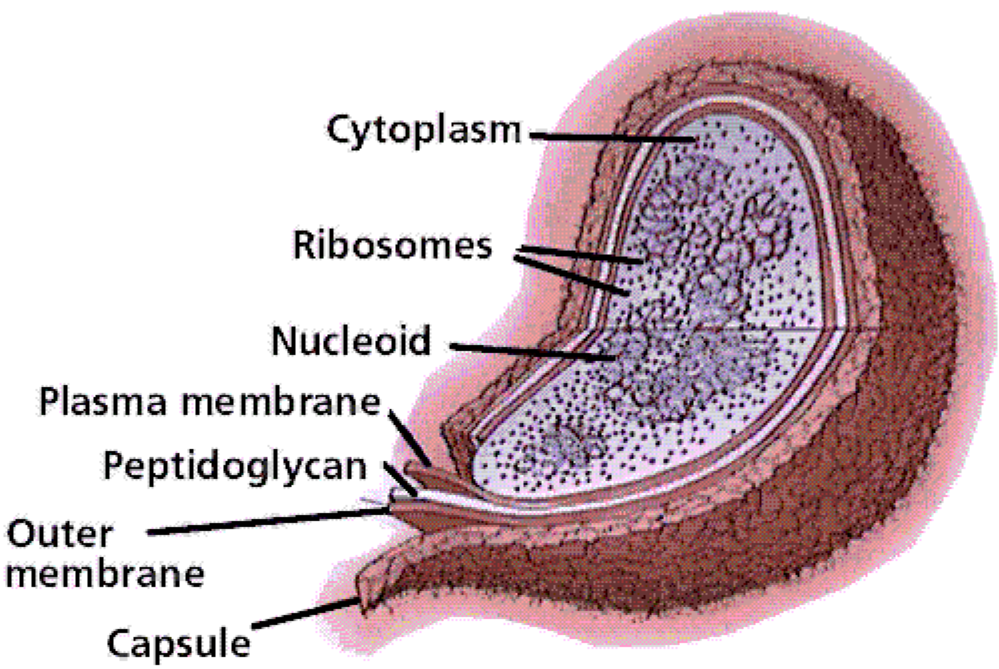


Figure 6. The main features of a generalized prokaryote cell. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.



The Cell Theory is one of the foundations of modern biology. Its major tenets are:

All living things are composed of one or more cells;

The chemical reactions of living cells take place within cells;

All cells originate from pre-existing cells; and

Cells contain hereditary information, which is passed from one generation to another.

Components of Cells

Cell Membrane (also known as plasma membrane or plasmalemma) is surrounds all cells. It: 1) separates the inner parts of the cell from the outer environment; and 2) acts as a selectively permeable barrier to allow certain chemicals, namely water, to pass and others to not pass. In multicellular organisms certain chemicals on the membrane surface act in the recognition of self. Antigens are substances located on the outside of cells, viruses and in some cases other chemicals. Antibodies are chemicals (Y-shaped) produced by an animal in response to a specific antigen. This is the basis of immunity and vaccination.

Hereditary material (both DNA and RNA) is needed for a cell to be able to replicate and/or reproduce. Most organisms use DNA. Viruses and viroids sometimes employ RNA as their hereditary material. Retroviruses include HIV (Human Immunodefficiency Virus, the causative agent of AIDS) and Feline Leukemia Virus (the only retrovirus for which a successful vaccine has been developed). Viroids are naked pieces of RNA that lack cytoplasm, membranes, etc. They are parasites of some plants and also as possible glimpses of the functioning of pre-cellular life forms. Prokaryotic DNA is organized as a circular chromosome contained in an area known as a nucleoid. Eukaryotic DNA is organized in linear structures, the eukaryotic chromosomes, which are associations of DNA and histone proteins contained within a double membrane nuclear envelope, an area known as the cell nucleus.

Organelles are formed bodies within the cytoplasm that perform certain functions. Some organelles are surrounded by membranes, we call these membrane-bound organelles.

Ribosomes are the tiny structures where proteins synthesis occurs. They are not membrane-bound and occur in all cells, although there are differences between the size of subunits in eukaryotic and prokaryotic ribosomes.

The Cell Wall is a structure surrounding the plasma membrane. Prokaryote and eukaryote (if they have one) cell walls differ in their structure and chemical composition. Plant cells have cellulose in their cell walls, other organisims have different materials cpmprising their walls. Animals are distinct as a group in their lack of a cell wall.

Membrane-bound organelles occur only in eukaryotic cells. They will be discussed in detail later. Eukaryotic cells are generally larger than prokaryotic cells. Internal complexity is usually greater in eukaryotes, with their compartmentalized membrane-bound organelles, than in prokaryotes. Some prokaryotes, such as *Anabaena azollae*, and *Prochloron*, have internal membranes associated with photosynthetic pigments.

The Origins of Multicellularity

The oldest accepted prokaryote fossils date to 3.5 billion years; Eukaryotic fossils to between 750 million years and possibly as old as 1.2-1.5 billion years. Multicellular fossils, purportedly of animals, have been recovered from 750Ma rocks in various parts of the world. The first eukaryotes were undoubtedly Protistans, a group that is thought to have given rise to the other eukaryotic kingdoms. Multicellularity allows specialization of function, for example muscle fibers are specialized for contraction, neuron cells for transmission of nerve messages.

Microscopes

Microscopes are important tools for studying cellular structures. In this class we will use light microscopes for our laboratory observations. Your text will also show light photomicrographs (pictures taken with a light microscope) and electron micrographs (pictures taken with an electron microscope). There are many terms and concepts which will help you in maximizing your study of microscopy.

There are many different types of microscopes used in studying biology. These include the light microscopes (dissecting, compound brightfield, and compound phase-contrast), electron microscopes (transmission and scanning), and atomic force microscope.

The microscope is an important tool used by biologists to magnify small objects. There are several concepts fundamental to microscopy.

Magnification is the ratio of enlargement (or eduction) between the specimen and its image (either printed photograph or the virtual image seen through the eyepiece). To calculate magnification we multiply the power of each lens through which the light from the specimen passes, indicating that product as GGGX, where GGG is the product. For example: if the light passes through two,lenses (an objective lens and an ocular lens) we multiply the 10X ocular value by the value of the objective lens (say it is 4X): 10 X 4=40, or 40X magnification.

Resolution is the ability to distinguish between two objects (or points). The closer the two objects are, the easier it is to distinguish recognize the distance between them. What microscopes do is to bring small objects "closer" to the observer by increasing the magnification of the sample. Since the sample is the same distance from the viewer, a "virtual image" is formed as the light (or electron beam) passes through the magnifying lenses. Objects such as a human hair appear smooth (and feel smooth) when viewed with the unaided or naked) eye. However, put a hair under a microscope and it takes on a VERY different look!

Working distance is the distance between the specimen and the magnifying lens.

Depth of field is a measure of the amount of a specimen that can be in focus.

Magnification and resolution are terms used frequently in the study of cell biology, often without an accurate definition of their meanings. Magnification is a ratio of the enlargement (or reduction) of an image (drawing or photomicrograph), usually expressed as X1, X1/2, X430, X1000, etc. Resolution is the ability to distinguish between two points. Generally resolution increases with magnification, although there does come a point of diminishing returns where you increase magnification beyond added resolution gain.

Scientists employ the metric system to measure the size and volume of specimens. The basic unit of length is the meter (slightly over 1 yard). Prefixes are added to the "meter" to indicate multiple meters (kilometer) or fractional meters (millimeter). Below are the values of some of the prefixes used in the metric system.

kilo = one thousand of the basic unit

meter = basic unit of length

centi = one hundreth (1/100) of the basic unit

milli = one thousandth (1/1000) of the basic unit

micro = one millionth (1/1,000,000) of the basic unit

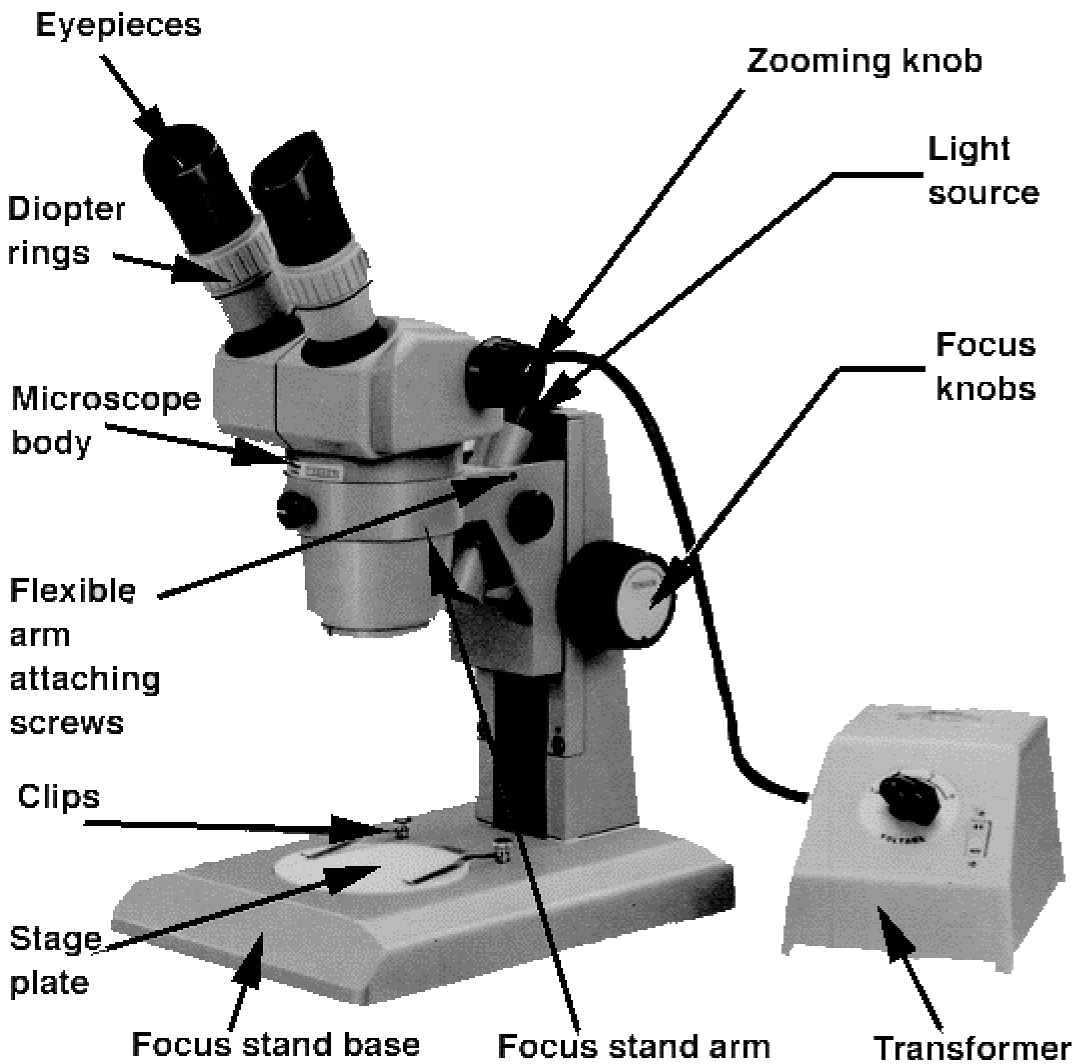
nano = one billionth (1/1,000,000,000) of the basic unit

The basic unit of length is the meter (m), and of volume it is the liter (l). The gram (g). Prefixes listed above can be applied to all of these basic units, abbreviated as km, kg, ml, mg, nm....etc. The Greek letter micron (µ) is applied to small measurements (thoud\sandths of a millimeter), producing the micrometer (symbolized as µm). Measurements in microscopy are usually expressed in the metric system. General units you will encounter in your continuing biology careers include micrometer (µm, 10^{-6}m), nanometer (nm, 10^{-9}m), and angstrom (Å, 10^{-10}m).

Light microscopes were the first to be developed, and still the most commonly used ones. The best resolution of light microscopes (LM) is 0.2 µm. Magnification of LMs is generally limited by the properties of the glass used to make microscope lenses and the physical properties of their light sources. The generally accepted maximum magnifications in biological uses are between 1000X and 1250X. Calculation of LM magnification is done by multiplying objective value by eyepiece value.

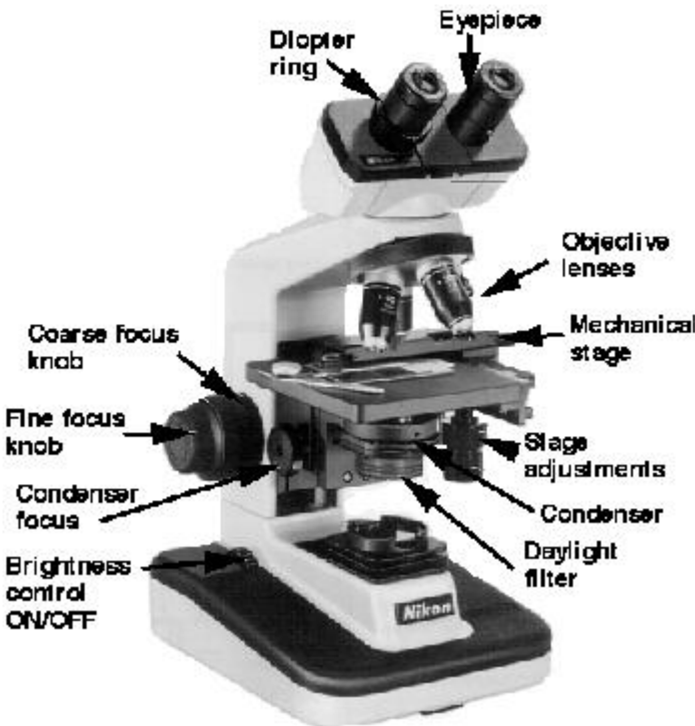
To view relatively large objects at lower magnifications we utilize the dissecting microscope (shown in Figure 7). Common uses of this microscope include examination of prepared microscope slides at low magnification, dissection (hence the name) of flowers or animal organs, and examinations of the surface of objects such as pennies and five dollar bills. Magnification on the dissecting microscope is calculated by multiplying the ocular (or eyepiece) value (usually 10X) by the value of the objective lens (a variable between 0.7 and 3X). The value of the objective lens is selected using a dial on the body tube of the microscope.

Figure 7. Parts of a Nikon dissecting microscope. Image courtesy of Nikon Co.



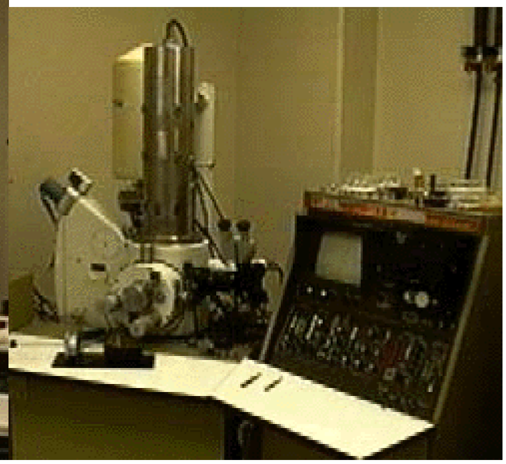
The compound light microscope, shown in Figure 8, uses two ground glass lenses to form the image. The lenses in this microscope, however, are aligned with the light source and specimen so that the light passes through the specimen, rather than reflects off the surface (as in the dissecting microscope shown in Figure 7). The compound microscope provides greater magnification (and resolution), but only thin specimens (or thin slices of a specimen) can be viewed with this type of microscope.

Figure 8. Parts of a Nikon compound microscope. Image courtesy of Nikon Co.



Electron microscopes, two examples of which are shown in Figure 9, are more rarely encountered by beginning biology students. However, the images gathered from these microscopes reveal a greater structure of the cell, so some familiarity with the strengths and weaknesses of each type is useful. Instead of using light as an imaging source, a high energy beam of electrons (between five thousand and one billion electron volts) is focused through electromagnetic lenses (instead of glass lenses used in the light microscope). The increased resolution results from the shorter wavelength of the electron beam, increasing resolution in the transmission electron microscope (TEM) to a theoretical limit of 0.2 nm. The magnifications reached by TEMs are commonly over 100,000X, depending on the nature of the sample and the operating condition of the TEM. The other type of electron microscope is the scanning electron microscope (SEM). It uses a different method of electron capture and displays images on high resolution television monitors. The resolution and magnification of the SEM are less than that of the TEM although still orders of magnitude above the LM.

Figure 9. Electron microscopes. The above (left) image of a transmission electron microscope is from http://nsm.fullerton.edu/~skarl/EM/Equipment/TEM.html. The above right image of a scanning electron microscope is from http://nsm.fullerton.edu/~skarl/EM/Equipment/SEM.html.

CELLS II: CELLULAR ORGANIZATION

Table of Contents

Life exhibits varying degrees of organization. Atoms are organized into molecules, molecules into organelles, and organelles into cells, and so on. According to the Cell Theory, all living things are composed of one or more cells, and the functions of a multicellular organism are a consequence of the types of cells it has. Cells fall into two broad groups: prokaryotes and eukaryotes. Prokaryotic cells are smaller (as a general rule) and lack much of the internal compartmentalization and complexity of eukaryotic cells. No matter which type of cell we are considering, all cells have certain features in common, such as a cell membrane, DNA and RNA, cytoplasm, and ribosomes. Eukaryotic cells have a great variety of organelles and structures.

Cell Size and Shape

The shapes of cells are quite varied with some, such as neurons, being longer than they are wide and others, such as parenchyma (a common type of plant cell) and erythrocytes (red blood cells) being equidimensional. Some cells are encased in a rigid wall, which constrains their shape, while others have a flexible cell membrane (and no rigid cell wall).

The size of cells is also related to their functions. Eggs (or to use the latin word, *ova*) are very large, often being the largest cells an organism produces. The large size of many eggs is related to the process of development that occurs after the egg is fertilized, when the contents of the egg (now termed a zygote) are used in a rapid series of cellular divisions, each requiring tremendous amounts of energy that is available in the zygote cells. Later in life the energy must be acquired, but at first a sort of inheritance/trust fund of energy is used.

Cells range in size from small bacteria to large, unfertilized eggs laid by birds and dinosaurs. The realtive size ranges of biological things is shown in Figure 1. In science we use the metric system for measuring. Here are some measurements and convesrions that will aid your understanding of biology.

1 meter = 100 cm = 1,000 mm = 1,000,000 µm = 1,000,000,000 nm

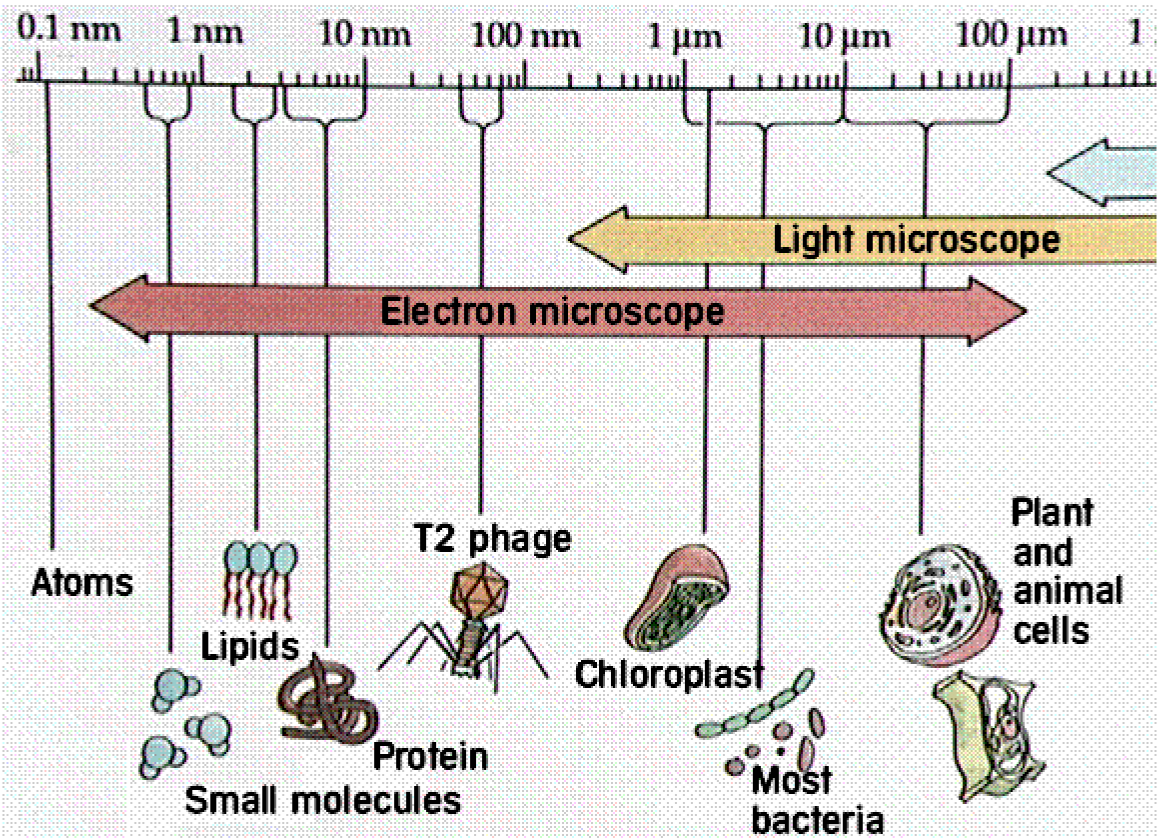
1 centimenter (cm) = 1/100 meter = 10 mm

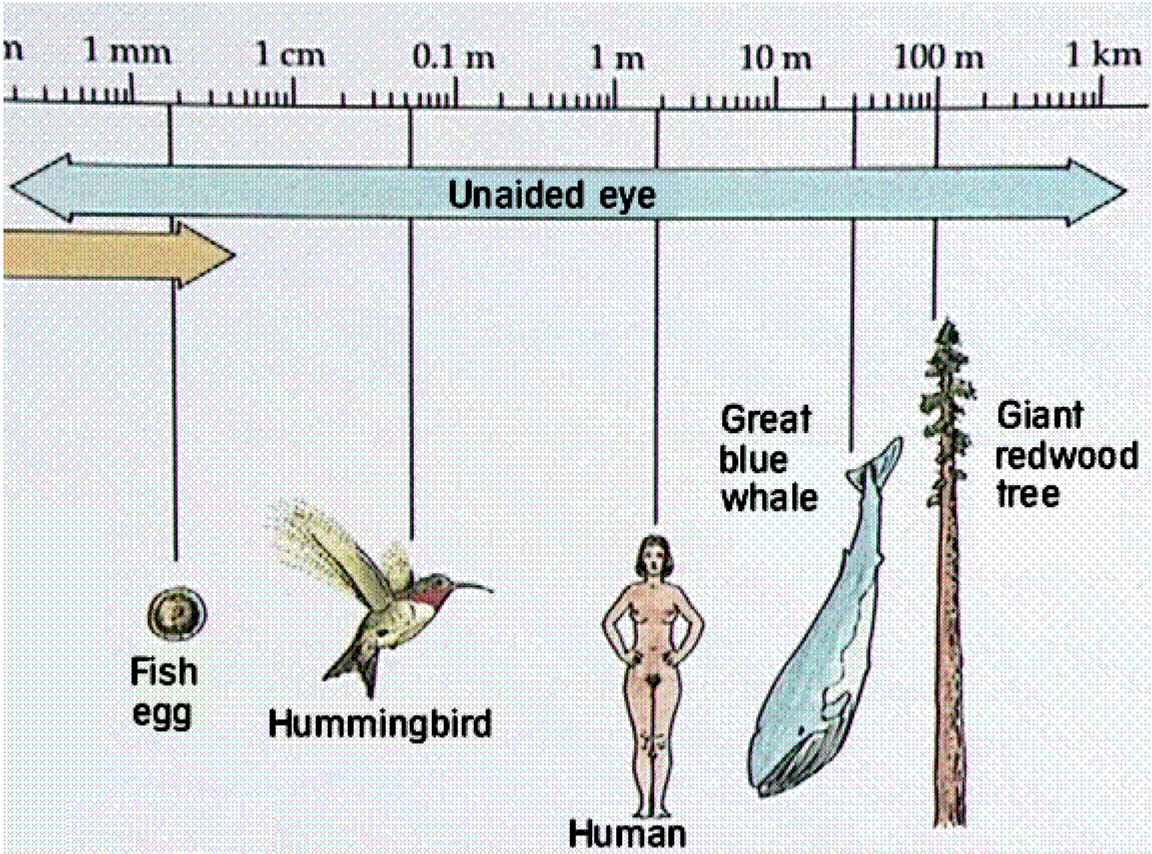
1 millimeter (mm) = 1/1000 meter = 1/10 cm

1 micrometer (μm) = 1/1,000,000 meter = 1/10,000 cm

1 nanometer (nm) = 1/1,000,000,000 meter = 1/10,000,000 cm

Figure 1. Sizes of viruses, cells, and organisms. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

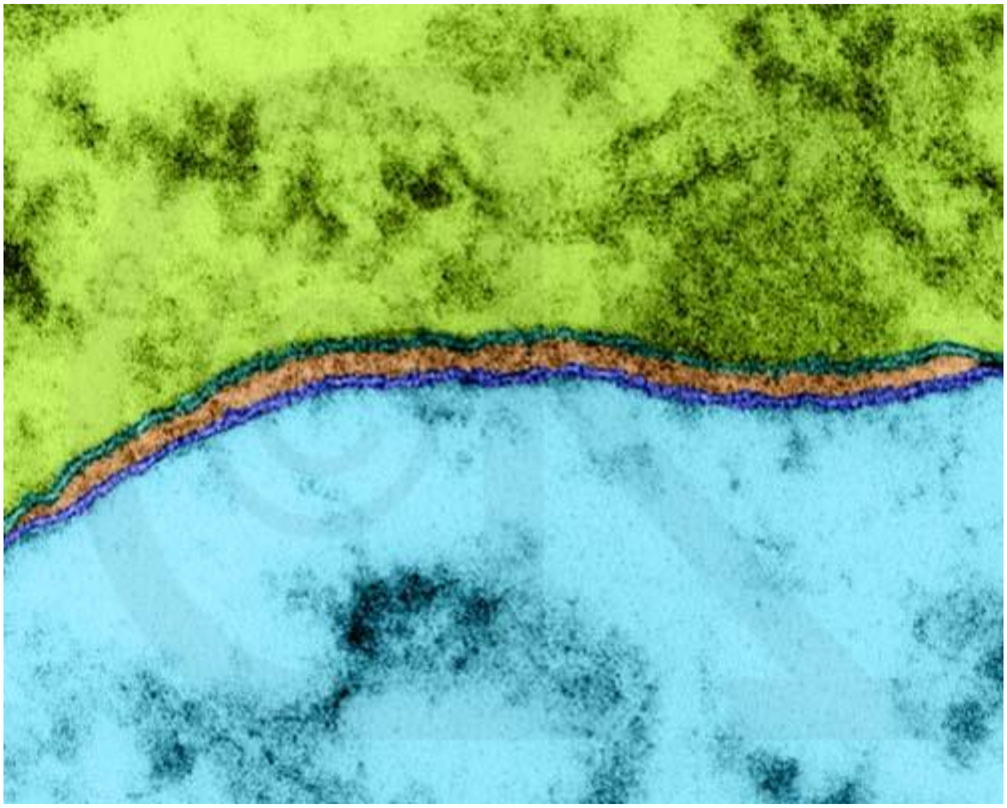




The Cell Membrane

The cell membrane functions as a semi-permeable barrier, allowing a very few molecules across it while fencing the majority of organically produced chemicals inside the cell. Electron microscopic examinations of cell membranes have led to the development of the lipid bilayer model (also referred to as the fluid-mosaic model). The most common molecule in the model is the phospholipid, which has a polar (hydrophilic) head and two nonpolar (hydrophobic) tails. These phospholipids are aligned tail to tail so the nonpolar areas form a hydrophobic region between the hydrophilic heads on the inner and outer surfaces of the membrane. This layering is termed a bilayer since an electron microscopic technique known as freeze-fracturing is able to split the bilayer, shown in Figure 2.

Figure 2. Cell Membranes from Opposing Neurons (TEM x436,740). This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.



Cholesterol is another important component of cell membranes embedded in the hydrophobic areas of the inner (tail-tail) region. Most bacterial cell membranes do not contain cholesterol. Cholesterol aids in the flexibility of a cell membrane.

Proteins, shown in Figure 2, are suspended in the inner layer, although the more hydrophilic areas of these proteins "stick out" into the cells interior as well as outside the cell. These proteins function as gateways that will allow certain molecules to cross into and out of the cell by moving through open areas of the protein channel. These integral proteins are sometimes known as gateway proteins. The outer surface of the membrane will tend to be rich in glycolipids, which have their hydrophobic tails embedded in the hydrophobic region of the membrane and their heads exposed outside the cell. These, along with carbohydrates attached to the integral proteins, are thought to function in the recognition of self, a sort of cellular identification system.

The contents (both chemical and organelles) of the cell are termed protoplasm, and are further subdivided into cytoplasm (all of the protoplasm except the contents of the nucleus) and nucleoplasm (all of the material, plasma and DNA etc., within the nucleus).

The Cell Wall

Not all living things have cell walls, most notably animals and many of the more animal-like protistans. Bacteria have cell walls containing the chemical peptidoglycan. Plant cells, shown in Figures 3 and 4, have a variety of chemicals incorporated in their cell walls. Cellulose, a nondigestible (to humans anyway) polysaccharide is the most common chemical in the plant primary cell wall. Some plant cells also have lignin and other chemicals embedded in their secondary walls.

The cell wall is located outside the plasma membrane. Plasmodesmata are connections through which cells communicate chemically with each other through their thick walls. Fungi and many protists have cell walls although they do not contain cellulose, rather a variety of chemicals (chitin for fungi).

Animal cells, shown in Figure 5, lack a cell wall, and must instead rely on their cell membrane to maintain the integrity of the cell. Many protistans also lack cell walls, using variously modified cell membranes o act as a boundary to the inside of the cell.

Figure 3. Structure of a typical plant cell. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

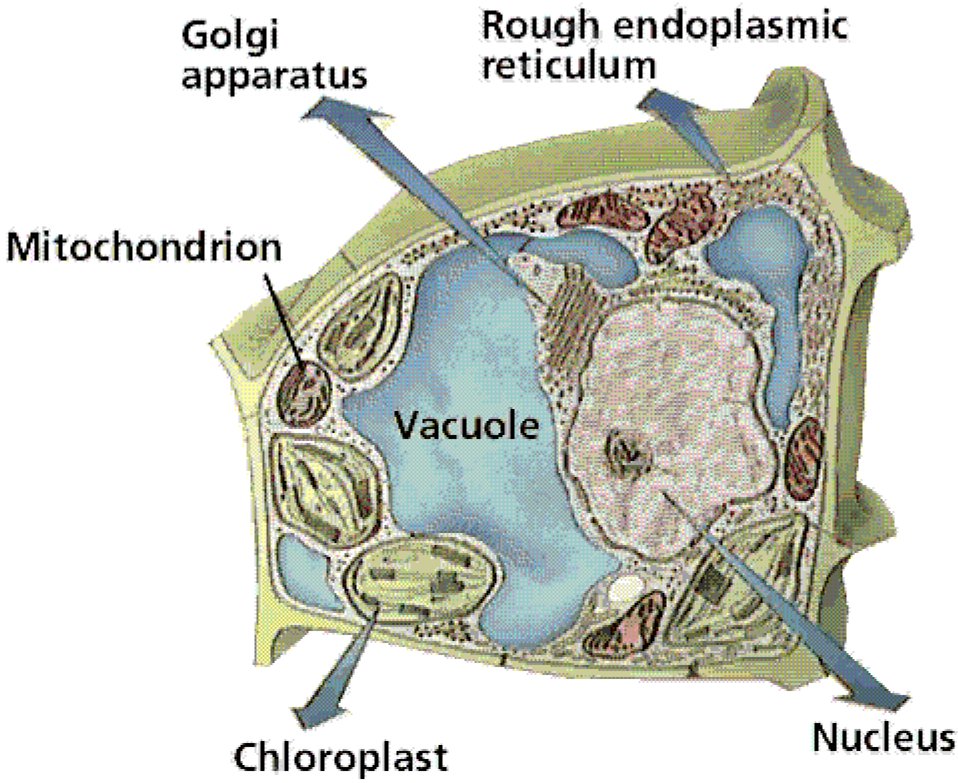


Figure 4. Lily Parenchyma Cell (cross-section) (TEM x7,210). Note the large nucleus and nucleolus in the center of the cell, mitochondria and plastids in the cytoplasm. This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.

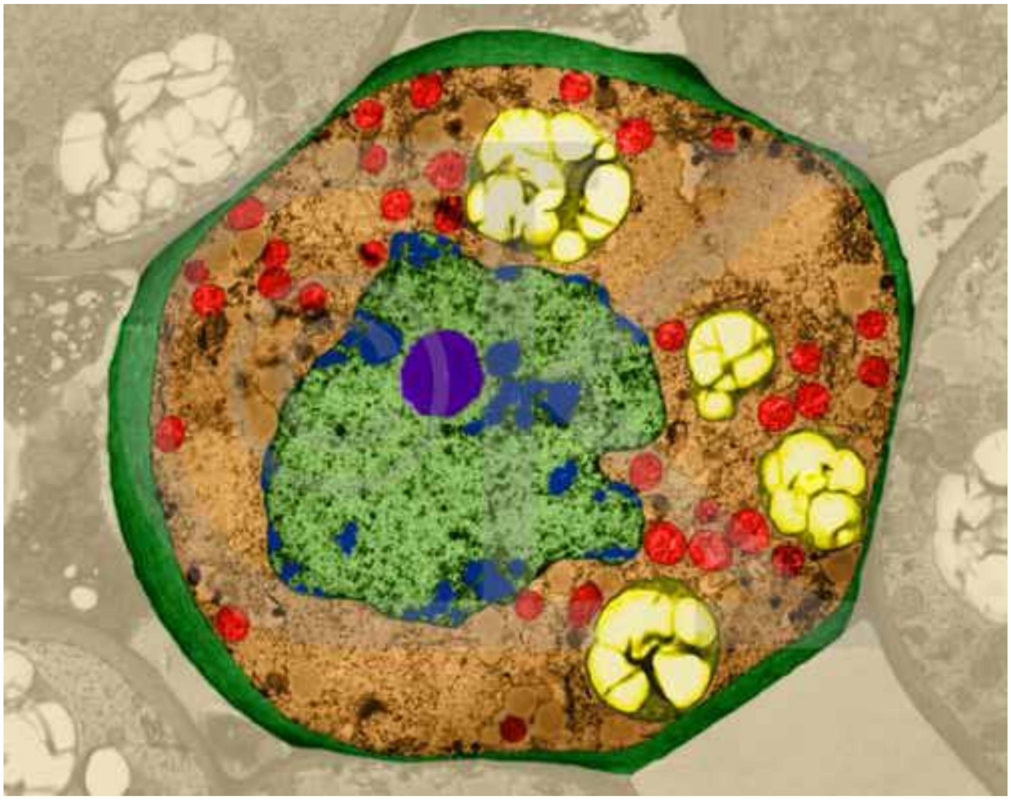
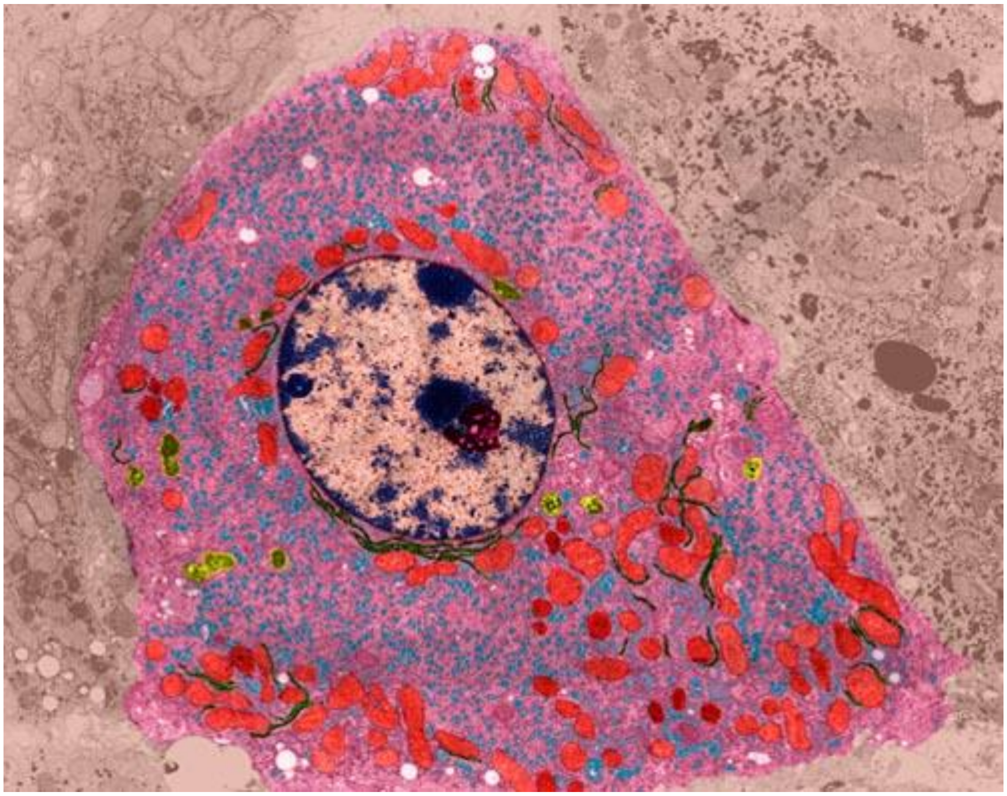


Figure 5. Liver Cell (TEM x9,400). This image is copyright Dennis Kunkel. This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.



The nucleus

The nucleus, shown in Figures 6 and 7, occurs only in eukaryotic cells. It is the location for most of the nucleic acids a cell makes, such as DNA and RNA. Danish biologist Joachim Hammerling carried out an important experiment in 1943. His work (click here for a diagram) showed the role of the nucleus in controlling the shape and features of the cell. Deoxyribonucleic acid, DNA, is the physical carrier of inheritance and with the exception of plastid DNA (cpDNA and mDNA, found in the chloroplast and mitochondrion respectively) all DNA is restricted to the nucleus. Ribonucleic acid, RNA, is formed in the nucleus using the DNA base sequence as a template. RNA moves out into the cytoplasm where it functions in the assembly of proteins. The nucleolus is an area of the nucleus (usually two nucleoli per nucleus) where ribosomes are constructed.

Figure 6. Structure of the nucleus. Note the chromatin, uncoiled DNA that occupies the space within the nuclear envelope. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

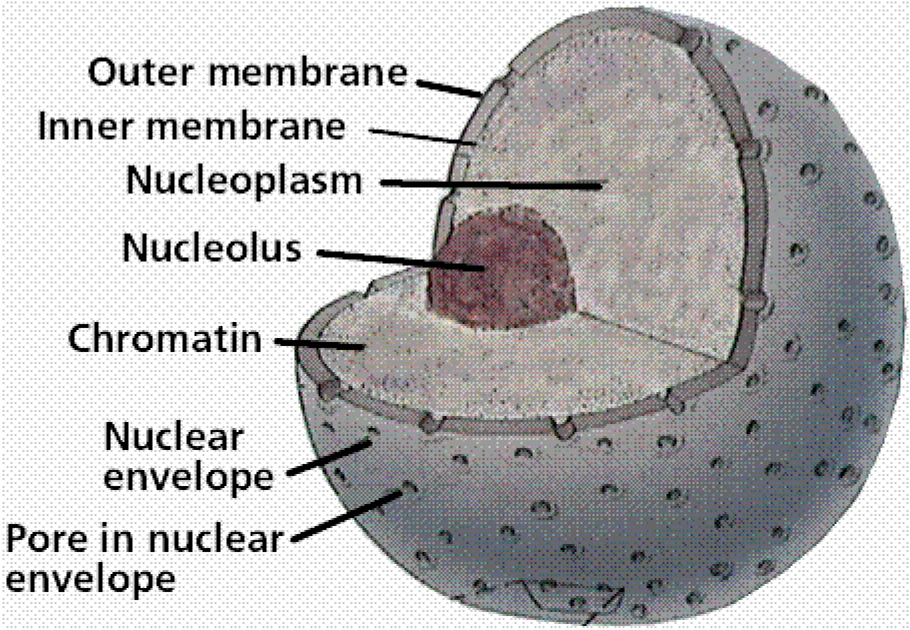
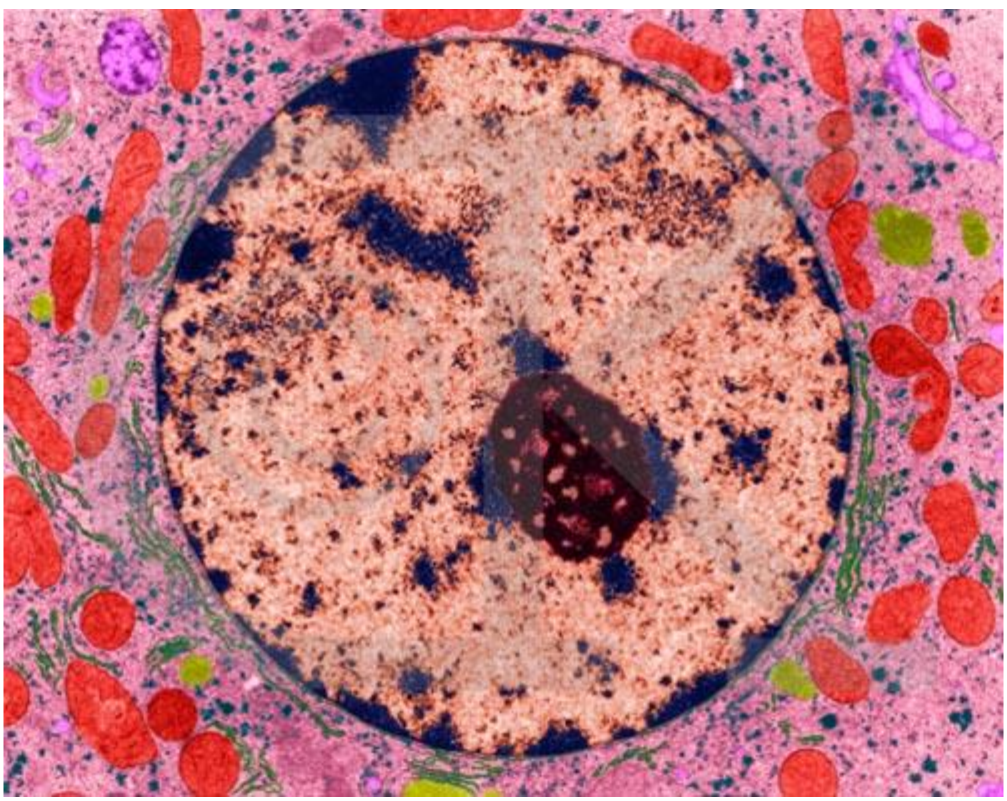


Figure 7. Liver cell nucleus and nucleolus (TEM x20,740). Cytoplasm, mitochondria, endoplasmic reticulum, and ribosomes also shown.This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.



The nuclear envelope, shown in Figure 8, is a double-membrane structure. Numerous pores occur in the envelope, allowing RNA and other chemicals to pass, but the DNA not to pass.

Figure 8. Structure of the nuclear envelope and nuclear pores. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

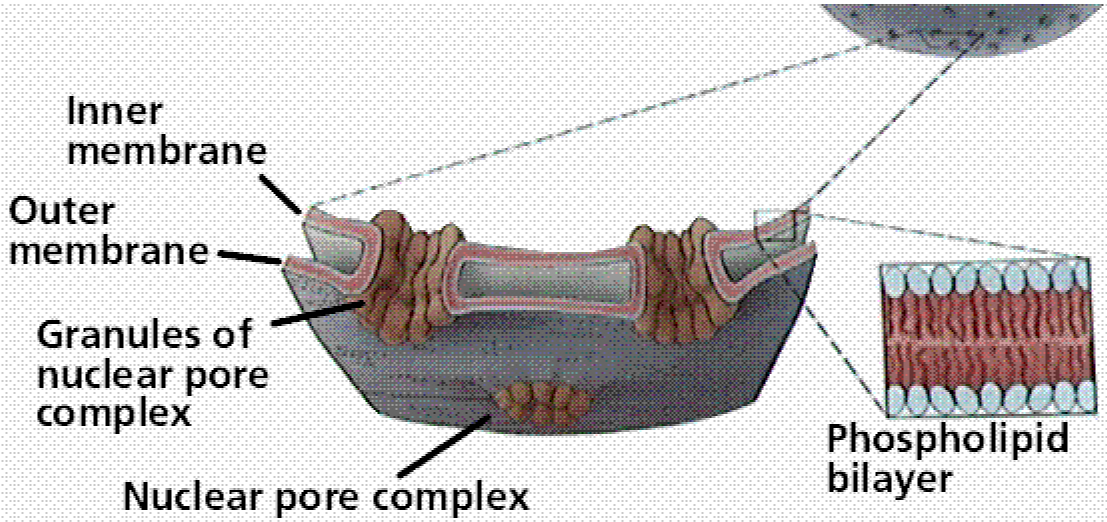
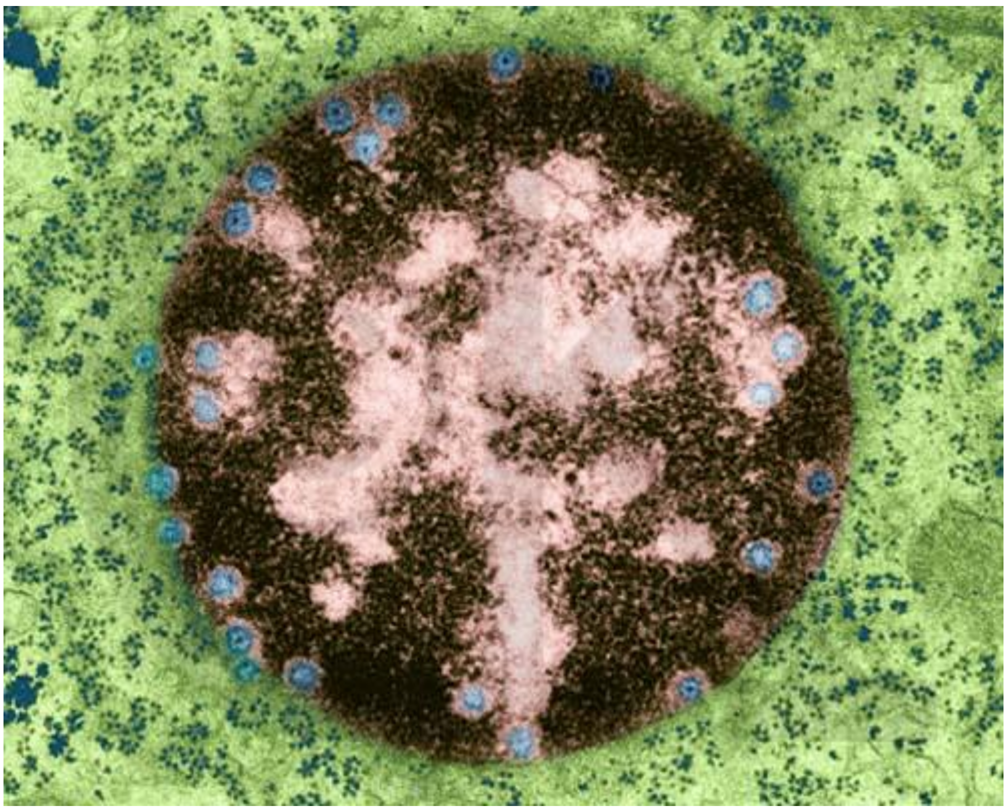


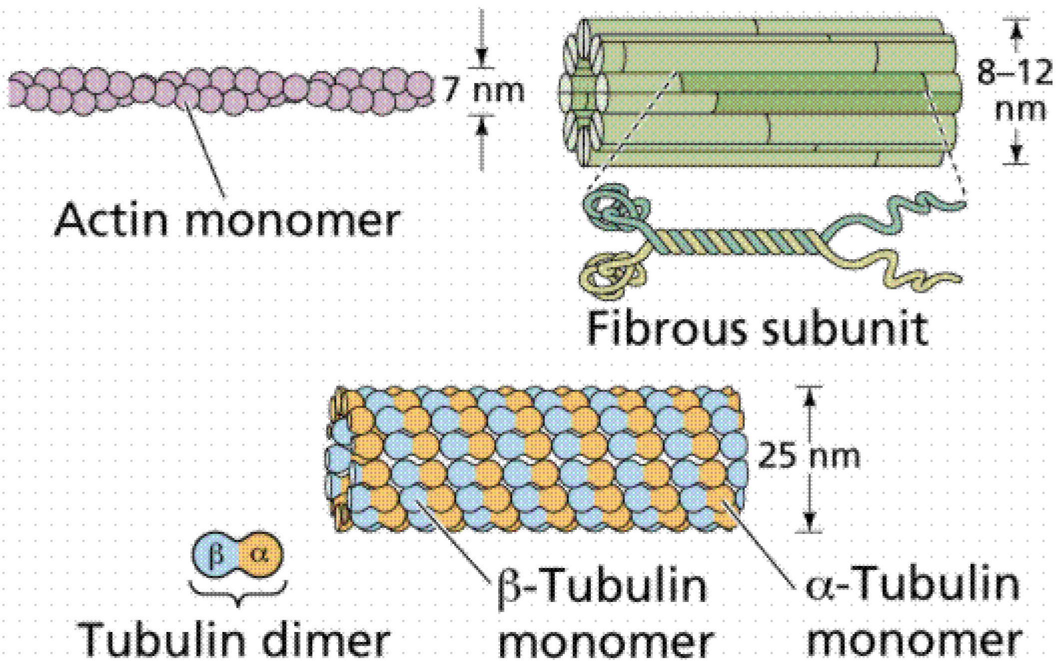
Figure 9. Nucleus with Nuclear Pores (TEM x73,200). The cytoplasm also contains numerous ribosomes. This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.



Cytoplasm

The cytoplasm was defined earlier as the material between the plasma membrane (cell membrane) and the nuclear envelope. Fibrous proteins that occur in the cytoplasm, referred to as the cytoskeleton maintain the shape of the cell as well as anchoring organelles, moving the cell and controlling internal movement of structures. Elements that comprose the cytoskeleton are shown in Figure 10. Microtubules function in cell division and serve as a "temporary scaffolding" for other organelles. Actin filaments are thin threads that function in cell division and cell motility. Intermediate filaments are between the size of the microtubules and the actin filaments.

Figure 10. Actin and tubulin components of the cytoskeleton. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.



Vacuoles and vesicles

Vacuoles are single-membrane organelles that are essentially part of the outside that is located within the cell. The single membrane is known in plant cells as a tonoplast. Many organisms will use vacuoles as storage areas. Vesicles are much smaller than vacuoles and function in transporting materials both within and to the outside of the cell.

Ribosomes

Ribosomes are the sites of protein synthesis. They are not membrane-bound and thus occur in both prokaryotes and eukaryotes. Eukaryotic ribosomes are slightly larger than prokaryotic ones. Structurally, the ribosome consists of a small and larger subunit, as shown in Figure 11. . Biochemically, the ribosome consists of ribosomal RNA (rRNA) and some 50 structural proteins. Often ribosomes cluster on the endoplasmic reticulum, in which case they resemble a series of factories adjoining a railroad line. Figure 12 illustrates the many ribosomes attached to the endoplasmic reticulum. Click here for Ribosomes (More than you ever wanted to know about ribosomes!)

Figure 11. Structure of the ribosome. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

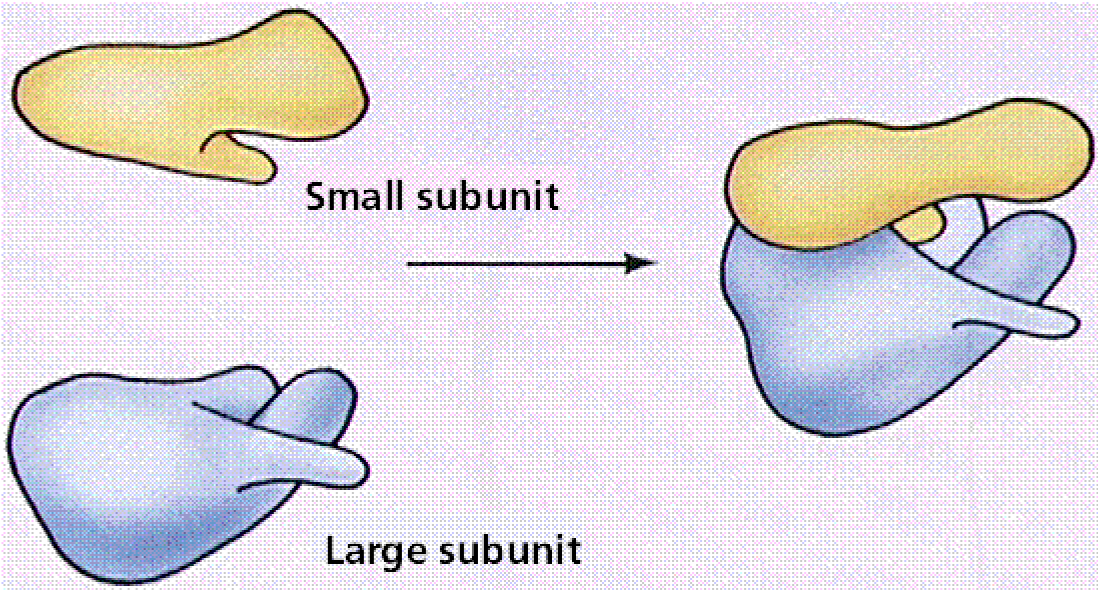
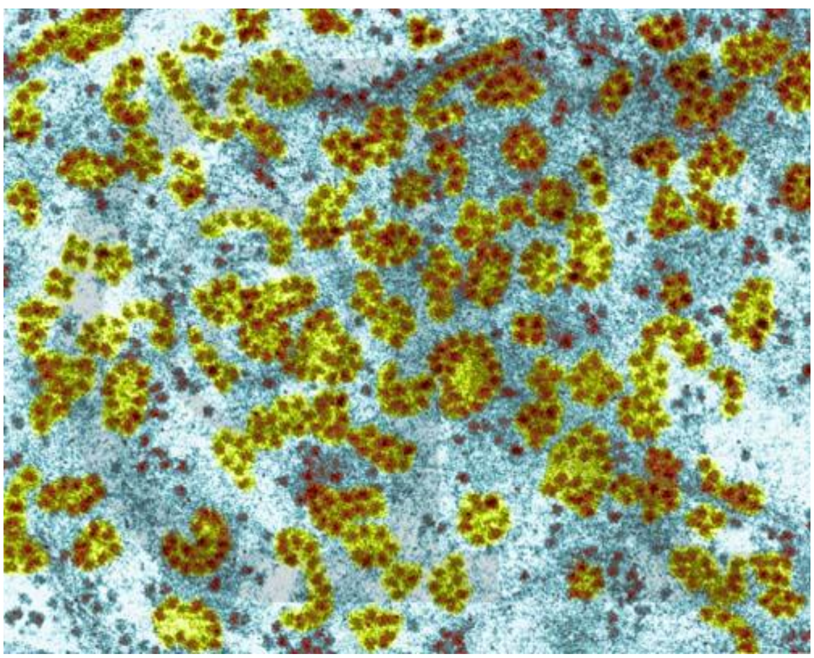


Figure 12. Ribosomes and Polyribosomes - liver cell (TEM x173,400). This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.



Endoplasmic reticulum | Back to Top

Endoplasmic reticulum, shown in Figure 13 and 14, is a mesh of interconnected membranes that serve a function involving protein synthesis and transport. Rough endoplasmic reticulum (Rough ER) is so-named because of its rough appearance due to the numerous ribosomes that occur along the ER. Rough ER connects to the nuclear envelope through which the messenger RNA (mRNA) that is the blueprint for proteins travels to the ribosomes. Smooth ER; lacks the ribosomes characteristic of Rough ER and is thought to be involved in transport and a variety of other functions.

Figure 13. The endoplasmic reticulum. Rough endoplasmic reticulum is on the left, smooth endoplasmic reticulum is on the right. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

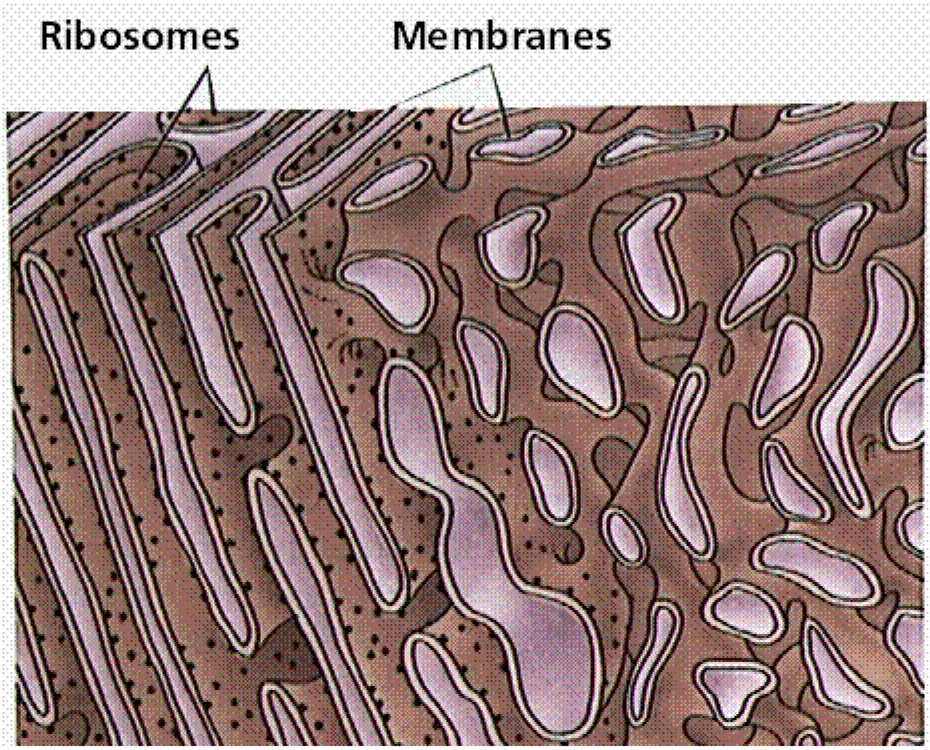
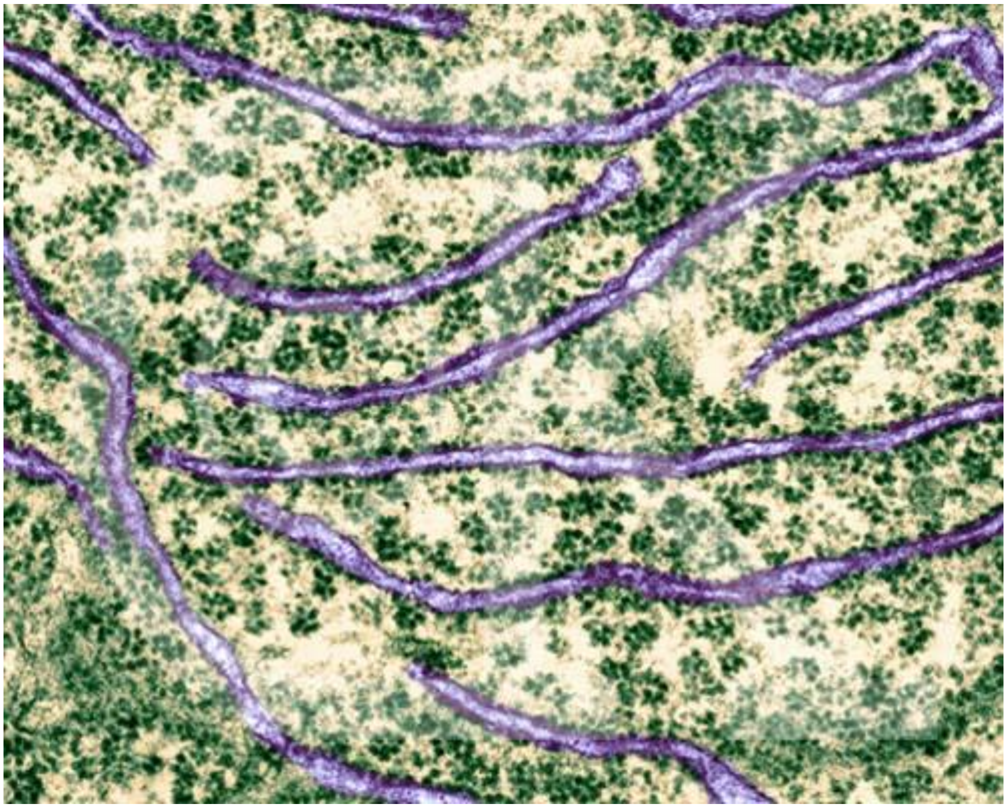


Figure 14. Rough Endoplasmic Reticulum with Ribosomes (TEM x61,560). This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.



Golgi Apparatus and Dictyosomes

Golgi Complexes, shown in Figure 15 and 16, are flattened stacks of membrane-bound sacs. Italian biologist Camillo Golgi discovered these structures in the late 1890s, although their precise role in the cell was not deciphered until the mid-1900s . Golgi function as a packaging plant, modifying vesicles produced by the rough endoplasmic reticulum. New membrane material is assembled in various cisternae (layers) of the golgi.

Figure 15. Structure of the Golgi apparatus and its functioning in vesicle-mediated transport. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

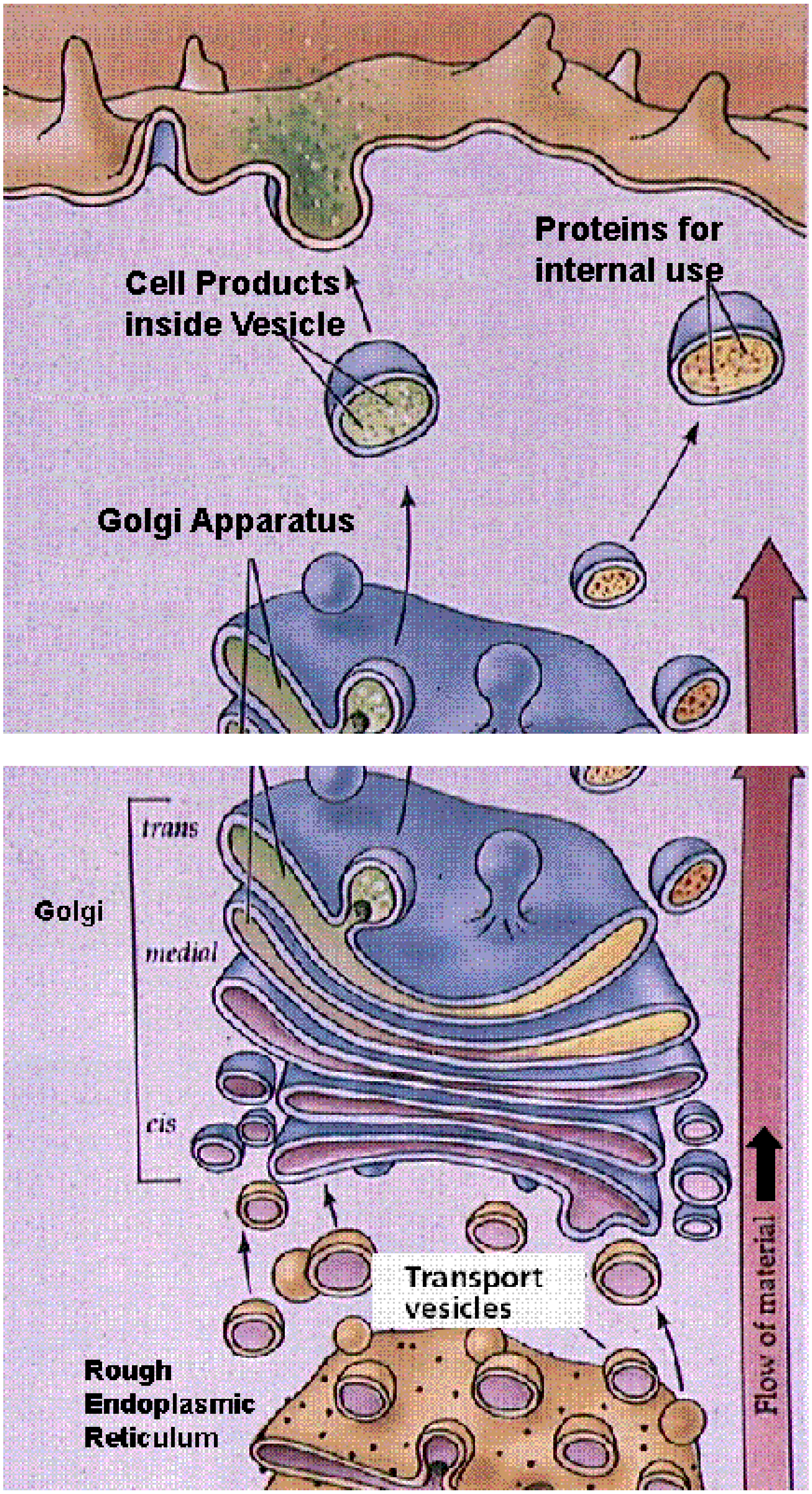


Figure 16. Golgi Apparatus in a plant parenchyma cell from *Sauromatum guttatum* (TEM x145,700). Note the numerous vesicles near the Golgi. This image is copyright Dennis Kunkel at

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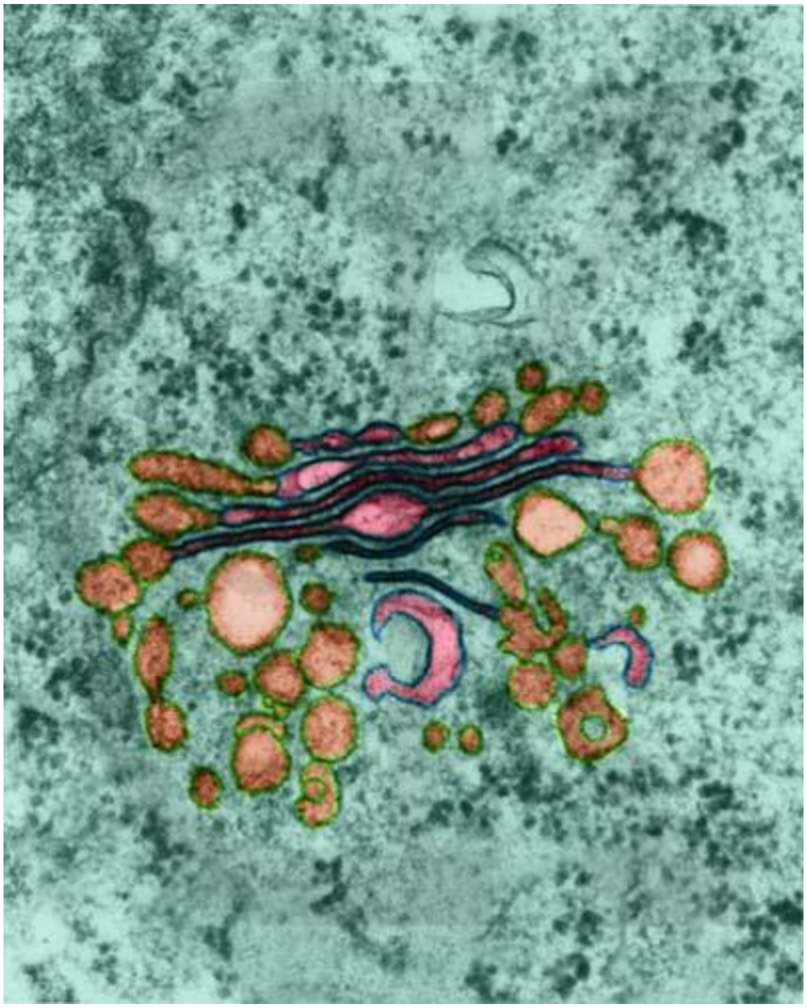
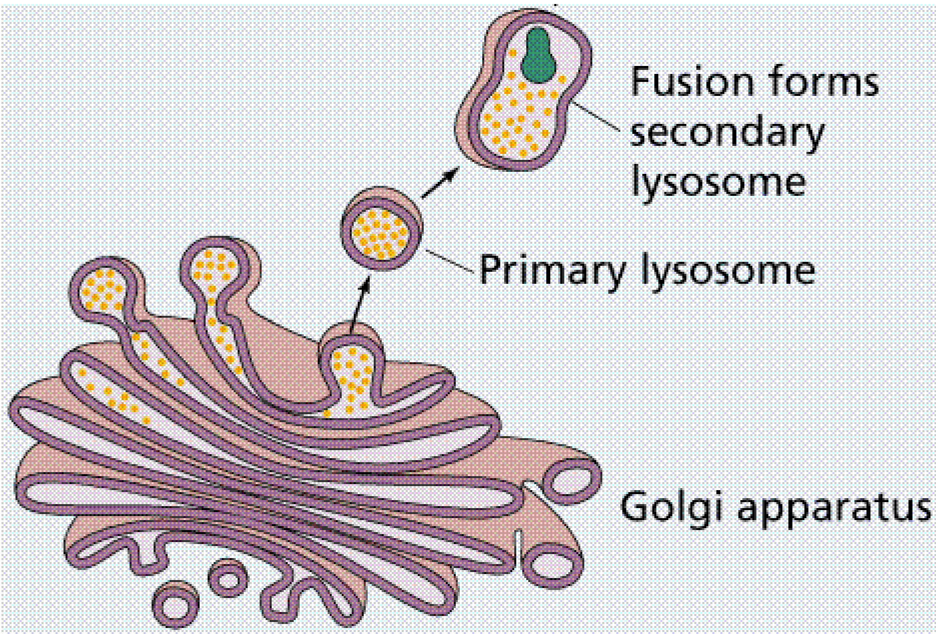


Lysosomes

Lysosomes, shown in Figure 17, are relatively large vesicles formed by the Golgi. They contain hydrolytic enzymes that could destroy the cell. Lysosome contents function in the extracellular breakdown of materials.

Figure 17. Role of the Golgi in forming lysosomes. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.



Mitochondria

Mitochondria contain their own DNA (termed mDNA) and are thought to represent bacteria-like organisms incorporated into eukaryotic cells over 700 million years ago (perhaps even as far back as 1.5 billion years ago). They function as the sites of energy release (following glycolysis in the cytoplasm) and ATP formation (by chemiosmosis). The mitochondrion has been termed the powerhouse of the cell. Mitochondria are bounded by two membranes. The inner membrane folds into a series of cristae, which are the surfaces on which adenosine triphosphate (ATP) is generated. The matrix is the area of the mitochondrion surrounded by the inner mitochondrial membrane. Ribosomes and mitochondrial DNA are found in the matrix. The significance of these features will be discussed below. The structure of mitochondria is shown in Figure 18 and 19.

Figure 18. Structure of a mitochondrion. Note the various infoldings of the mitochondrial inner membrane that produce the cristae. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

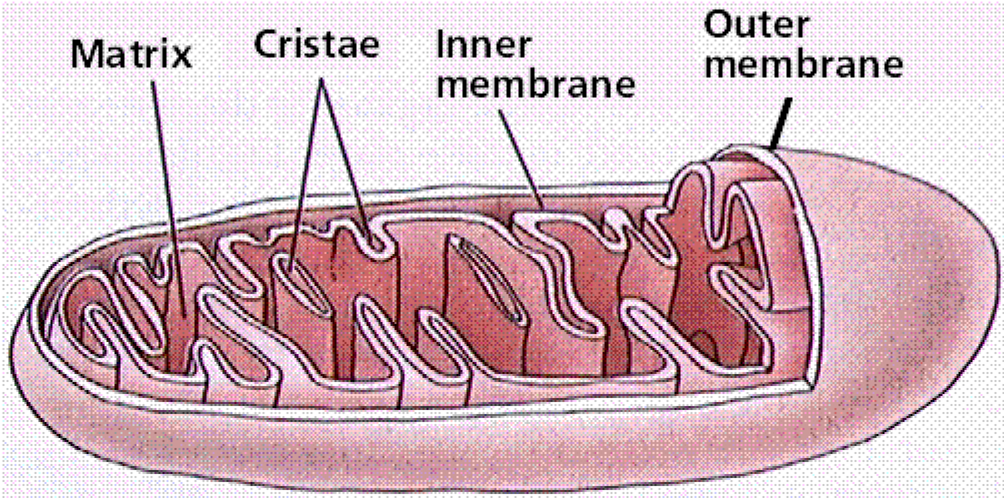
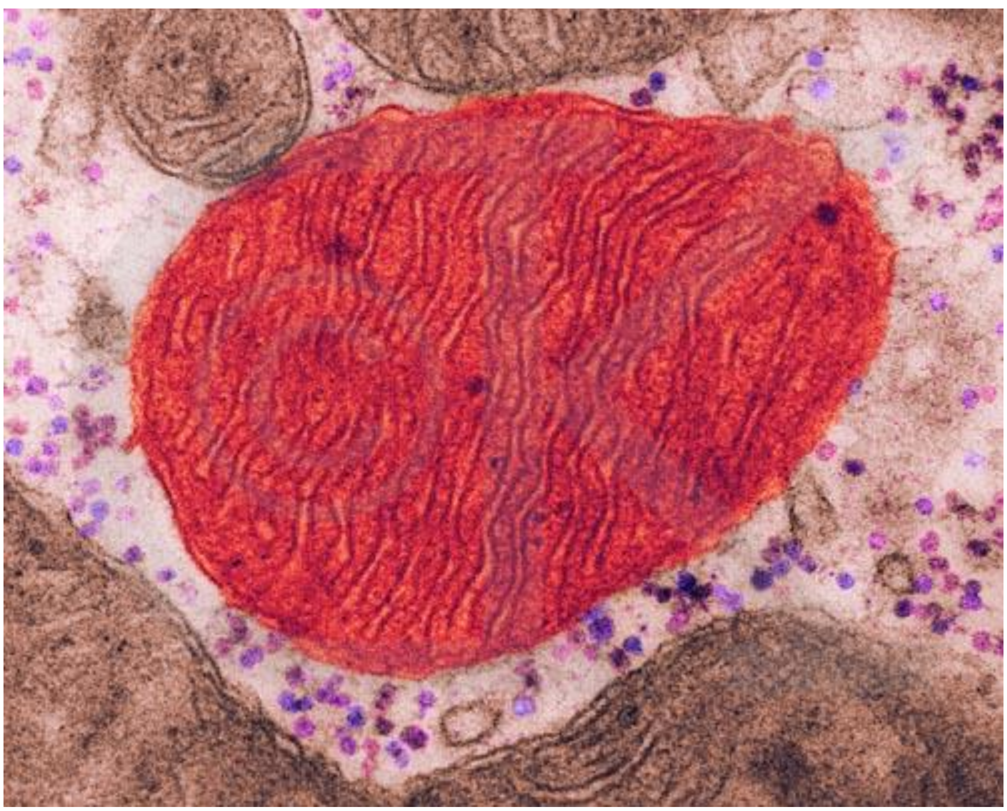


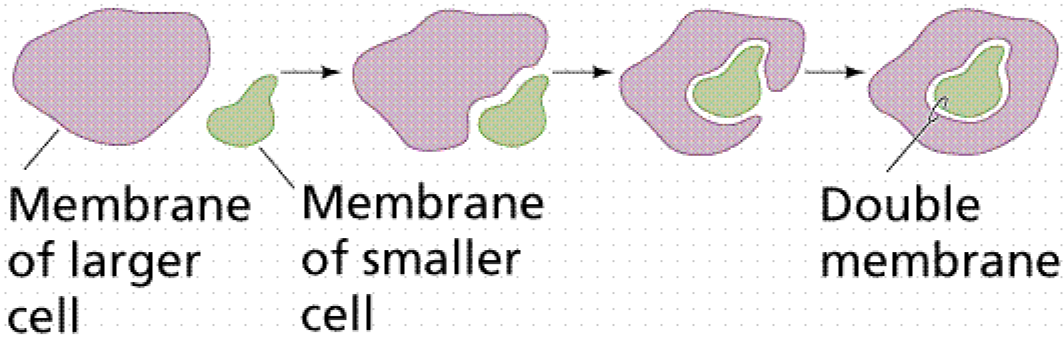
Figure 19. Muscle Cell Mitochondrion (TEM x190,920). This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.



Mitochondria and endosymbiosis

During the 1980s, Lynn Margulis proposed the theory of endosymbiosis to explain the origin of mitochondria and chloroplasts from permanent resident prokaryotes. According to this idea, a larger prokaryote (or perhaps early eukaryote) engulfed or surrounded a smaller prokaryote some 1.5 billion to 700 million years ago. Steps in this sequence are illustrated in Figure 20.

Figure 20. The basic events in endosymbiosis. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

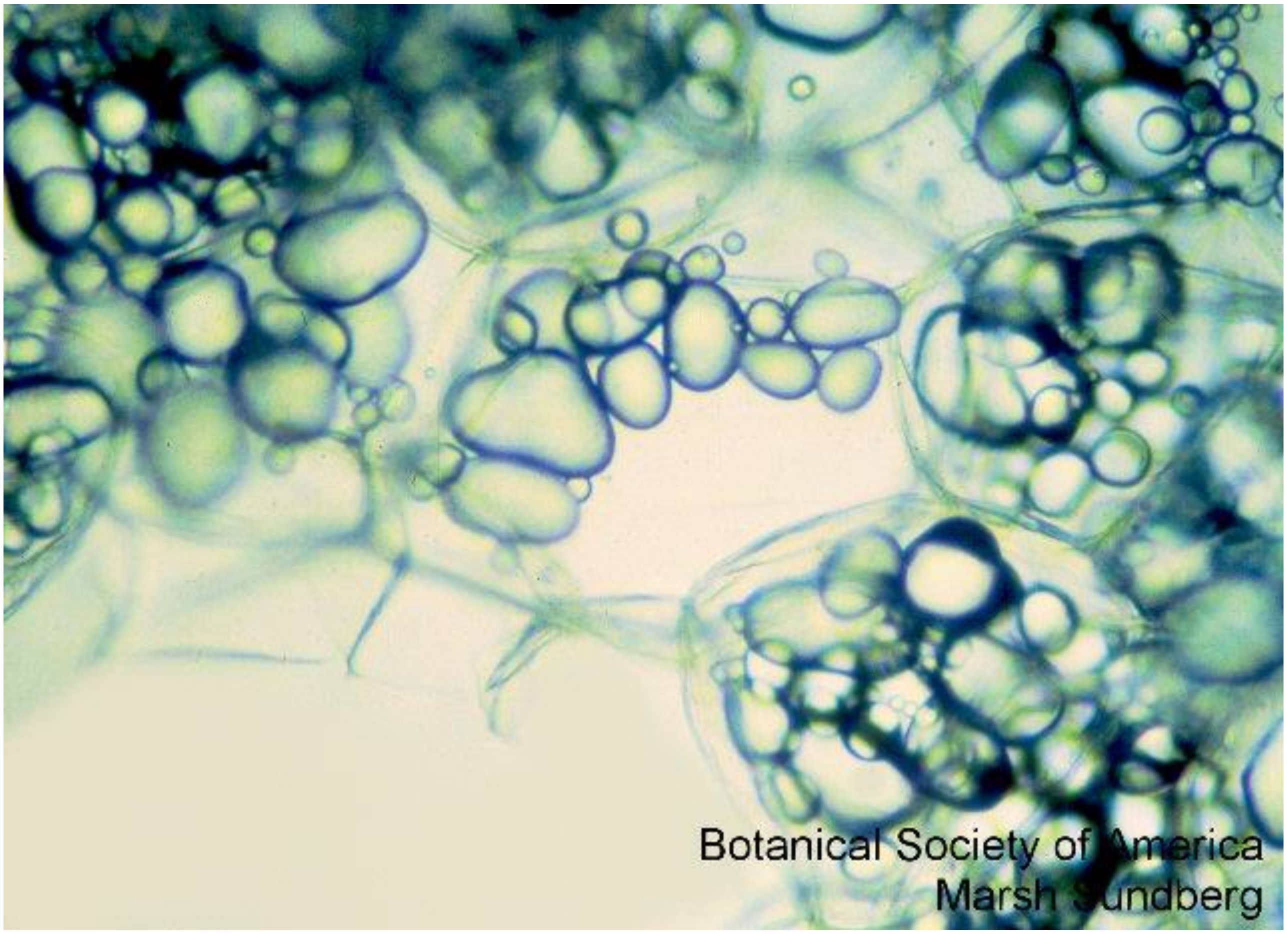


Instead of digesting the smaller organisms the large one and the smaller one entered into a type of symbiosis known as mutualism, wherein both organisms benefit and neither is harmed. The larger organism gained excess ATP provided by the "protomitochondrion" and excess sugar provided by the "protochloroplast", while providing a stable environment and the raw materials the endosymbionts required. This is so strong that now eukaryotic cells cannot survive without mitochondria (likewise photosynthetic eukaryotes cannot survive without chloroplasts), and the endosymbionts can not survive outside their hosts. Nearly all eukaryotes have mitochondria. Mitochondrial division is remarkably similar to the prokaryotic methods that will be studied later in this course. A summary of the theory is available by clicking here.

Plastids

Plastids are also membrane-bound organelles that only occur in plants and photosynthetic eukaryotes. Leucoplasts, also known as amyloplasts (and shown in Figure 21) store starch, as well as sometimes protein or oils. Chromoplasts store pigments associated with the bright colors of flowers and/or fruits.

Figure 21. Starch grains ina fresh-cut potato tuber. Image from http://images.botany.org/set-13/13-008v.jpg.



Chloroplasts, illustrated in Figures 22 and 23, are the sites of photosynthesis in eukaryotes. They contain chlorophyll, the green pigment necessary for photosynthesis to occur, and associated accessory pigments (carotenes and xanthophylls) in photosystems embedded in membranous sacs, thylakoids (collectively a stack of thylakoids are a granum [plural = grana]) floating in a fluid termed the stroma. Chloroplasts contain many different types of accessory pigments, depending on the taxonomic group of the organism being observed.

Figure 22. Structure of the chloroplast. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

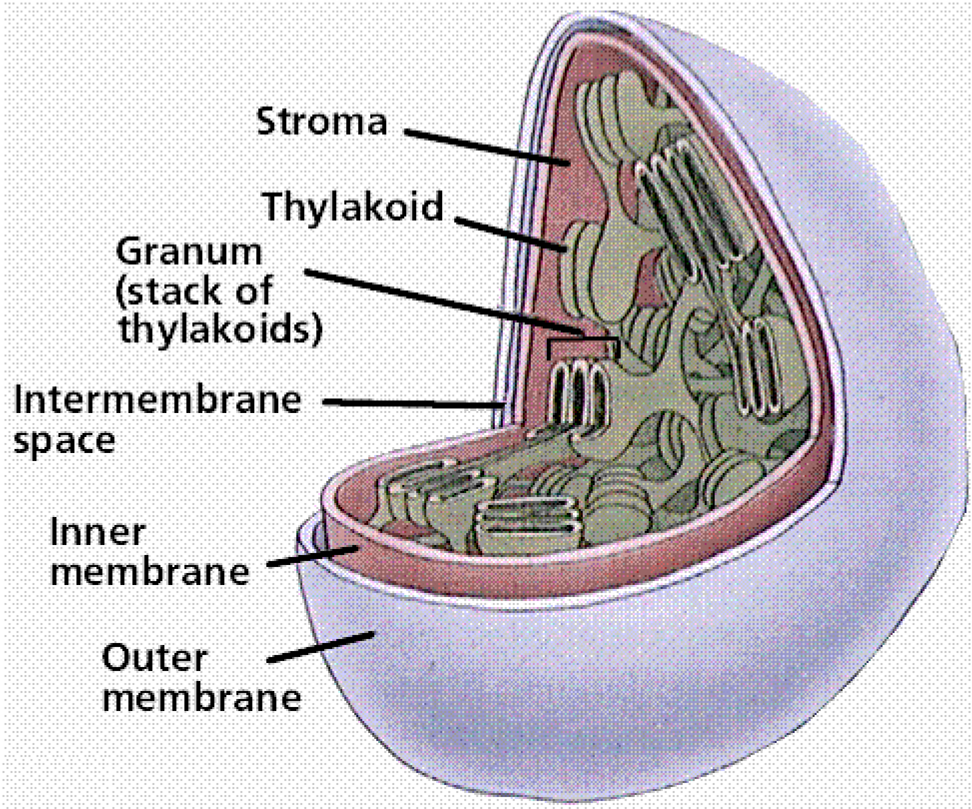
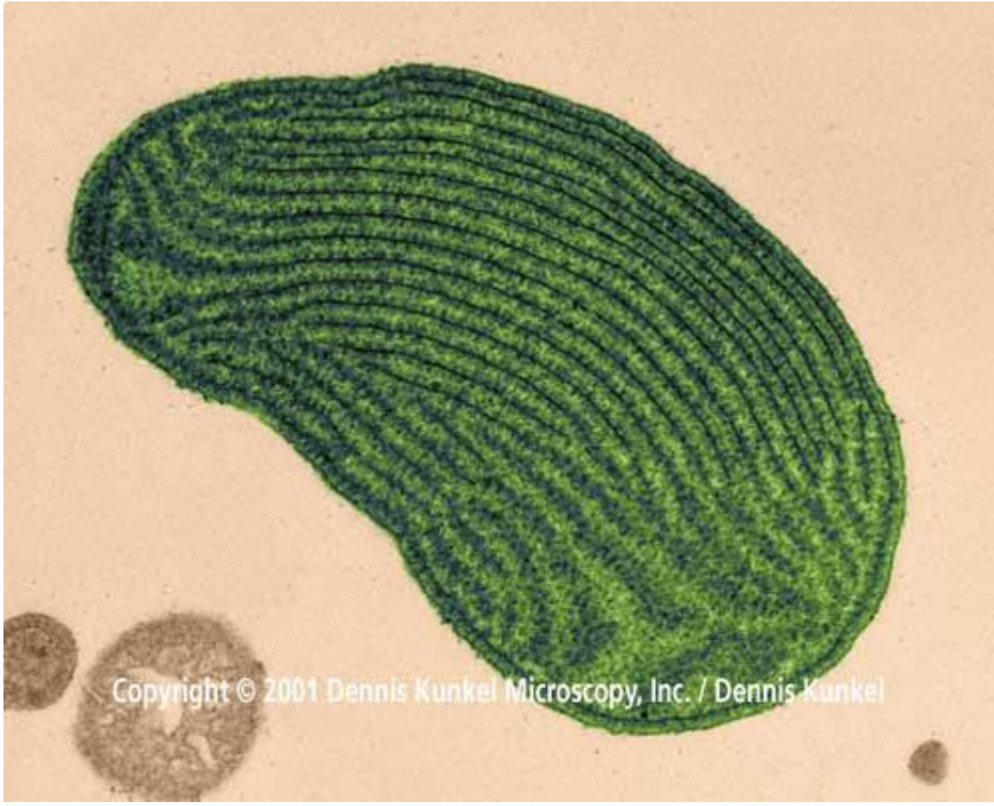


Figure 23. Chloroplast from red alga (*Griffthsia* spp.). x5,755--(Based on an image size of 1 inch in the narrow dimension). This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.



Chloroplasts and endosymbiosis

Like mitochondria, chloroplasts have their own DNA, termed cpDNA. Chloroplasts of Green Algae (Protista) and Plants (descendants of some of the Green Algae) are thought to have originated by endosymbiosis of a prokaryotic alga similar to living *Prochloron* (the sole genus present in the Prochlorobacteria, shown in Figure 24). Chloroplasts of Red Algae (Protista) are very similar biochemically to cyanobacteria (also known as blue-green bacteria [algae to chronologically enhanced folks like myself :)]). Endosymbiosis is also invoked for this similarity, perhaps indicating more than one endosymbiotic event occurred.

Figure 24. *Prochloron*, a photosynthetic bacteria, reveals the presence of numerous thylakoids in the transmission electron micrograph on the left. *Prochloron* occurs in long filaments, as shown by the light micrograph on the right below. Image from http://www.cas.muohio.edu/~wilsonkg/bot191/mouseth/m19p32.jpg.

Cell Movement

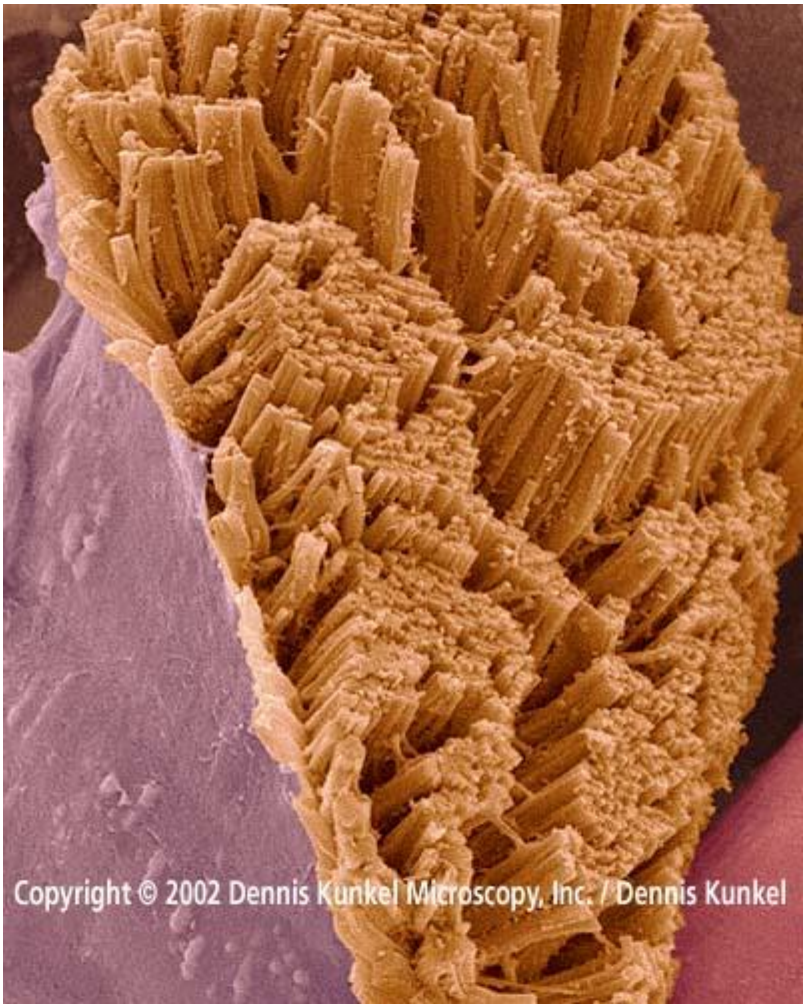
Cell movement; is both internal, referred to as cytoplasmic streaming, and external, referred to as motility. Internal movements of organelles are governed by actin filaments and other components of the cytoskeleton. These filaments make an area in which organelles such as chloroplasts can move. Internal movement is known as cytoplasmic streaming. External movement of cells is determined by special organelles for locomotion.

The cytoskeleton is a network of connected filaments and tubules. It extends from the nucleus to the plasma membrane. Electron microscopic studies showed the presence of an organized cytoplasm. Immunofluorescence microscopy identifies protein fibers as a major part of this cellular feature. The cytoskeleton components maintain cell shape and allow the cell and its organelles to move.

Actin filaments, shown in Figure 25, are long, thin fibers approximately seven nm in diameter. These filaments occur in bundles or meshlike networks. These filaments are polar, meaning there are differences between the ends of the strand. An actin filament consists of two chains of globular actin monomers twisted to form a helix. Actin filaments play a structural role, forming a dense complex web just under the plasma membrane. Actin filaments in microvilli of intestinal cells act to shorten the cell and thus to pull it out of the intestinal lumen. Likewise, the filaments can extend the cell into intestine when food is to be absorbed. In plant cells, actin filaments form tracts along which chloroplasts circulate.

Actin filaments move by interacting with myosin, The myosin combines with and splits ATP, thus binding to actin and changing the configuration to pull the actin filament forward. Similar action accounts for pinching off cells during cell division and for amoeboid movement.

Figure 25. Skeletal muscle fiber with exposed intracellular actin myosin filaments. The muscle fiber was cut perpendicular to its length to expose the intracellular actin myosin filaments. SEM X220. This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.



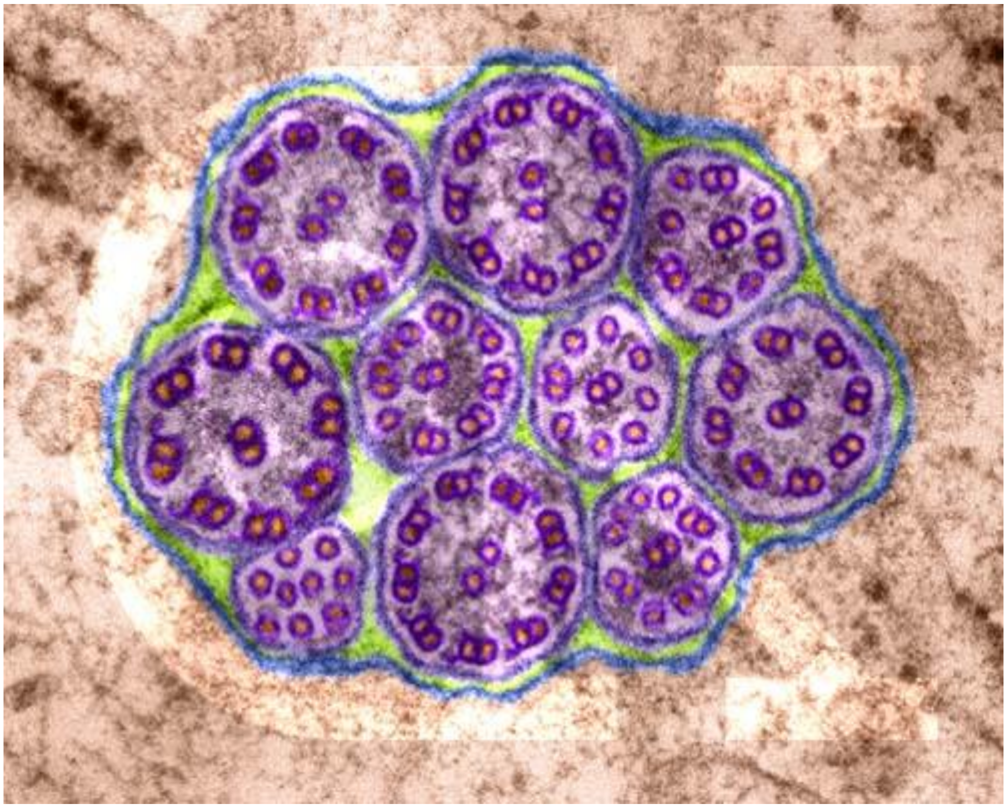
Intermediate filaments are between eight and eleven nm in diameter. They are between actin filaments and microtubules in size. The intermediate fibers are rope-like assemblies of fibrous polypeptides. Some of them support the nuclear envelope, while others support the plasma membrane, form cell-to-cell junctions.

Microtubules are small hollow cylinders (25 nm in diameter and from 200 nm-25 µm in length). These microtubules are composed of a globular protein tubulin. Assembly brings the two types of tubulin (alpha and beta) together as dimers, which arrange themselves in rows.

In animal cells and most protists, a structure known as a centrosome occurs. The centrosome contains two centrioles lying at right angles to each other. Centrioles are short cylinders with a 9 + 0 pattern of microtubule triplets. Centrioles serve as basal bodies for cilia and flagella. Plant and fungal cells have a structure equivalent to a centrosome, although it does not contain centrioles.

Cilia are short, usually numerous, hairlike projections that can move in an undulating fashion (e.g., the protzoan *Paramecium*, the cells lining the human upper respiratory tract). Flagella are longer, usually fewer in number, projections that move in whip-like fashion (e.g., sperm cells). Cilia and flagella are similar except for length, cilia being much shorter. They both have the characteristic 9 + 2 arrangement of microtubules shown in figures 26.

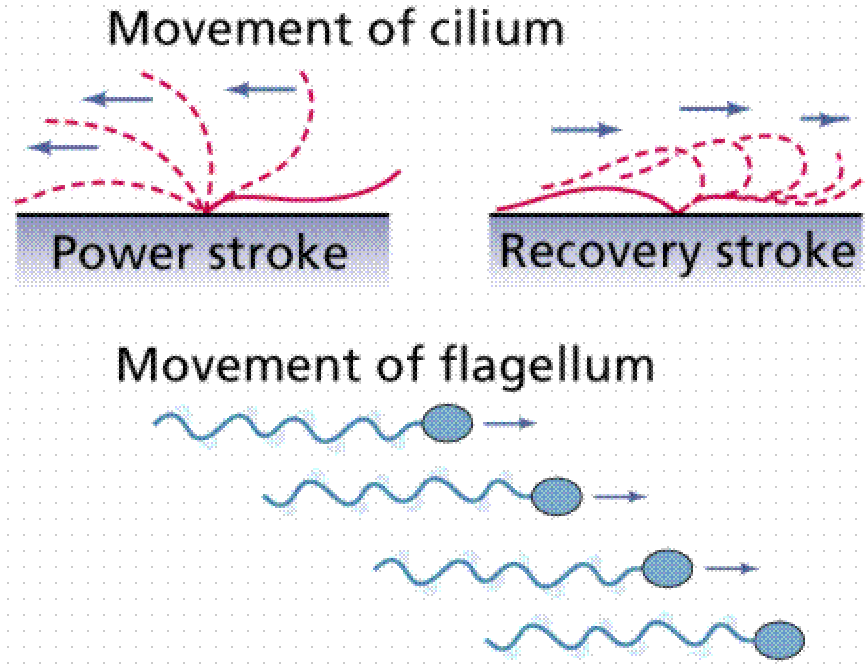
Figure 26. Cilia from an epithelial cell in cross section (TEM x199,500). Note the 9 + 2 arrangement of cilia. This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.



Cilia and flagella move when the microtubules slide past one another. Both oif these locomotion structures have a basal body at base with thesame arrangement of microtubule triples as centrioles. Cilia and flagella grow by the addition of tubulin dimers to their tips.

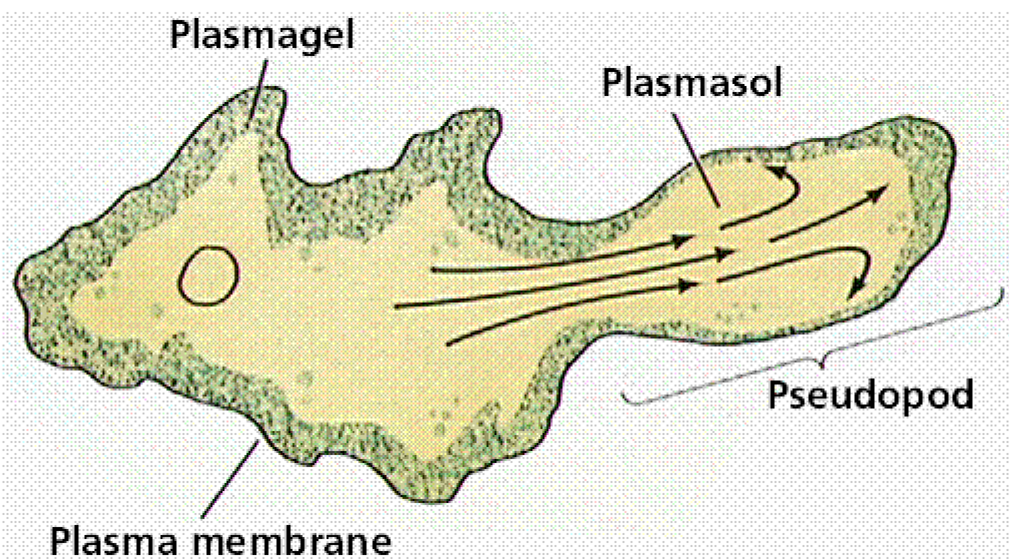
Flagella work as whips pulling (as in *Chlamydomonas* or *Halosphaera*) or pushing (dinoflagellates, a group of single-celled Protista) the organism through the water. Cilia work like oars on a viking longship (*Paramecium* has 17,000 such oars covering its outer surface). The movement of these structures is shown in Figure 27.

Figure 27. Movement of cilia and flagella. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.



Not all cells use cilia or flagella for movement. Some, such as *Amoeba*, *Chaos (Pelomyxa)* and human leukocytes (white blood cells), employ pseudopodia to move the cell. Unlike cilia and flagella, pseudopodia are not structures, but rather are associated with actin near the moving edge of the cell. The formation of a pseudopod is shown in Figure 28.

Figure 28. Formation and functioning of a pseudopod by an amoeboid cell. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.



CELL DIVISION: MEIOSIS AND SEXUAL REPRODUCTION

Meiosis

Sexual reproduction occurs only in eukaryotes. During the formation of gametes, the number of chromosomes is reduced by half, and returned to the full amount when the two gametes fuse during fertilization.

Ploidy

Haploid and diploid are terms referring to the number of sets of chromosomes in a cell. Gregor Mendel determined his peas had two sets of alleles, one from each parent. Diploid organisms are those with two (di) sets. Human beings (except for their gametes), most animals and many plants are diploid. We abbreviate diploid as 2n. Ploidy is a term referring to the number of sets of chromosomes. Haploid organisms/cells have only one set of chromosomes, abbreviated as n. Organisms with more than two sets of chromosomes are termed polyploid. Chromosomes that carry the same genes are termed homologous chromosomes. The alleles on homologous chromosomes may differ, as in the case of heterozygous individuals. Organisms (normally) receive one set of homologous chromosomes from each parent.

Meiosis is a special type of nuclear division which segregates one copy of each homologous chromosome into each new "gamete". Mitosis maintains the cell's original ploidy level (for example, one diploid 2n cell producing two diploid 2n cells; one haploid n cell producing two haploid n cells; etc.). Meiosis, on the other hand, reduces the number of sets of chromosomes by half, so that when gametic recombination (fertilization) occurs the ploidy of the parents will be reestablished.

Most cells in the human body are produced by mitosis. These are the somatic (or vegetative) line cells. Cells that become gametes are referred to as germ line cells. The vast majority of cell divisions in the human body are mitotic, with meiosis being restricted to the gonads.

Life Cycles

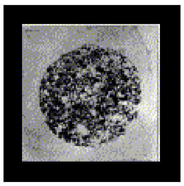
Life cycles are a diagrammatic representation of the events in the organism's development and reproduction. When interpreting life cycles, pay close attention to the ploidy level of particular parts of the cycle and where in the life cycle meiosis occurs. For example, animal life cycles have a dominant diploid phase, with the gametic (haploid) phase being a relative few cells. Most of the cells in your body are diploid, germ line diploid cells will undergo meiosis to produce gametes, with fertilization closely following meiosis.

Plant life cycles have two sequential phases that are termed alternation of generations. The sporophyte phase is "diploid", and is that part of the life cycle in which meiosis occurs. However, many plant species are thought to arise by polyploidy, and the use of "diploid" in the last sentence was meant to indicate that the greater number of chromosome sets occur in this phase. The gametophyte phase is "haploid", and is the part of the life cycle in which gametes are produced (by mitosis of haploid cells). In flowering plants (angiosperms) the multicelled visible plant (leaf, stem, etc.) is sporophyte, while pollen and ovaries contain the male and female gametophytes, respectively. Plant life cycles differ from animal ones by adding a phase (the haploid gametophyte) after meiosis and before the production of gametes.

Many protists and fungi have a haploid dominated life cycle. The dominant phase is haploid, while the diploid phase is only a few cells (often only the single celled zygote, as in *Chlamydomonas*). Many protists reproduce by mitosis until their environment deteriorates, then they undergo sexual reproduction to produce a resting zygotic cyst.

Phases of Meiosis

Two successive nuclear divisions occur, Meiosis I (Reduction) and Meiosis II (Division). Meiosis produces 4 haploid cells. Mitosis produces 2 diploid cells. The old name for meiosis was reduction/ division. Meiosis I reduces the ploidy level from 2n to n (reduction) while Meiosis II divides the remaining set of chromosomes in a mitosis-like process (division). Most of the differences between the processes occur during Meiosis I.



The above image is from http://www.biology.uc.edu/vgenetic/meiosis/

Prophase I

Prophase I has a unique event -- the pairing (by an as yet undiscovered mechanism) of homologous chromosomes. Synapsis is the process of linking of the replicated homologous chromosomes. The resulting chromosome is termed a tetrad, being composed of two chromatids from each chromosome, forming a thick (4-strand) structure. Crossing-over may occur at this point. During crossing-over chromatids break and may be reattached to a **different** homologous chromosome.

The alleles on this tetrad:

A B C D E F G

A B C D E F G

a b c d e f g

a b c d e f g

will produce the following chromosomes if there is a crossing-over event between the 2nd and 3rd chromosomes from the top:

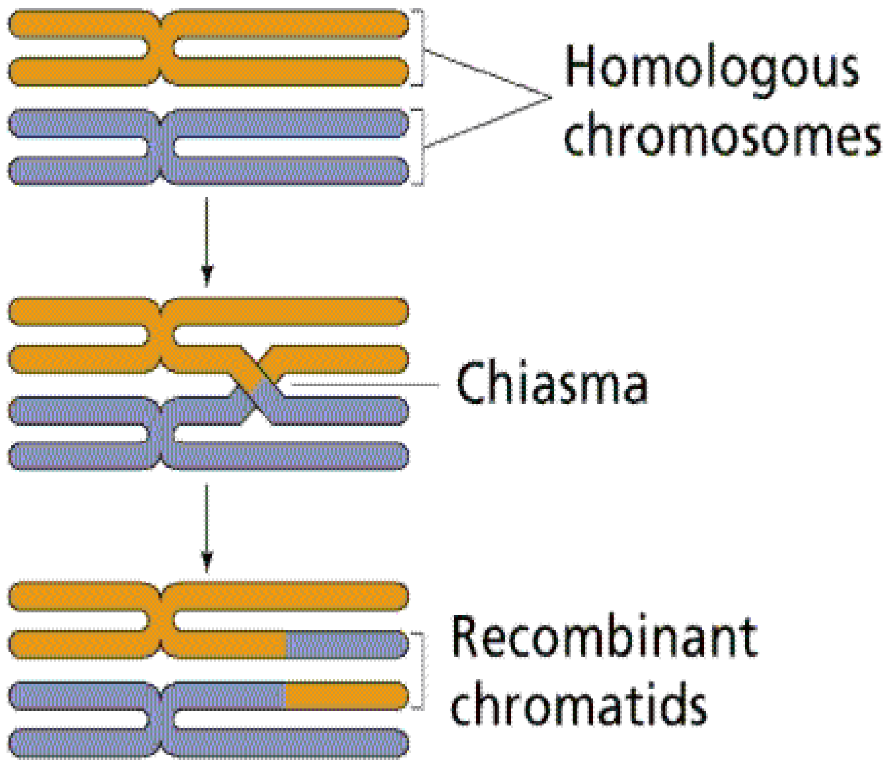
A B C D E F G

A B c d e f g

a b C D E F G

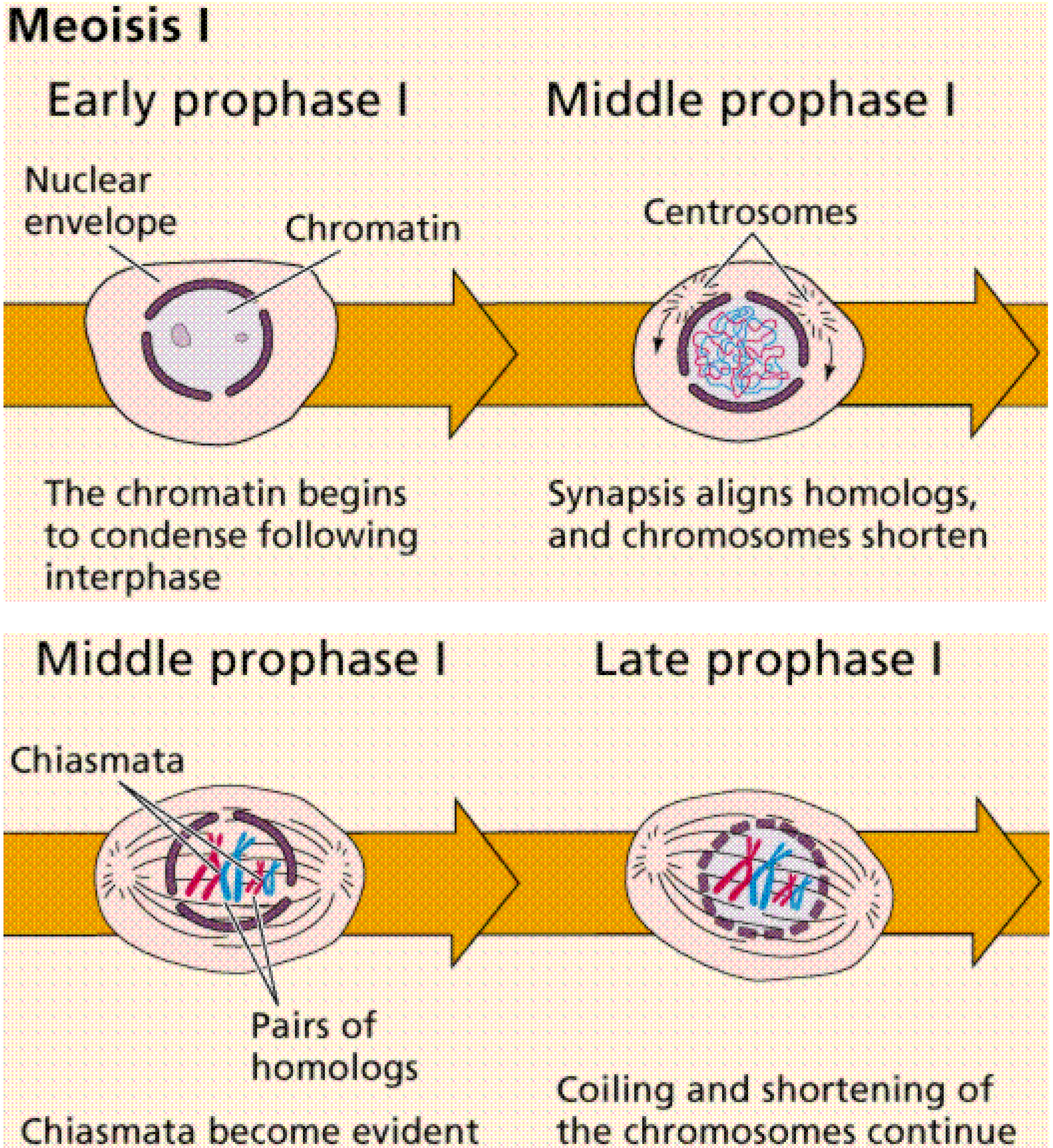
a b c d e f g

Thus, instead of producing only two types of chromosome (all capital or all lower case), four different chromosomes are produced. This doubles the variability of gamete genotypes. The occurrence of a crossing-over is indicated by a special structure, a chiasma (plural chiasmata) since the recombined inner alleles will align more with others of the same type (e.g. a with a, B with B). Near the end of Prophase I, the homologous chromosomes begin to separate slightly, although they remain attached at chiasmata.



Crossing-over between homologous chromosomes produces chromosomes with new associations of genes and alleles. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Events of Prophase I (save for synapsis and crossing over) are similar to those in Prophase of mitosis: chromatin condenses into chromosomes, the nucleolus dissolves, nuclear membrane is disassembled, and the spindle apparatus forms.



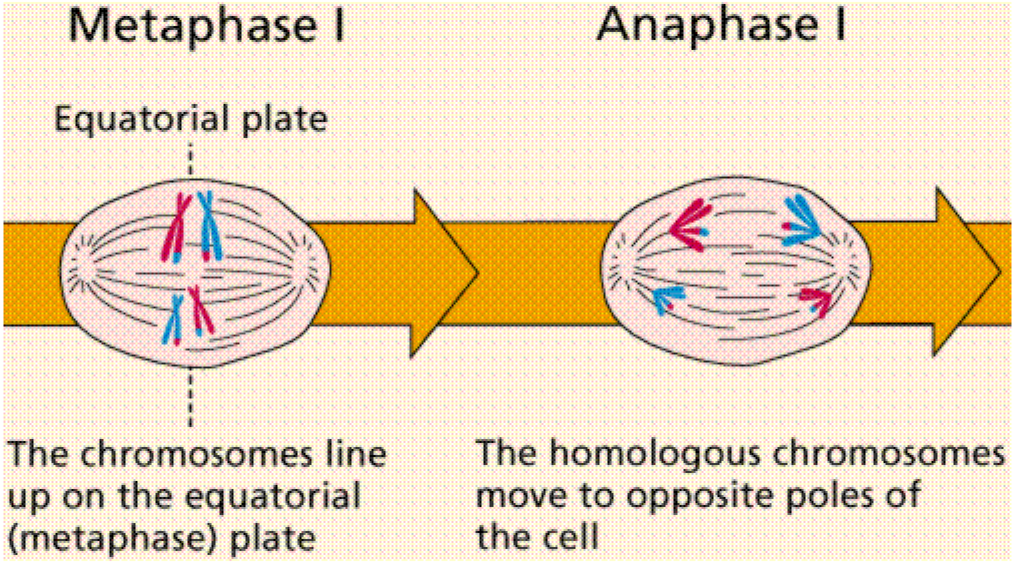
Major events in Prophase I. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Metaphase I

Metaphase I is when tetrads line-up along the equator of the spindle. Spindle fibers attach to the centromere region of each homologous chromosome pair. Other metaphase events as in mitosis.

Anaphase I

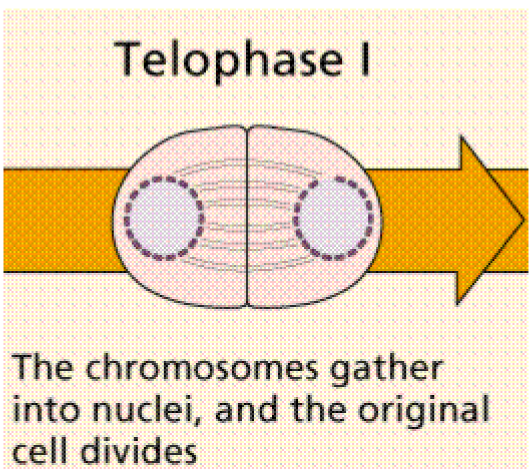
Anaphase I is when the tetrads separate, and are drawn to opposite poles by the spindle fibers. The centromeres in Anaphase I remain intact.



Events in prophase and metaphse I. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Telophase I

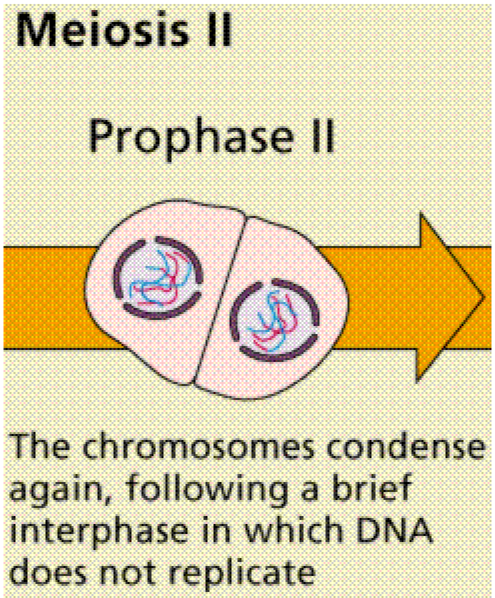
Telophase I is similar to Telophase of mitosis, except that only one set of (replicated) chromosomes is in each "cell". Depending on species, new nuclear envelopes may or may not form. Some animal cells may have division of the centrioles during this phase.



The events of Telophase I. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Prophase II

During Prophase II, nuclear envelopes (if they formed during Telophase I) dissolve, and spindle fibers reform. All else is as in Prophase of mitosis. Indeed Meiosis II is very similar to mitosis.



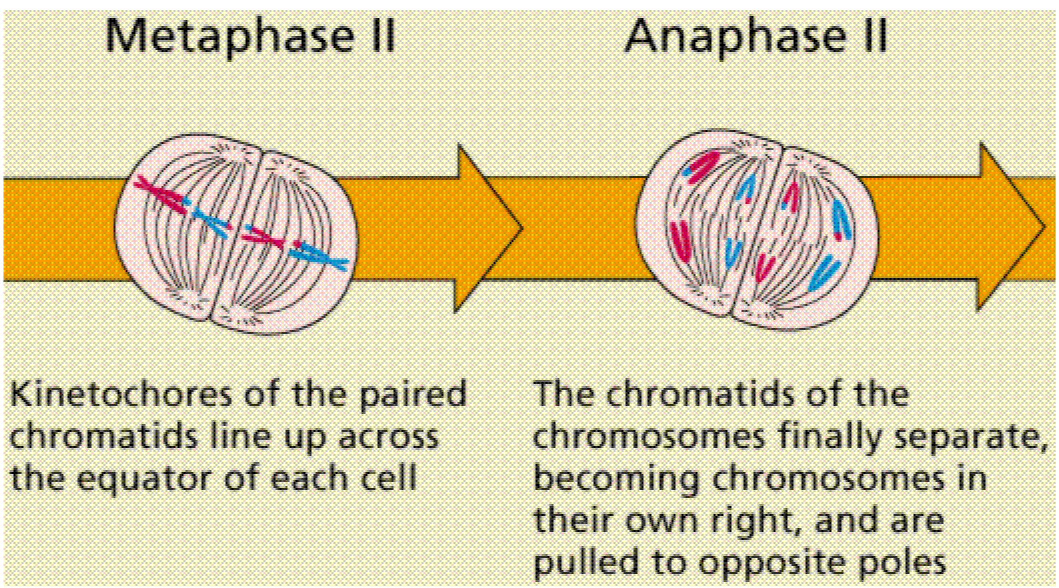
The events of Prophase II. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Metaphase II

Metaphase II is similar to mitosis, with spindles moving chromosomes into equatorial area and attaching to the opposite sides of the centromeres in the kinetochore region.

Anaphase II

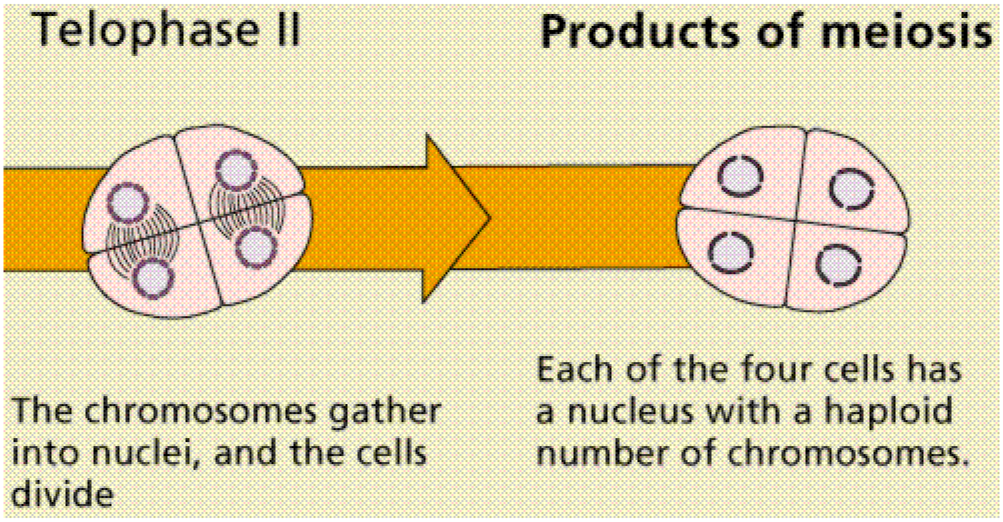
During Anaphase II, the centromeres split and the former chromatids (now chromosomes) are segregated into opposite sides of the cell.



The events of Metaphase II and Anaphase II. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Telophase II

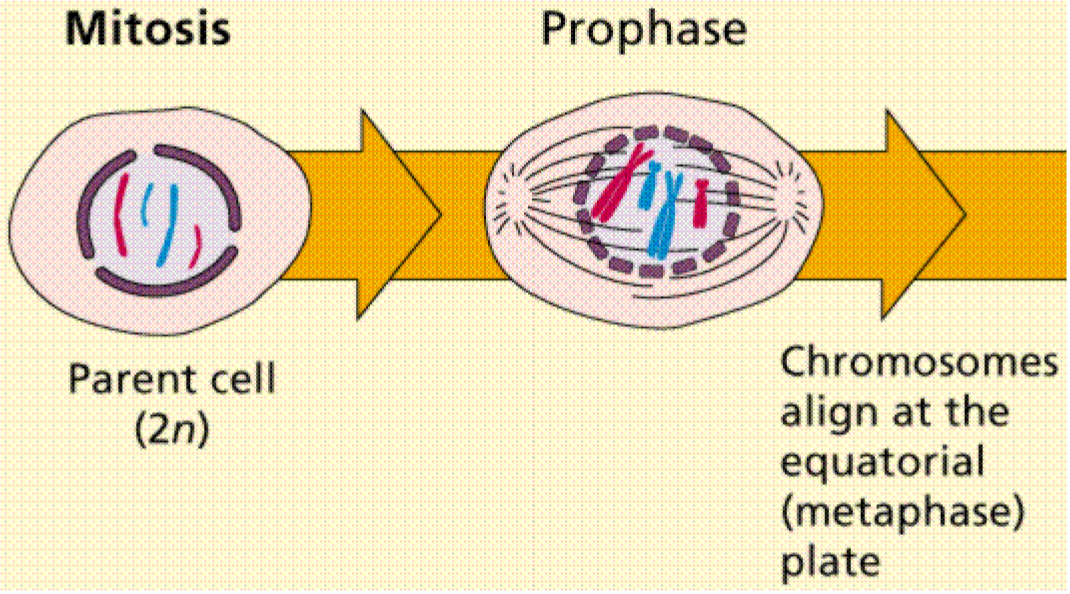
Telophase II is identical to Telophase of mitosis. Cytokinesis separates the cells.

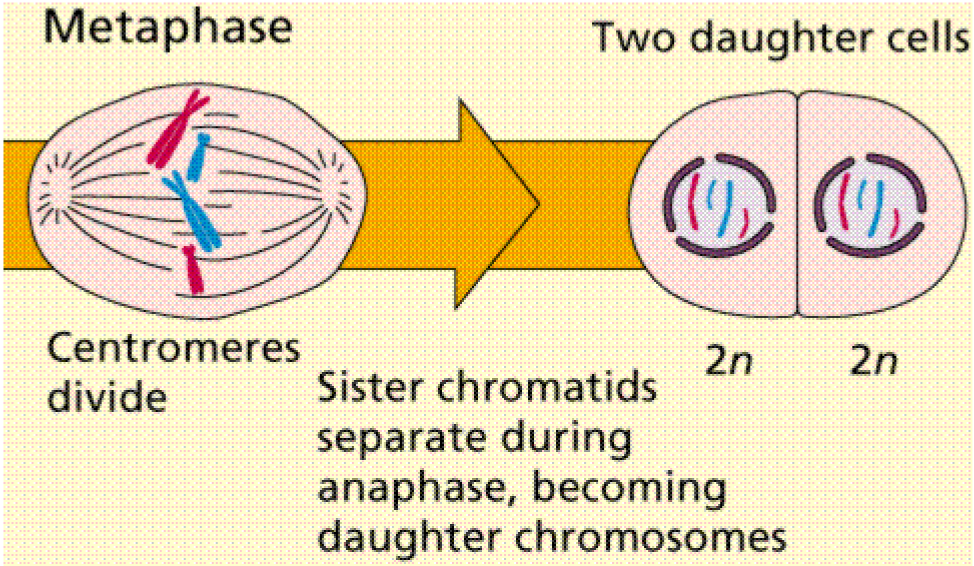


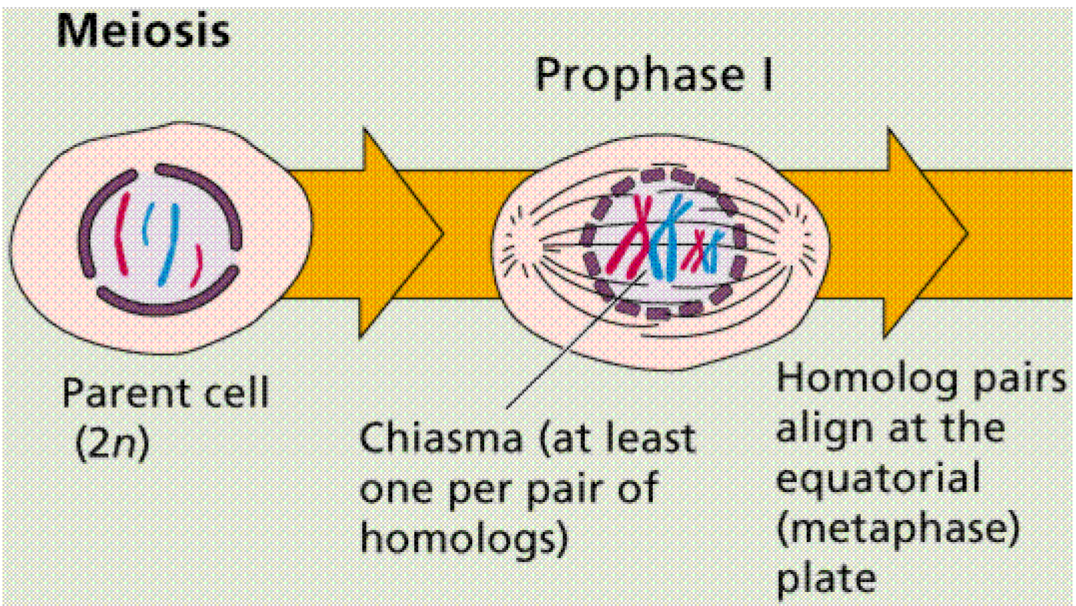
The events of Telophase II. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

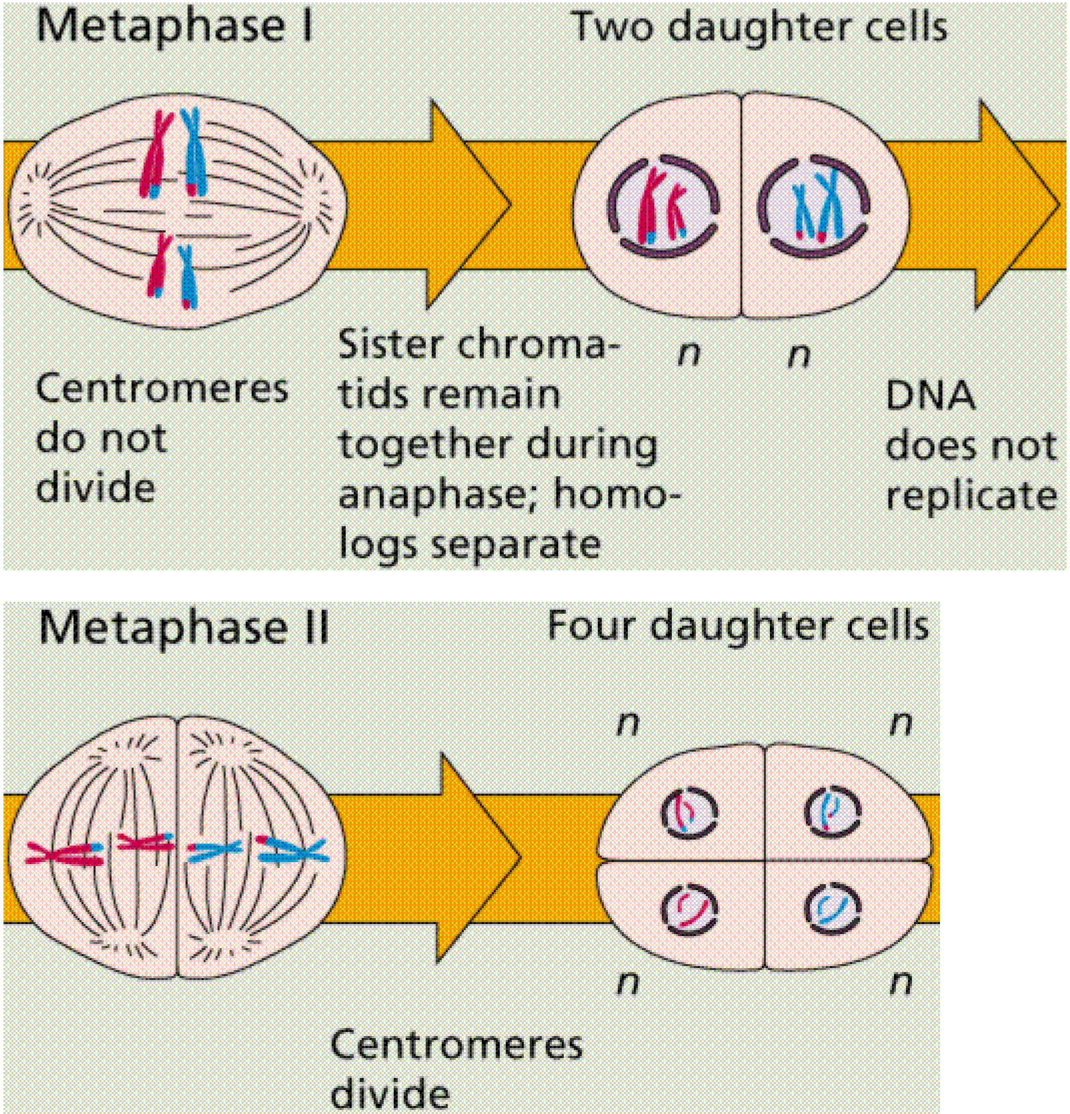
Comparison of Mitosis and Meiosis

Mitosis maintains ploidy level, while meiosis reduces it. Meiosis may be considered a reduction phase followed by a slightly altered mitosis. Meiosis occurs in a relative few cells of a multicellular organism, while mitosis is more common.




Metaphase
Two daughter cells
Centromeres divide
2n
2n
Sister chromatids separate during anaphase, becoming daughter chromosomes

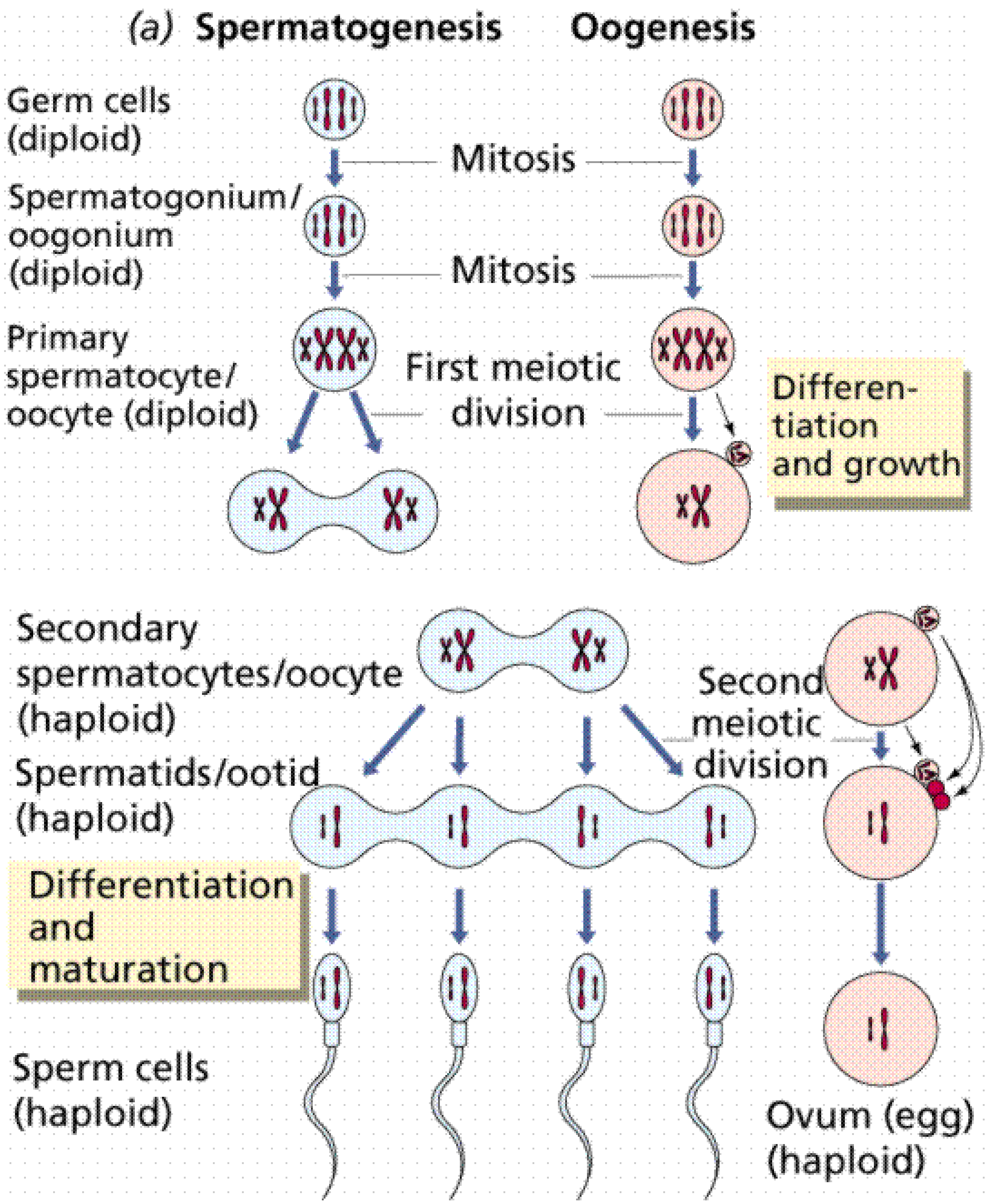

Meiosis
Prophase I
Parent cell (2n)
Chiasma (at least one per pair of homologs)
Homolog pairs align at the equatorial (metaphase) plate



Comparison of the events in Mitosis and Meiosis. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Gametogenesis

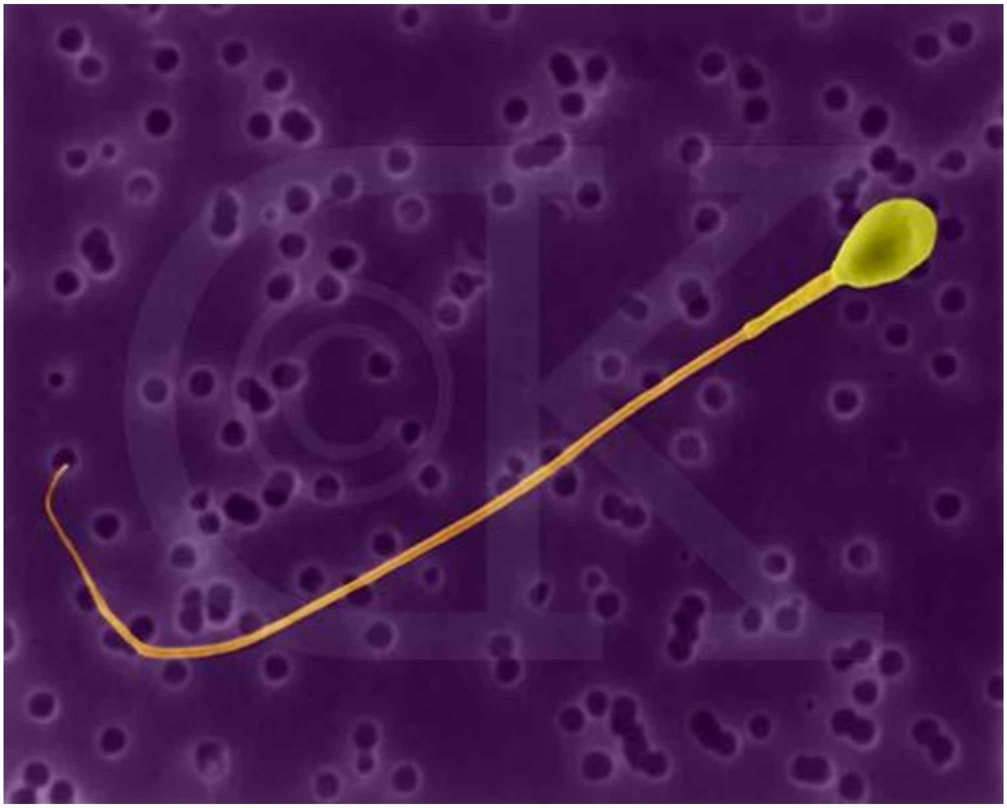
Gametogenesis is the process of forming gametes (by definition haploid, n) from diploid cells of the germ line. Spermatogenesis is the process of forming sperm cells by meiosis (in animals, by mitosis in plants) in specialized organs known as gonads (in males these are termed testes). After division the cells undergo differentiation to become sperm cells. Oogenesis is the process of forming an ovum (egg) by meiosis (in animals, by mitosis in the gametophyte in plants) in specialized gonads known as ovaries. Whereas in spermatogenesis all 4 meiotic products develop into gametes, oogenesis places most of the cytoplasm into the large egg. The other cells, the polar bodies, do not develop. This all the cytoplasm and organelles go into the egg. Human males produce 200,000,000 sperm per day, while the female produces one egg (usually) each menstrual cycle.



Gametogenesis. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Spermatogenesis

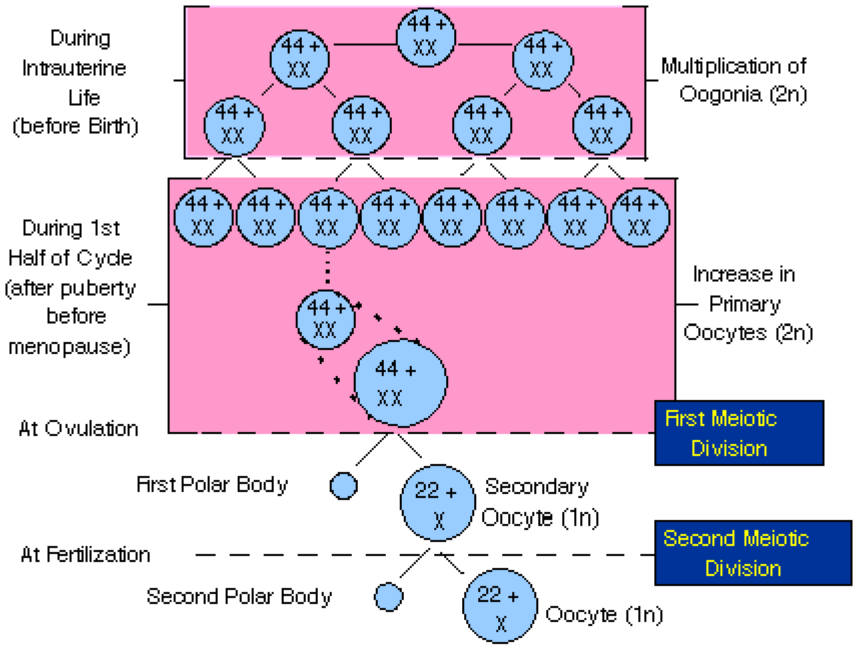
Sperm production begins at puberty at continues throughout life, with several hundred million sperm being produced each day. Once sperm form they move into the epididymis, where they mature and are stored.



Human Sperm (SEM x5,785). This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.

Oogenesis

The ovary contains many follicles composed of a developing egg surrounded by an outer layer of follicle cells. Each egg begins oogenesis as a primary oocyte. At birth each female carries a lifetime supply of developing oocytes, each of which is in Prophase I. A developing egg (secondary oocyte) is released each month from puberty until menopause, a total of 400-500 eggs.



PHOTOSYNTHESIS

What is Photosynthesis?

Photosynthesis is the process by which plants, some bacteria, and some protistans use the energy from sunlight to produce sugar, which cellular respiration converts into ATP, the "fuel" used by all living things. The conversion of unusable sunlight energy into usable chemical energy, is associated with the actions of the green pigment chlorophyll. Most of the time, the photosynthetic process uses water and releases the oxygen that we absolutely must have to stay alive. Oh yes, we need the food as well!

We can write the overall reaction of this process as:

$6H_2O + 6CO_2$ ----------> $C_6H_{12}O_6 + 6O_2$

Most of us don't speak chemicalese, so the above chemical equation translates as:

six molecules of water plus six molecules of carbon dioxide produce one molecule of sugar plus six molecules of oxygen

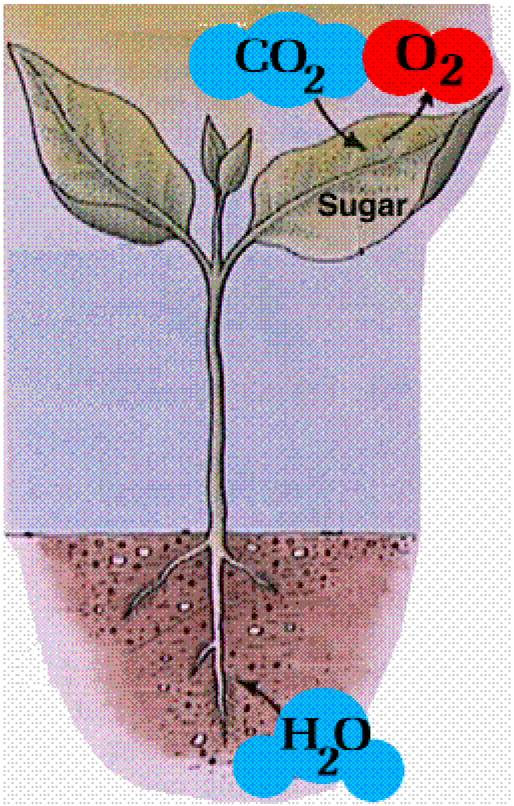
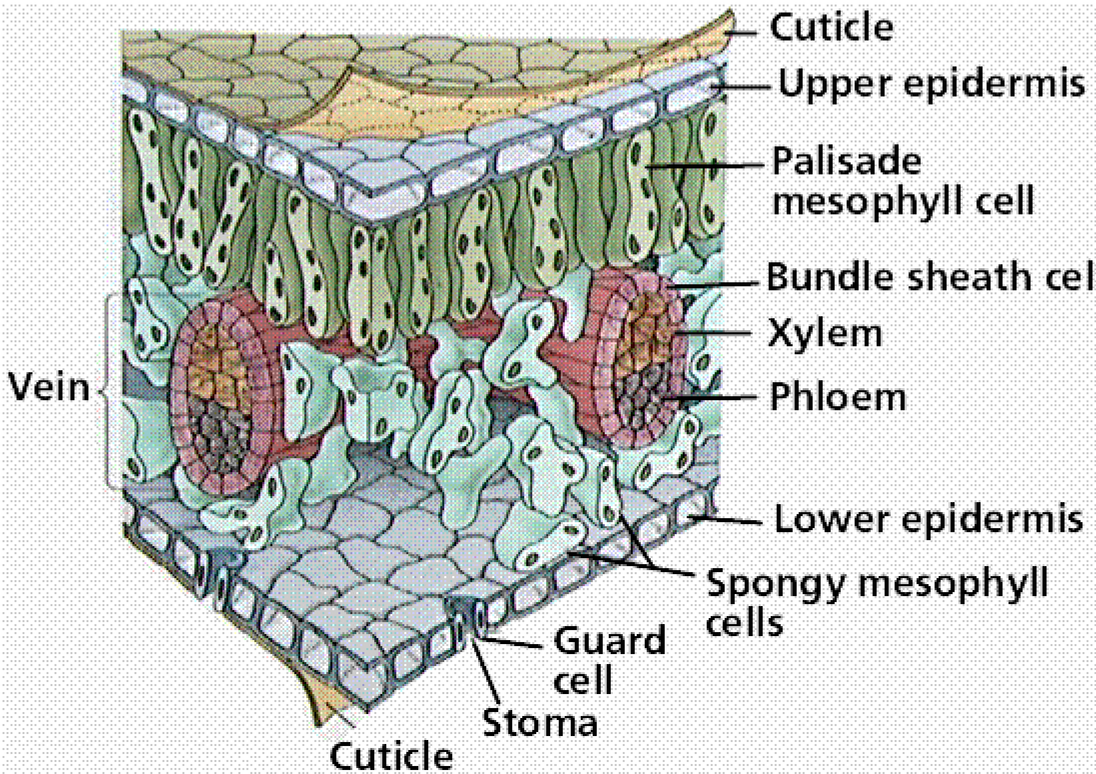


Diagram of a typical plant, showing the inputs and outputs of the photosynthetic process. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Leaves and Leaf Structure

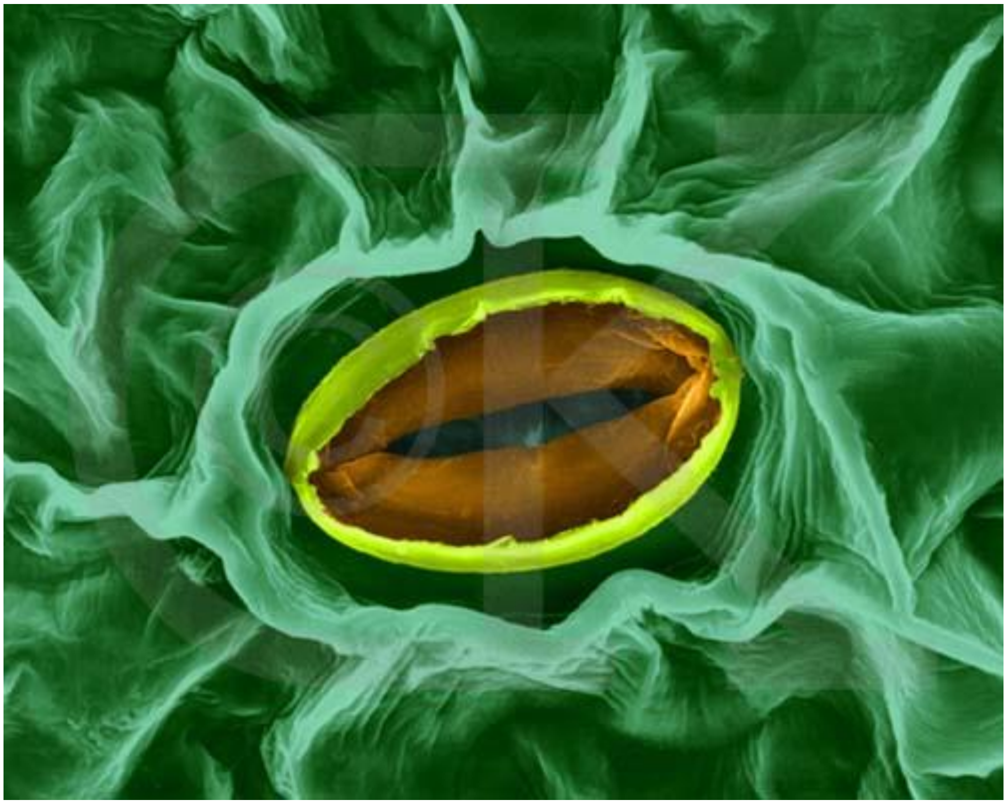
Plants are the only photosynthetic organisms to have leaves (and not all plants have leaves). A leaf may be viewed as a solar collector crammed full of photosynthetic cells.

The raw materials of photosynthesis, water and carbon dioxide, enter the cells of the leaf, and the products of photosynthesis, sugar and oxygen, leave the leaf.



Cross section of a leaf, showing the anatomical features important to the study of photosynthesis: stoma, guard cell, mesophyll cells, and vein. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

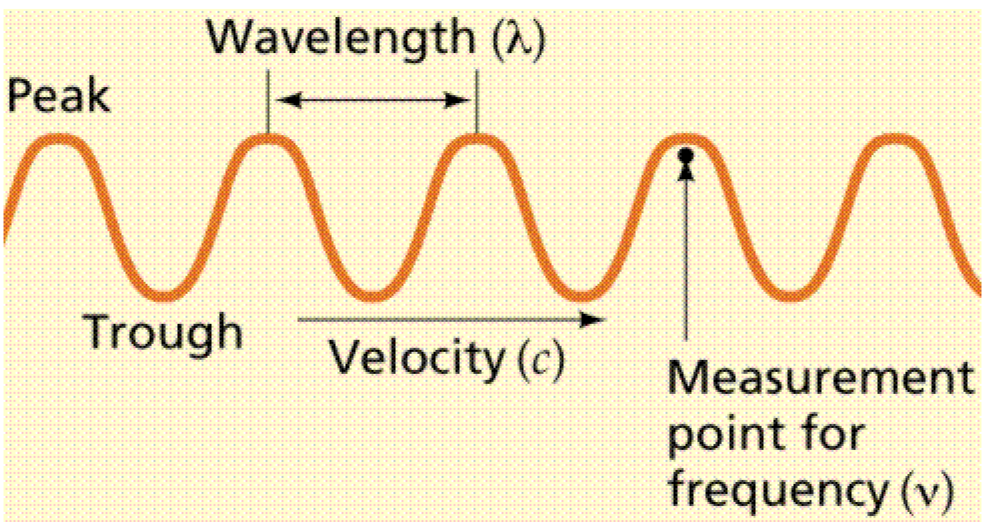
Water enters the root and is transported up to the leaves through specialized plant cells known as xylem (pronounces zigh-lem). Land plants must guard against drying out (desiccation) and so have evolved specialized structures known as stomata to allow gas to enter and leave the leaf. Carbon dioxide cannot pass through the protective waxy layer covering the leaf (cuticle), but it can enter the leaf through an opening (the stoma; plural = stomata; Greek for hole) flanked by two guard cells. Likewise, oxygen produced during photosynthesis can only pass out of the leaf through the opened stomata. Unfortunately for the plant, while these gases are moving between the inside and outside of the leaf, a great deal water is also lost. Cottonwood trees, for example, will lose 100 gallons of water per hour during hot desert days. Carbon dioxide enters single-celled and aquatic autotrophs through no specialized structures.



Pea Leaf Stoma, *Vicea* sp. (SEM x3,520). This image is copyright Dennis Kunkel at www.DennisKunkel.com, used with permission.

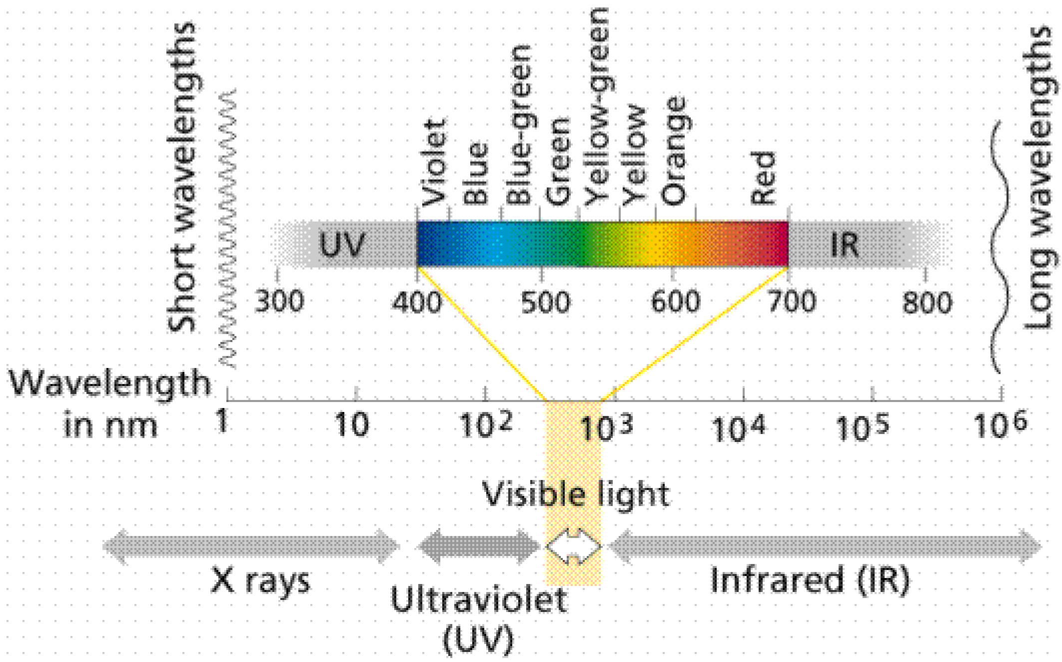
The Nature of Light

White light is separated into the different colors (=wavelengths) of light by passing it through a prism. Wavelength is defined as the distance from peak to peak (or trough to trough). The energy of is inversely porportional to the wavelength: longer wavelengths have less energy than do shorter ones.



Wavelength and other saspects of the wave nature of light. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

The order of colors is determined by the wavelength of light. Visible light is one small part of the electromagnetic spectrum. The longer the wavelength of visible light, the more red the color. Likewise the shorter wavelengths are towards the violet side of the spectrum. Wavelengths longer than red are referred to as infrared, while those shorter than violet are ultraviolet.

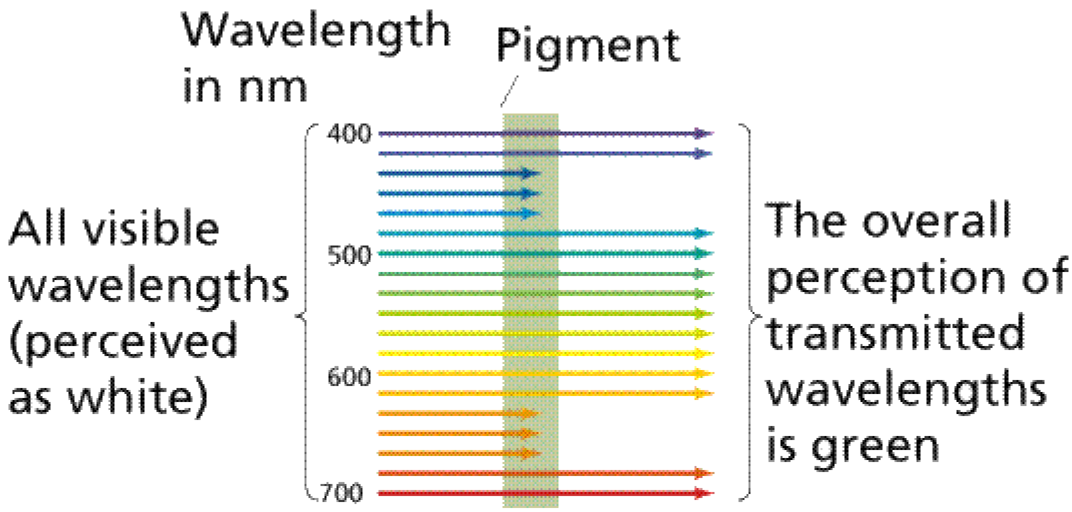


The electromagnetic spectrum. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Light behaves both as a wave and a particle. Wave properties of light include the bending of the wave path when passing from one material (medium) into another (i.e. the prism, rainbows, pencil in a glass-of-water, etc.). The particle properties are demonstrated by the photoelectric effect. Zinc exposed to ultraviolet light becomes positively charged because light energy forces electrons from the zinc. These electrons can create an electrical current. Sodium, potassium and selenium have critical wavelengths in the visible light range. The critical wavelength is the maximum wavelength of light (visible or invisible) that creates a photoelectric effect.

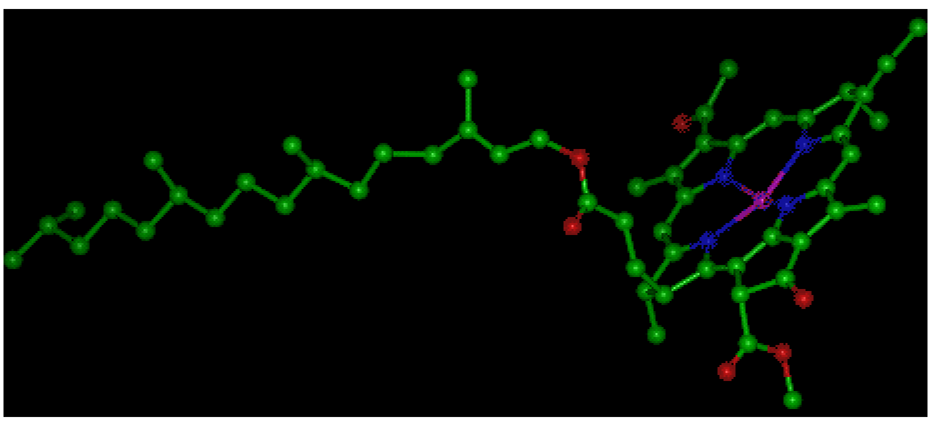
Chlorophyll and Accessory Pigments

A pigment is any substance that absorbs light. The color of the pigment comes from the wavelengths of light reflected (in other words, those not absorbed). Chlorophyll, the green pigment common to all photosynthetic cells, absorbs all wavelengths of visible light except green, which it reflects to be detected by our eyes. Black pigments absorb all of the wavelengths that strike them. White pigments/lighter colors reflect all or almost all of the energy striking them. Pigments have their own characteristic absorption spectra, the absorption pattern of a given pigment.

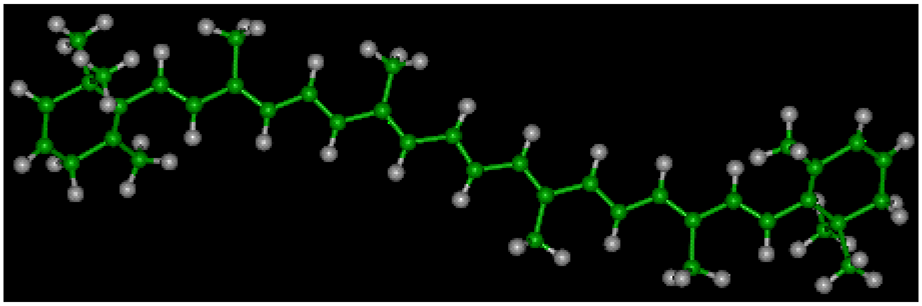


Absorption and transmission of different wavelengths of light by a hypothetical pigment. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Chlorophyll is a complex molecule. Several modifications of chlorophyll occur among plants and other photosynthetic organisms. All photosynthetic organisms (plants, certain protistans, prochlorobacteria, and cyanobacteria) have chlorophyll a. Accessory pigments absorb energy that chlorophyll a does not absorb. Accessory pigments include chlorophyll b (also c, d, and e in algae and protistans), xanthophylls, and carotenoids (such as beta-carotene). Chlorophyll a absorbs its energy from the Violet-Blue and Reddish orange-Red wavelengths, and little from the intermediate (Green-Yellow-Orange) wavelengths.

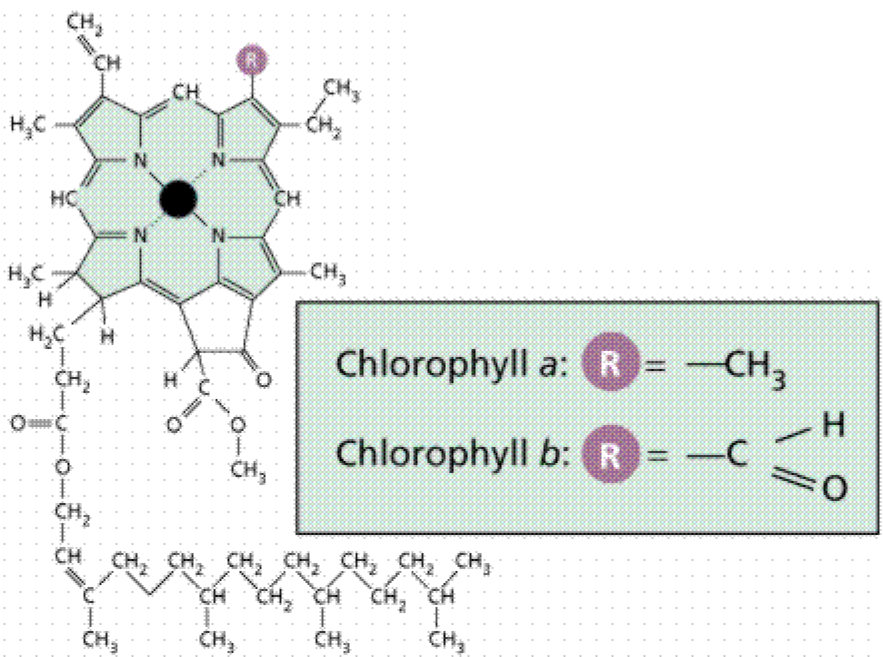


Molecular model of chlorophyll. The above image is from http://www.nyu.edu:80/pages/mathmol/library/photo.



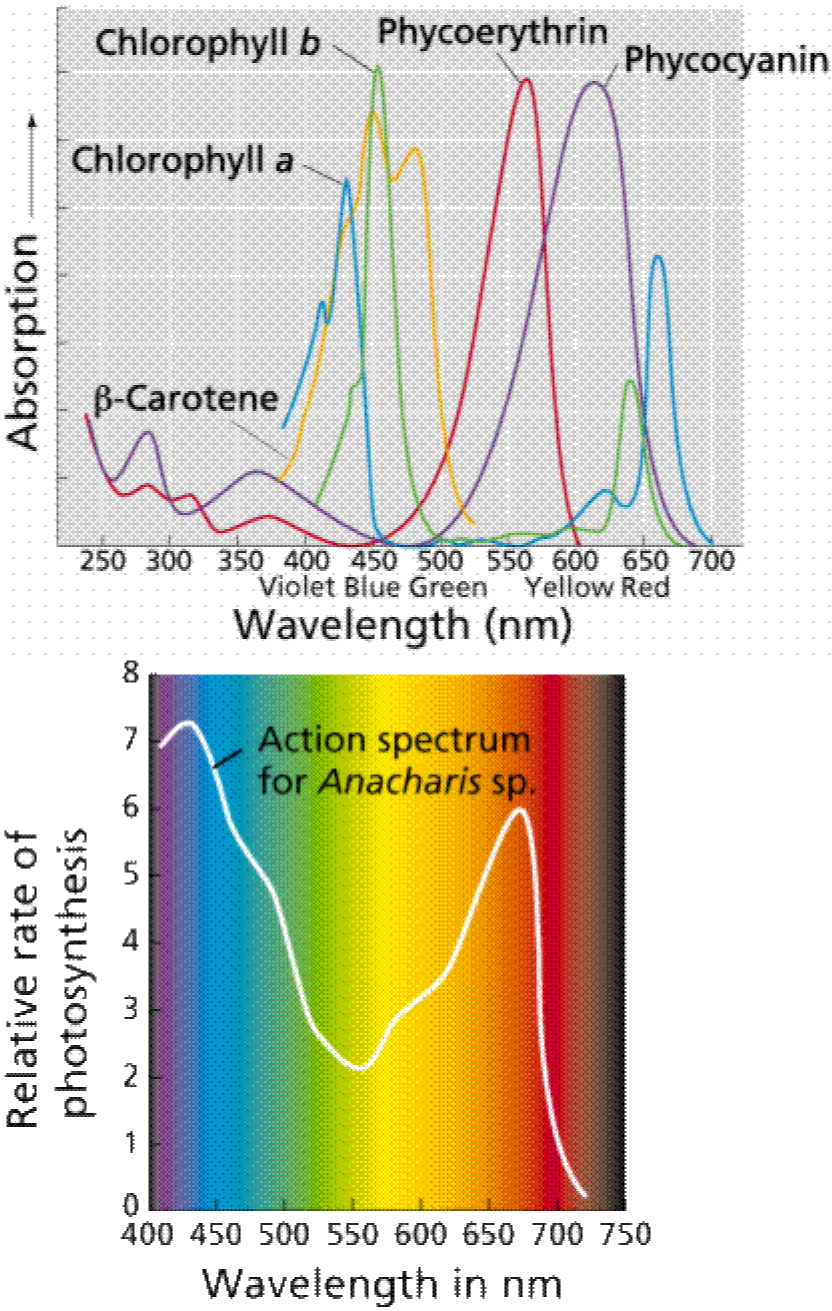
Molecular model of carotene. The above image is from http://www.nyu.edu:80/pages/mathmol/library/photo.

Carotenoids and chlorophyll b absorb some of the energy in the green wavelength. Why not so much in the orange and yellow wavelengths? Both chlorophylls also absorb in the orange-red end of the spectrum (with longer wavelengths and lower energy). The origins of photosynthetic organisms in the sea may account for this. Shorter wavelengths (with more energy) do not penetrate much below 5 meters deep in sea water. The ability to absorb some energy from the longer (hence more penetrating) wavelengths might have been an advantage to early photosynthetic algae that were not able to be in the upper (photic) zone of the sea all the time.



The molecular structure of chlorophylls. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

The action spectrum of photosynthesis is the relative effectiveness of different wavelengths of light at generating electrons. If a pigment absorbs light energy, one of three things will occur. Energy is dissipated as heat. The energy may be emitted immediately as a longer wavelength, a phenomenon known as fluorescence. Energy may trigger a chemical reaction, as in photosynthesis. Chlorophyll only triggers a chemical reaction when it is associated with proteins embedded in a membrane (as in a chloroplast) or the membrane infoldings found in photosynthetic prokaryotes such as cyanobacteria and prochlorobacteria.

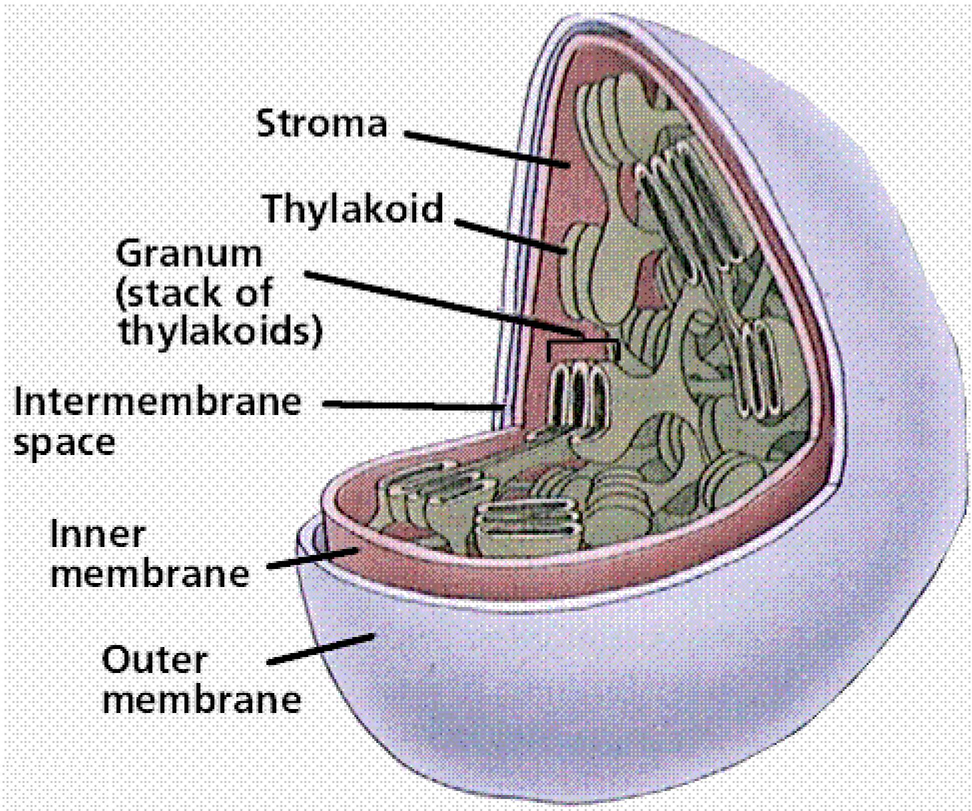


Absorption spectrum of several plant pigments (left) and action spectrum of elodea (right), a common aquarium plant used in lab experiments about photosynthesis. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

The structure of the chloroplast and photosynthetic membranes

The thylakoid is the structural unit of photosynthesis. Both photosynthetic prokaryotes and eukaryotes have these flattened sacs/vesicles containing photosynthetic chemicals. Only eukaryotes have chloroplasts with a surrounding membrane.

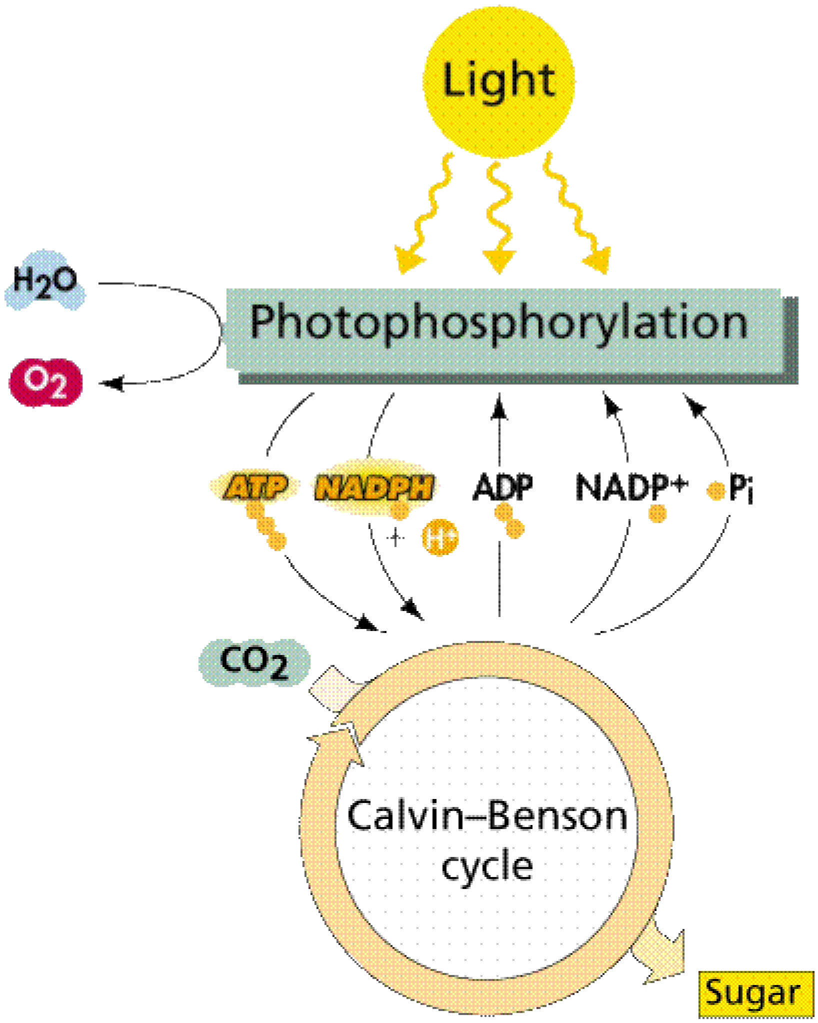
Thylakoids are stacked like pancakes in stacks known collectively as grana. The areas between grana are referred to as stroma. While the mitochondrion has two membrane systems, the chloroplast has three, forming three compartments.



Structure of a chloroplast. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Stages of Photosynthesis

Photosynthesis is a two stage process. The first process is the Light Dependent Process (Light Reactions), requires the direct energy of light to make energy carrier molecules that are used in the second process. The Light Independent Process (or Dark Reactions) occurs when the products of the Light Reaction are used to form C-C covalent bonds of carbohydrates. The Dark Reactions can usually occur in the dark, if the energy carriers from the light process are present. Recent evidence suggests that a major enzyme of the Dark Reaction is indirectly stimulated by light, thus the term Dark Reaction is somewhat of a misnomer. The Light Reactions occur in the grana and the Dark Reactions take place in the stroma of the chloroplasts.



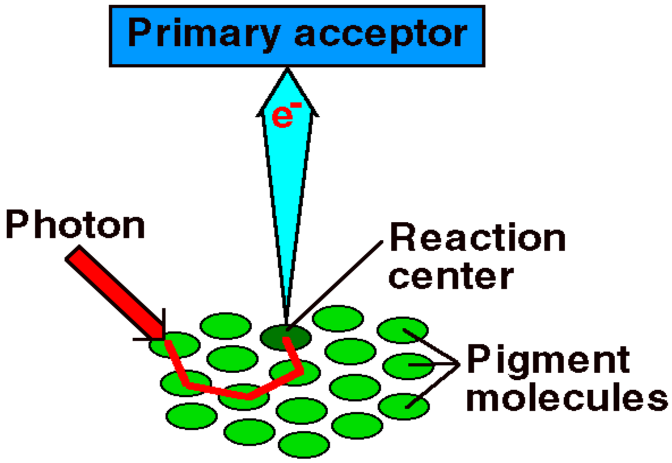
Overview of the two steps in the photosynthesis process. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Light Reactions

In the Light Dependent Processes (Light Reactions) light strikes chlorophyll a in such a way as to excite electrons to a higher energy state. In a series of reactions the energy is converted (along an electron transport process) into ATP and NADPH. Water is split in the process, releasing oxygen as a by-product of the reaction. The ATP and NADPH are used to make C-C bonds in the Light Independent Process (Dark Reactions).

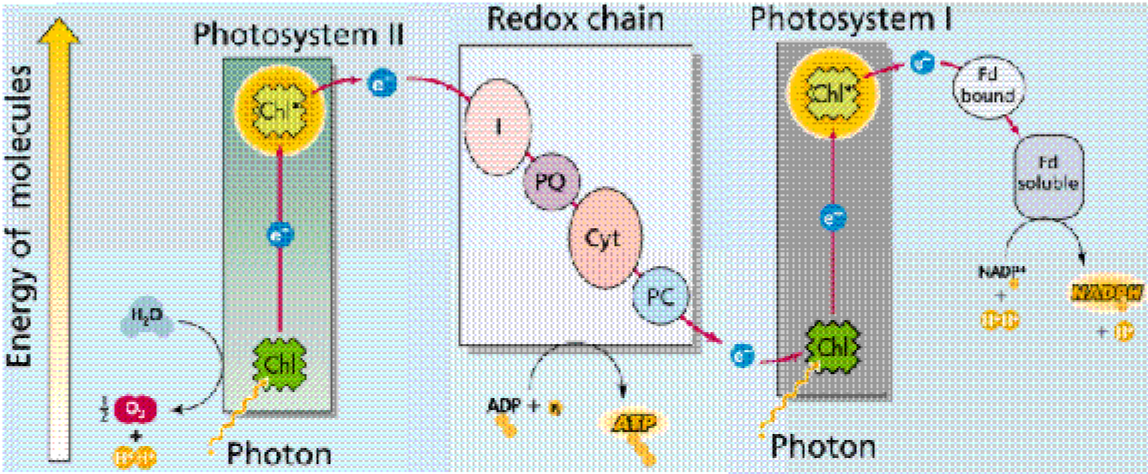
In the Light Independent Process, carbon dioxide from the atmosphere (or water for aquatic/marine organisms) is captured and modified by the addition of Hydrogen to form carbohydrates (general formula of carbohydrates is $[CH_2O]_n$). The incorporation of carbon dioxide into organic compounds is known as carbon fixation. The energy for this comes from the first phase of the photosynthetic process. Living systems cannot directly utilize light energy, but can, through a complicated series of reactions, convert it into C-C bond energy that can be released by glycolysis and other metabolic processes.

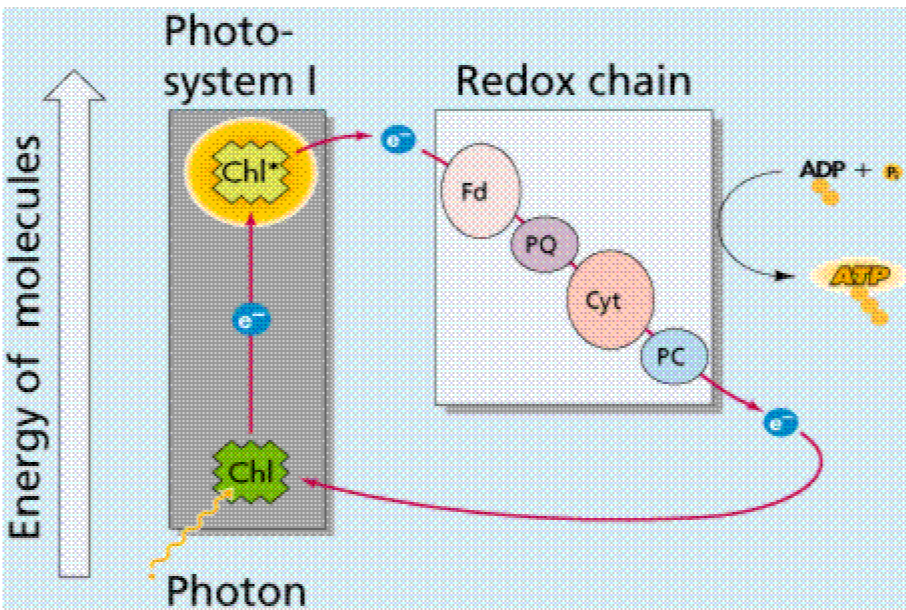
Photosystems are arrangements of chlorophyll and other pigments packed into thylakoids. Many Prokaryotes have only one photosystem, Photosystem II (so numbered because, while it was most likely the first to evolve, it was the second one discovered). Eukaryotes have Photosystem II plus Photosystem I. Photosystem I uses chlorophyll a, in the form referred to as P700. Photosystem II uses a form of chlorophyll a known as P680. Both "active" forms of chlorophyll a function in photosynthesis due to their association with proteins in the thylakoid membrane.



Action of a photosystem. This image is from the University of Minnesota page at http://genbiol.cbs.umn.edu/Multimedia/examples.html.

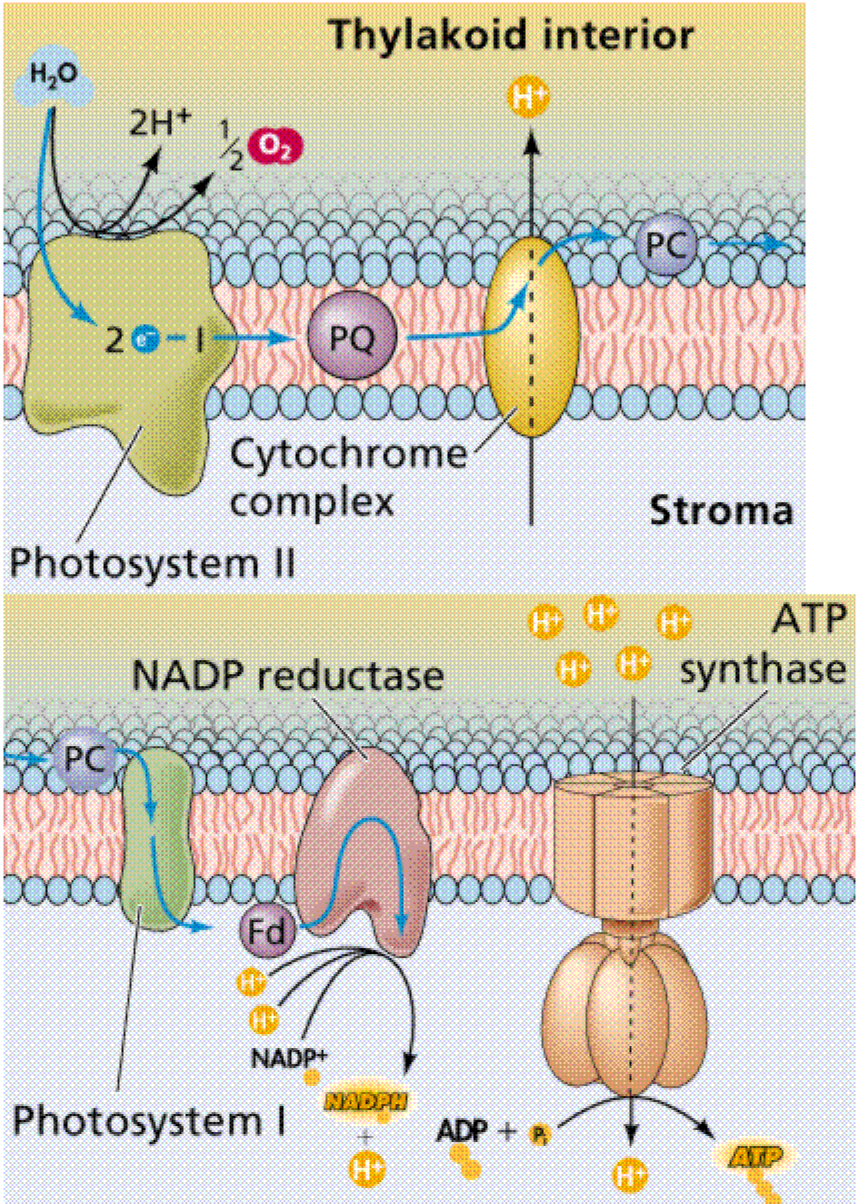
Photophosphorylation is the process of converting energy from a light-excited electron into the pyrophosphate bond of an ADP molecule. This occurs when the electrons from water are excited by the light in the presence of P680. The energy transfer is similar to the chemiosmotic electron transport occurring in the mitochondria. Light energy causes the removal of an electron from a molecule of P680 that is part of Photosystem II. The P680 requires an electron, which is taken from a water molecule, breaking the water into H^+ ions and O^{-2} ions. These O^{-2} ions combine to form the diatomic O_2 that is released. The electron is "boosted" to a higher energy state and attached to a primary electron acceptor, which begins a series of redox reactions, passing the electron through a series of electron carriers, eventually attaching it to a molecule in Photosystem I. Light acts on a molecule of P700 in Photosystem I, causing an electron to be "boosted" to a still higher potential. The electron is attached to a different primary electron acceptor (that is a different molecule from the one associated with Photosystem II). The electron is passed again through a series of redox reactions, eventually being attached to $NADP^+$ and H^+ to form NADPH, an energy carrier needed in the Light Independent Reaction. The electron from Photosystem II replaces the excited electron in the P700 molecule. There is thus a continuous flow of electrons from water to NADPH. This energy is used in Carbon Fixation. Cyclic Electron Flow occurs in some eukaryotes and primitive photosynthetic bacteria. No NADPH is produced, only ATP. This occurs when cells may require additional ATP, or when there is no $NADP^+$ to reduce to NADPH. In Photosystem II, the pumping to H ions into the thylakoid and the conversion of ADP + P into ATP is driven by electron gradients established in the thylakoid membrane.





Noncyclic photophosphorylation (top) and cyclic photophosphorylation (bottom). These processes are better known as the light reactions. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

The above diagrams present the "old" view of photophosphorylation. We now know where the process occurs in the chloroplast, and can link that to chemiosmotic synthesis of ATP.



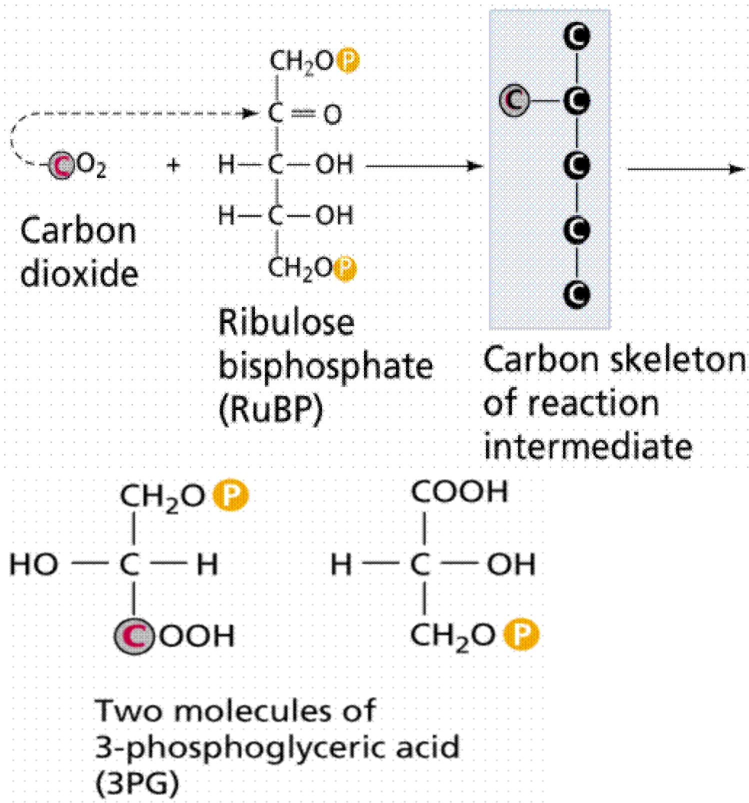
Chemiosmosis as it operates in photophosphorylation within a chloroplast. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Halobacteria, which grow in extremely salty water, are facultative aerobes, they can grow when oxygen is absent. Purple pigments, known as retinal (a pigment also found in the human eye) act similar to chlorophyll. The complex of retinal and membrane proteins is known as bacteriorhodopsin, which generates electrons which establish a proton gradient that powers an ADP-ATP pump, generating ATP from sunlight without chlorophyll. This supports the theory that chemiosmotic processes are universal in their ability to generate ATP.

Dark Reaction

Carbon-Fixing Reactions are also known as the Dark Reactions (or Light Independent Reactions). Carbon dioxide enters single-celled and aquatic autotrophs through no specialized structures, diffusing into the cells. Land plants must guard against drying out (desiccation) and so have evolved specialized structures known as stomata to allow gas to enter and leave the leaf. The Calvin Cycle occurs in the stroma of chloroplasts (where would it occur in a prokaryote?). Carbon dioxide is captured by the chemical ribulose biphosphate (RuBP). RuBP is a 5-C chemical. Six molecules of carbon dioxide enter the Calvin Cycle, eventually producing one molecule of glucose. The reactions in this process were worked out by Melvin Calvin (shown below).

The above image is from http://www-itg.lbl.gov/ImgLib/COLLECTIONS/BERKELEY-LAB/PEOPLE/INDIVIDUALS/index/BIOCHEM_523.html, Ernest OrlandoLawrence Berkeley National Laboratory. " One of the new areas, cultivated both in Donner and the Old Radiation Laboratory, was the study of organic compounds labeled with carbon-14. Melvin Calvin took charge of this work at the end of the war in order to provide raw materials for John Lawrence's researches and for his own study of photosynthesis. Using carbon-14, available in plenty from Hanford reactors, and the new techniques of ion exchange, paper chromatography, and radioautography, Calvin and his many associates mapped the complete path of carbon in photosynthesis. The accomplishment brought him the Nobel prize in chemistry in 1961. (The preceding information was excerpted from the text of the Fall 1981 issue of LBL Newsmagazine.) Citation Caption: LBL News, Vol.6, No.3, Fall 1981 Melvin Calvin shown with some of the apparatus he used to study the role of carbon in photosynthesis."

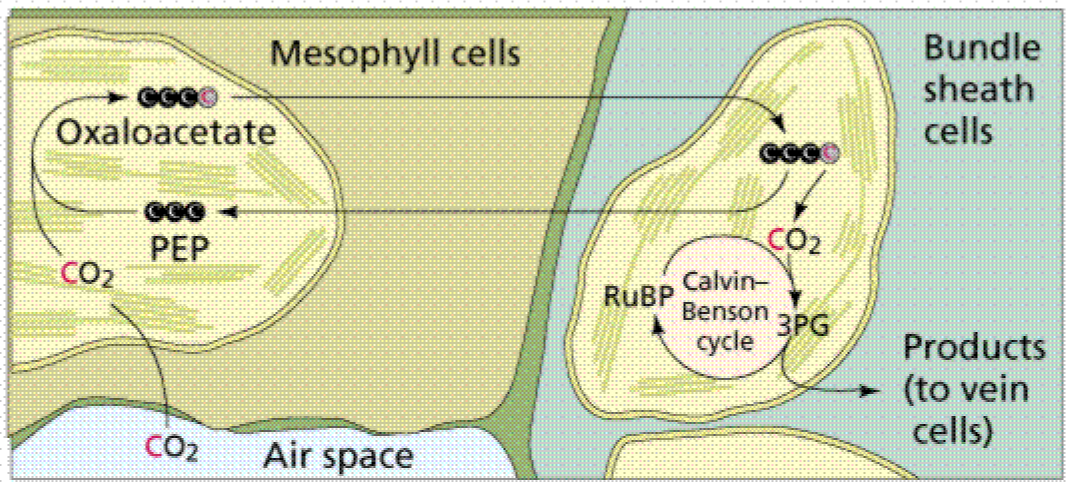


The first steps in the Calvin ccycle. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

The first stable product of the Calvin Cycle is phosphoglycerate (PGA), a 3-C chemical. The energy from ATP and NADPH energy carriers generated by the photosystems is used to attach phosphates to (phosphorylate) the PGA. Eventually there are 12 molecules of glyceraldehyde phosphate (also known as phosphoglyceraldehyde or PGAL, a 3-C), two of which are removed from the cycle to make a glucose. The remaining PGAL molecules are converted by ATP energy to reform 6 RuBP molecules, and thus start the cycle again. Remember the complexity of life, each reaction in this process, as in Kreb's Cycle, is catalyzed by a different reaction-specific enzyme.

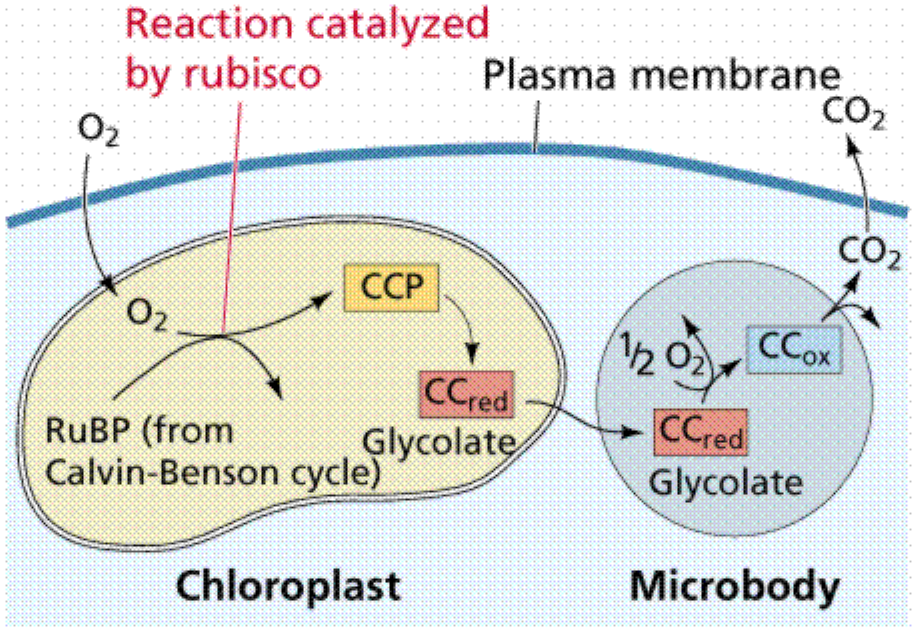
C-4 Pathway

Some plants have developed a preliminary step to the Calvin Cycle (which is also referred to as a C-3 pathway), this preamble step is known as C-4. While most C-fixation begins with RuBP, C-4 begins with a new molecule, phosphoenolpyruvate (PEP), a 3-C chemical that is converted into oxaloacetic acid (OAA, a 4-C chemical) when carbon dioxide is combined with PEP. The OAA is converted to Malic Acid and then transported from the mesophyll cell into the bundle-sheath cell, where OAA is broken down into PEP plus carbon dioxide. The carbon dioxide then enters the Calvin Cycle, with PEP returning to the mesophyll cell. The resulting sugars are now adjacent to the leaf veins and can readily be transported throughout the plant.



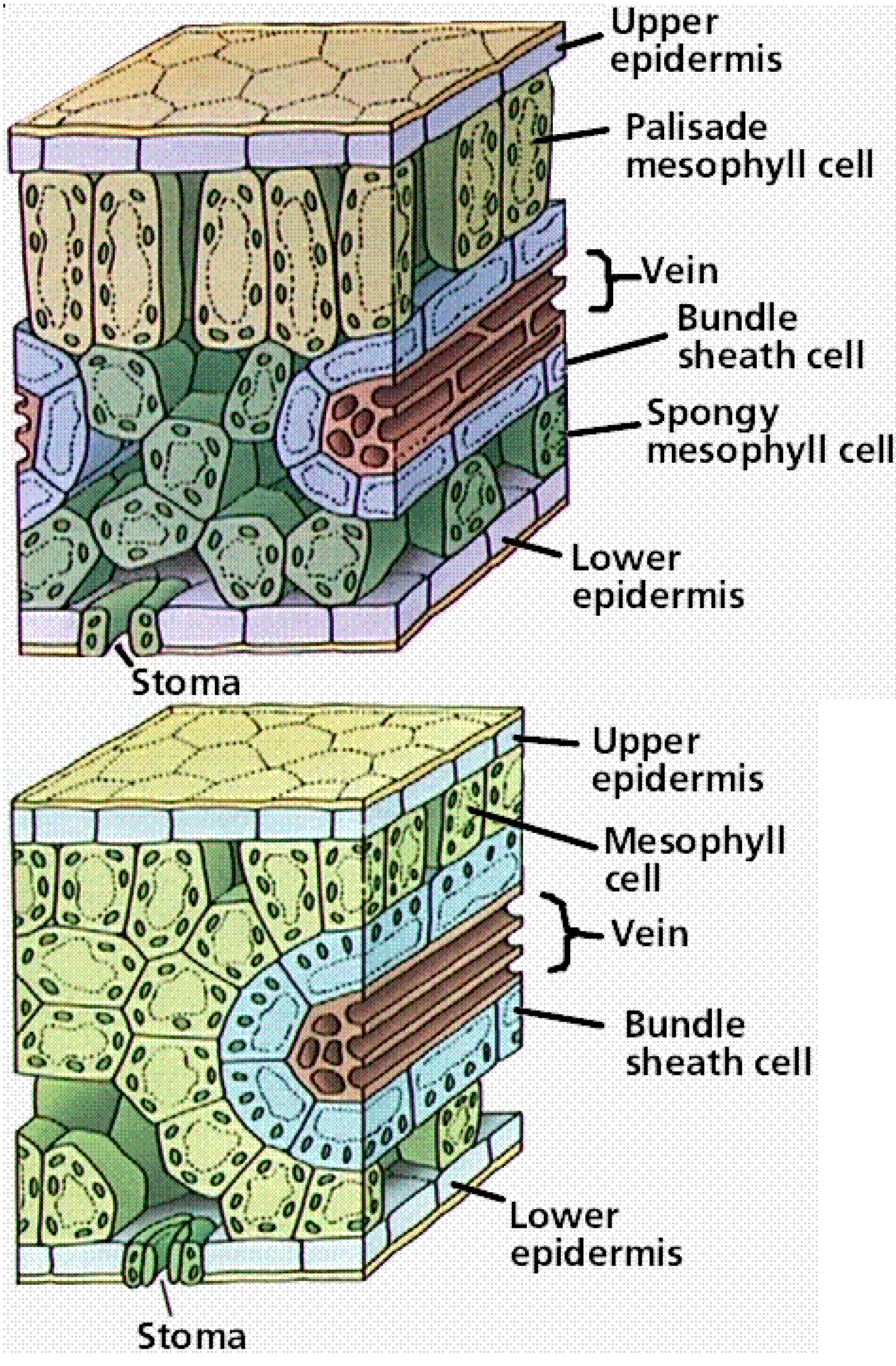
C-4 photosynthsis involves the separation of carbon fixation and carbohydrate systhesis in space and time. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

The capture of carbon dioxide by PEP is mediated by the enzyme PEP carboxylase, which has a stronger affinity for carbon dioxide than does RuBP carboxylase When carbon dioxide levels decline below the threshold for RuBP carboxylase, RuBP is catalyzed with oxygen instead of carbon dioxide. The product of that reaction forms glycolic acid, a chemical that can be broken down by photorespiration, producing neither NADH nor ATP, in effect dismantling the Calvin Cycle. C-4 plants, which often grow close together, have had to adjust to decreased levels of carbon dioxide by artificially raising the carbon dioxide concentration in certain cells to prevent photorespiration. C-4 plants evolved in the tropics and are adapted to higher temperatures than are the C-3 plants found at higher latitudes. Common C-4 plants include crabgrass, corn, and sugar cane. Note that OAA and Malic Acid also have functions in other processes, thus the chemicals would have been present in all plants, leading scientists to hypothesize that C-4 mechanisms evolved several times independently in response to a similar environmental condition, a type of evolution known as convergent evolution.



Photorespiration. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

We can see anatomical differences between C3 and C4 leaves.



Leaf anatomy of a C3 (top) and C4 (bottom) plant. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

The Carbon Cycle Plants may be viewed as carbon sinks, removing carbon dioxide from the atmosphere and oceans by fixing it into organic chemicals. Plants also produce some carbon dioxide by their respiration, but this is quickly used by photosynthesis. Plants also convert energy from light into chemical energy of C-C covalent bonds. Animals are carbon dioxide producers that derive their energy from carbohydrates and other chemicals produced by plants by the process of photosynthesis.

The balance between the plant carbon dioxide removal and animal carbon dioxide generation is equalized also by the formation of carbonates in the oceans. This removes excess carbon dioxide from the air and water (both of which are in equilibrium with regard to carbon dioxide). Fossil fuels, such as petroleum and coal, as well as more recent fuels such as peat and wood generate carbon dioxide when burned. Fossil fuels are formed ultimately by organic processes, and represent also a tremendous carbon sink. Human activity has greatly increased the concentration of carbon dioxide in air. This increase has led to global warming, an increase in temperatures around the world, the Greenhouse Effect. The increase in carbon dioxide and other pollutants in the air has also led to acid rain, where water falls through polluted air and chemically combines with carbon dioxide, nitrous oxides, and sulfur oxides, producing rainfall with pH as low as 4. This results in fish kills and changes in soil pH which can alter the natural vegetation and uses of the land. The Global Warming problem can lead to melting of the ice caps in Greenland and Antarctica, raising sea-level as much as 120 meters. Changes in sea-level and temperature would affect climate changes, altering belts of grain production and rainfall patterns.

INTRODUCTION TO GENETICS

For much of human history people were unaware of the scientific details of how babies were conceived and how heredity worked. Clearly they were conceived, and clearly there was some hereditary connection between parents and children, but the mechanisms were not readily apparent. The Greek philosophers had a variety of ideas: Theophrastus proposed that male flowers caused female flowers to ripen; Hippocrates speculated that "seeds" were produced by various body parts and transmitted to offspring at the time of conception, and Aristotle thought that male and female semen mixed at conception. Aeschylus, in 458 BC, proposed the male as the parent, with the female as a "nurse for the young life sown within her".

During the 1700s, Dutch microscopist Anton van Leeuwenhoek (1632-1723) discovered "animalcules" in the sperm of humans and other animals. Some scientists speculated they saw a "little man" (homunculus) inside each sperm. These scientists formed a school of thought known as the "spermists". They contended the only contributions of the female to the next generation were the womb in which the homunculus grew, and prenatal influences of the womb. An opposing school of thought, the ovists, believed that the future human was in the egg, and that sperm merely stimulated the growth of the egg. Ovists thought women carried eggs containing boy and girl children, and that the gender of the offspring was determined well before conception.

Pangenesis was an idea that males and females formed "pangenes" in every organ. These pangenes subsequently moved through their blood to the genitals and then to the children. The concept originated with the ancient Greeks and influenced biology until little over 100 years ago. The terms "blood relative", "full-blooded", and "royal blood" are relicts of pangenesis. Francis Galton, Charles Darwin's cousin, experimentally tested and disproved pangenesis during the 1870s.

Blending theories of inheritance supplanted the spermists and ovists during the 19th century. The mixture of sperm and egg resulted in progeny that were a "blend" of two parents' characteristics. Sex cells are known collectively as gametes (*gamos*, Greek, meaning marriage). According to the blenders, when a black furred animal mates with white furred animal, you would expect all resulting progeny would be gray (a color intermediate between black and white). This is often not the case. Blending theories ignore characteristics skipping a generation. Charles Darwin had to deal with the implications of blending in his theory of evolution. He was forced to recognize blending as not important (or at least not the major principle), and suggest that science of the mid-1800s had not yet got the correct answer. That answer came from a contemporary, Gregor Mendel, although Darwin apparently never knew of Mendel's work.

The Monk and his peas

An Austrian monk, Gregor Mendel, developed the fundamental principles that would become the modern science of genetics. Mendel demonstrated that heritable properties are parceled out in discrete units, independently inherited. These eventually were termed genes.

Gregor Mendel, the Austrian monk who figured out the rules of hereity. The above photo is from http://www.open.cz/project/tourist/person/photo.htm.

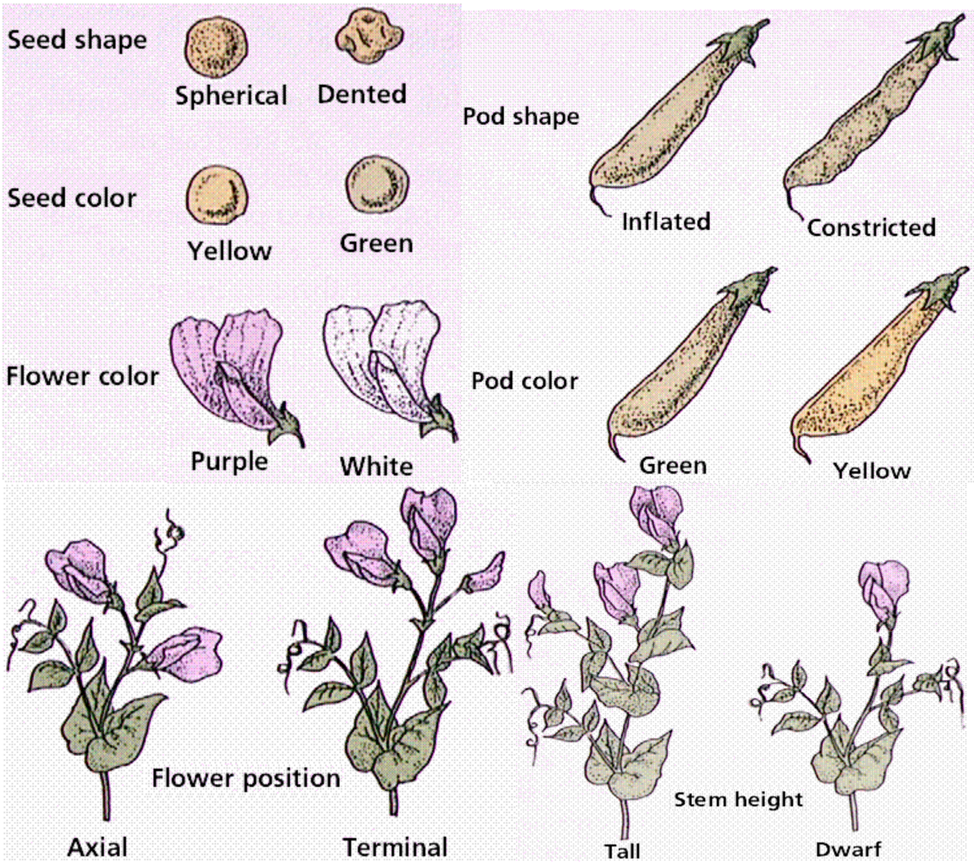
Mendel reasoned an organism for genetic experiments should have:

a number of different traits that can be studied

plant should be self-fertilizing and have a flower structure that limits accidental contact

offspring of self-fertilized plants should be fully fertile.

Mendel's experimental organism was a common garden pea (*Pisum sativum*), which has a flower that lends itself to self-pollination. The male parts of the flower are termed the anthers. They produce pollen, which contains the male gametes (sperm). The female parts of the flower are the stigma, style, and ovary. The egg (female gamete) is produced in the ovary. The process of pollination (the transfer of pollen from anther to stigma) occurs prior to the opening of the pea flower. The pollen grain grows a pollen tube which allows the sperm to travel through the stigma and style, eventually reaching the ovary. The ripened ovary wall becomes the fruit (in this case the pea pod). Most flowers allow cross-pollination, which can be difficult to deal with in genetic studies if the male parent plant is not known. Since pea plants are self-pollinators, the genetics of the parent can be more easily understood. Peas are also self-compatible, allowing self-fertilized embryos to develop as readily as out-fertilized embryos. Mendel tested all 34 varieties of peas available to him through seed dealers. The garden peas were planted and studied for eight years. Each character studied had two distinct forms, such as tall or short plant height, or smooth or wrinkled seeds. Mendel's experiments used some 28,000 pea plants.



Some of Mendel's traits as expressed in garden peas. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Mendel's contribution was unique because of his methodical approach to a definite problem, use of clear-cut variables and application of mathematics (statistics) to the problem. Gregor Using pea plants and statistical methods, Mendel was able to demonstrate that traits were passed from each parent to their offspring through the inheritance of genes.

Mendel's work showed:

Each parent contributes one factor of each trait shown in offspring.

The two members of each pair of factors segregate from each other during gamete formation.

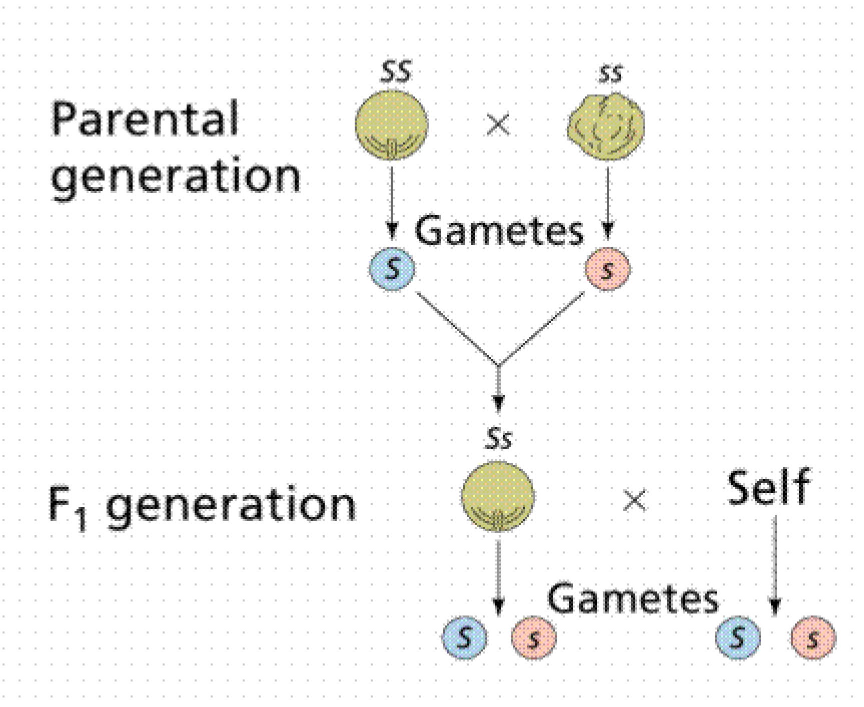
The blending theory of inheritance was discounted.

Males and females contribute equally to the traits in their offspring.

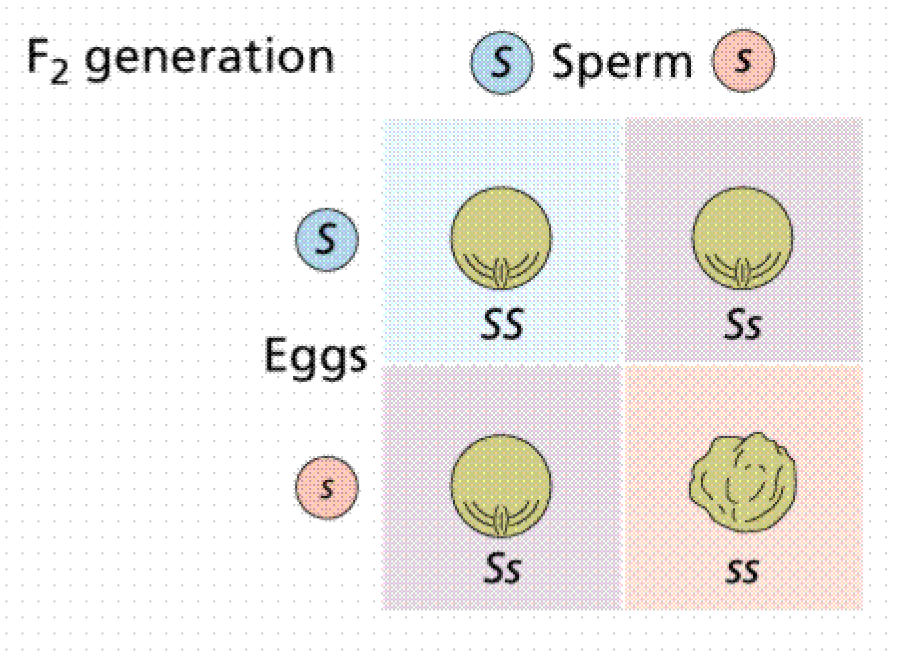
Acquired traits are not inherited.

Principle of Segregation

Mendel studied the inheritance of seed shape first. A cross involving only one trait is referred to as a monohybrid cross. Mendel crossed pure-breeding (also referred to as true-breeding) smooth-seeded plants with a variety that had always produced wrinkled seeds (60 fertilizations on 15 plants). All resulting seeds were smooth. The following year, Mendel planted these seeds and allowed them to self-fertilize. He recovered 7324 seeds: 5474 smooth and 1850 wrinkled. To help with record keeping, generations were labeled and numbered. The parental generation is denoted as the P1 generation. The offspring of the P1 generation are the F1 generation (first filial). The self-fertilizing F1 generation produced the F2 generation (second filial).



Inheritance of two alleles, S and s, in peas. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.



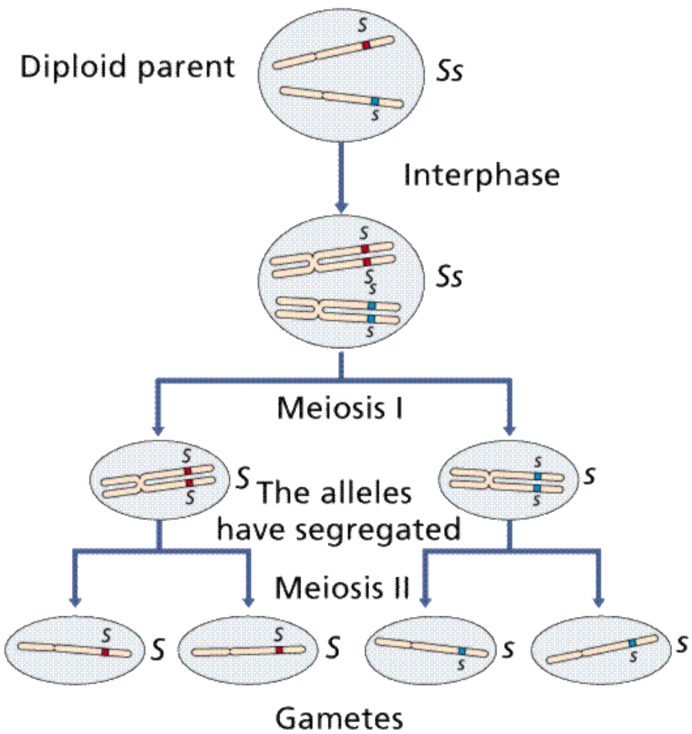
Punnett square explaining the behavior of the S and s alleles. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

P1: smooth X wrinkled

F1 : all smooth

F2 : 5474 smooth and 1850 wrinkled

Meiosis, a process unknown in Mendel's day, explains how the traits are inherited.



The inheritance of the S and s alleles explained in light of meiosis. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Mendel studied seven traits which appeared in two discrete forms, rather than continuous characters which are often difficult to distinguish. When "true-breeding" tall plants were crossed with "true-breeding" short plants, all of the offspring were tall plants. The parents in the cross were the P1 generation, and the offspring represented the F1 generation. The trait referred to as tall was considered dominant, while short was recessive. Dominant traits were defined by Mendel as those which appeared in the F1 generation in crosses between true-breeding strains. Recessives were those which "skipped" a generation, being expressed only when the dominant trait is absent. Mendel's plants exhibited complete dominance, in which the phenotypic expression of alleles was either dominant or recessive, not "in between".

When members of the F1 generation were crossed, Mendel recovered mostly tall offspring, with some short ones also occurring. Upon statistically analyzing the F2 generation, Mendel determined the ratio of tall to short plants was approximately 3:1. Short plants have skipped the F1 generation, and show up in the F2 and succeeding generations. Mendel concluded that the traits under study were governed by discrete (separable) factors. The factors were inherited in pairs, with each generation having a pair of trait factors. We now refer to these trait factors as alleles. Having traits inherited in pairs allows for the observed phenomena of traits "skipping" generations.

Summary of Mendel's Results:

The F1 offspring showed only one of the two parental traits, and always the same trait.

Results were always the same regardless of which parent donated the pollen (was male).

The trait not shown in the F1 reappeared in the F2 in about 25% of the offspring.

Traits remained unchanged when passed to offspring: they did not blend in any offspring but behaved as separate units.

Reciprocal crosses showed each parent made an equal contribution to the offspring.

Mendel's Conclusions:

Evidence indicated factors could be hidden or unexpressed, these are the recessive traits.

The term phenotype refers to the outward appearance of a trait, while the term genotype is used for the genetic makeup of an organism.

Male and female contributed equally to the offsprings' genetic makeup: therefore the number of traits was probably two (the simplest solution).

Upper case letters are traditionally used to denote dominant traits, lower case letters for recessives.

Mendel reasoned that factors must segregate from each other during gamete formation (remember, meiosis was not yet known!) to retain the number of traits at 2. The Principle of Segregation proposes the separation of paired factors during gamete formation, with each gamete receiving one or the other factor, usually not both. Organisms carry two alleles for every trait. These traits separate during the formation of gametes.

A hypertext version (in German or English, annotated also available) of Mendel's 1865 paper is available by clicking here.

Dihybrid Crosses

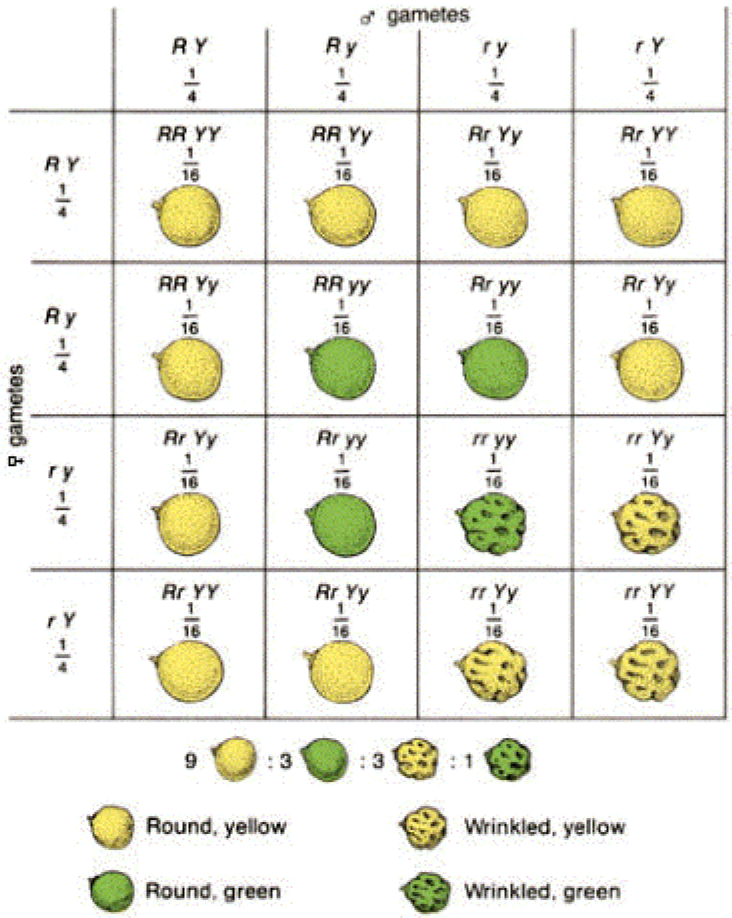
When Mendel considered two traits per cross (dihybrid, as opposed to single-trait-crosses, monohybrid), The resulting (F2) generation did not have 3:1 dominant:recessive phenotype ratios. The two traits, if considered to inherit independently, fit into the principle of segregation. Instead of 4 possible genotypes from a monohybrid cross, dihybrid crosses have as many as 16 possible genotypes.

Mendel realized the need to conduct his experiments on more complex situations. He performed experiments tracking two seed traits: shape and color. A cross concerning two traits is known as a dihybrid cross.

Crosses With Two Traits

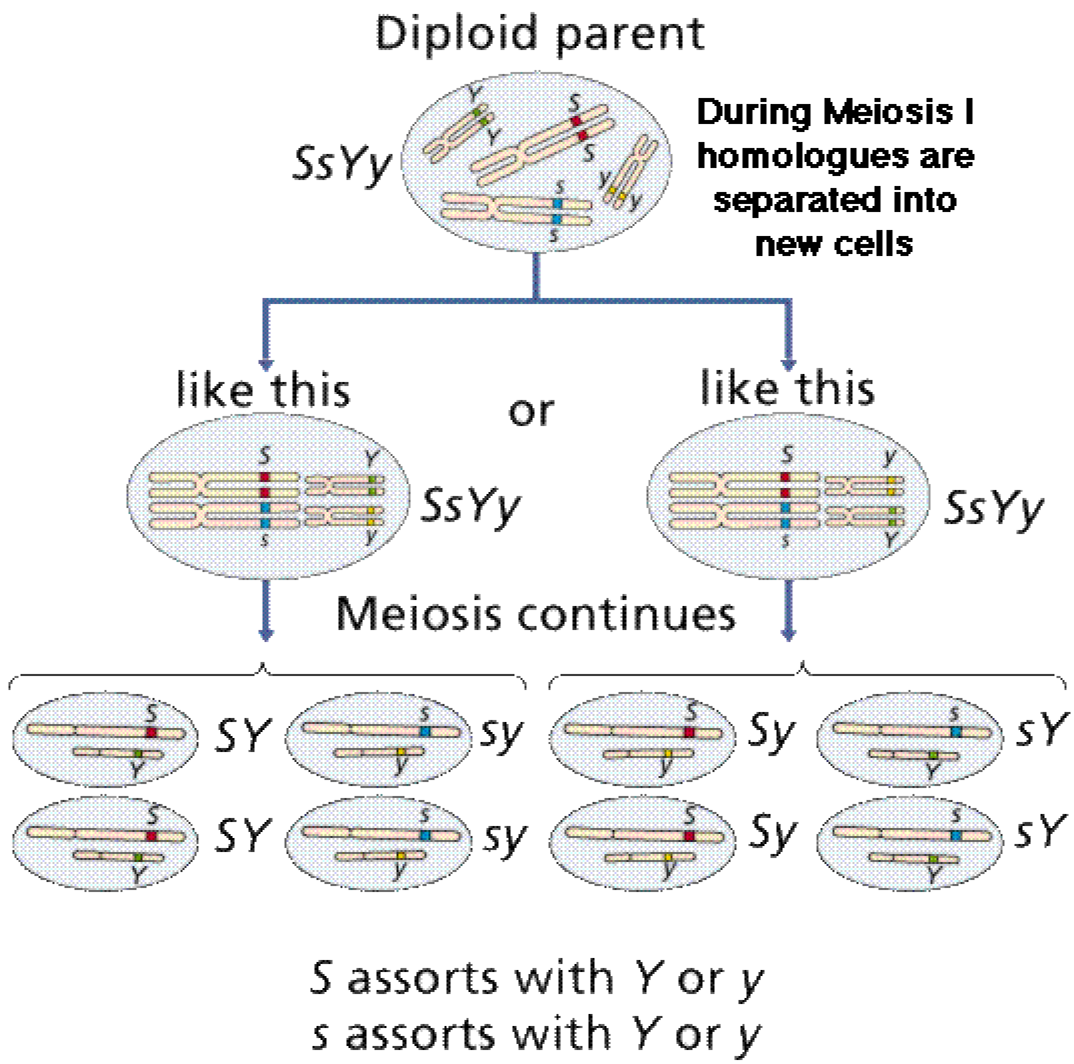
Smooth seeds (S) are dominant over wrinkled (s) seeds.

Yellow seed color (Y) is dominant over green (g).



Inheritance of two traits simultaneously, a dihybrid cross. The above graphic is from the Genetics pages at McGill University (http://www.mcgill.ca/nrs/dihyb2.gif).

Again, meiosis helps us understand the behavior of alleles.



The inheritance of two traits on different chromosomes can be explained by meiosis. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Methods, Results, and Conclusions

Mendel started with true-breeding plants that had smooth, yellow seeds and crossed them with true-breeding plants having green, wrinkled seeds. All seeds in the F1 had smooth yellow seeds. The F2 plants self-fertilized, and produced four phenotypes:

315 smooth yellow

108 smooth green

101 wrinkled yellow

32 wrinkled green

Mendel analyzed each trait for separate inheritance as if the other trait were not present.The 3:1 ratio was seen separately and was in accordance with the Principle of Segregation. The segregation of S and s alleles must have happened independently of the segregation of Y and y alleles. The chance of any gamete having a Y is 1/2; the chance of any one gamete having a S is 1/2.The chance of a gamete having both Y and S is the product of their individual chances (or 1/2 X 1/2 = 1/4). The chance of two gametes forming any given genotype is 1/4 X 1/4 (remember, the product of their individual chances). Thus, the Punnett Square has 16 boxes. Since there are more possible combinations to produce a smooth yellow phenotype (SSYY, SsYy, SsYY, and SSYy), that phenotype is more common in the F2.

From the results of the second experiment, Mendel formulated the Principle of Independent Assortment -- that when gametes are formed, alleles assort independently. If traits assort independent of each other during gamete formation, the results of the dihybrid cross can make sense. Since Mendel's time, scientists have discovered chromosomes and DNA. We now interpret the Principle of Independent Assortment as alleles of genes on different chromosomes are inherited independently during the formation of gametes. This was not known to Mendel.

Punnett squares deal only with probability of a genotype showing up in the next generation. Usually if enough offspring are produced, Mendelian ratios will also be produced.

Step 1 **-** definition of alleles and determination of dominance.

Step 2 **-** determination of alleles present in all different types of gametes.

Step 3 **-** construction of the square.

Step 4 **-** recombination of alleles into each small square.

Step 5 **-** Determination of Genotype and Phenotype ratios in the next generation.

Step 6 **-** Labeling of generations, for example P1, F1, etc.

While answering genetics problems, there are certain forms and protocols that will make unintelligible problems easier to do. The term "true-breeding strain" is a code word for homozygous. Dominant alleles are those that show up in the next generation in crosses between two different "true-breeding strains". The key to any genetics problem is the recessive phenotype (more properly the phenotype that represents the recessive genotype). It is that organism whose genotype can be determined by examination of the phenotype. Usually homozygous dominant and heterozygous individuals have identical phenotypes (although their genotypes are different). This becomes even more important in dihybrid crosses.

Mutations

Hugo de Vries, one of three turn-of-the-century scientists who rediscovered the work of Mendel, recognized that occasional abrupt, sudden changes occurred in the patterns of inheritance in the primrose plant. These sudden changes he termed mutations. De Vries proposed that new alleles arose by mutations. Charles Darwin, in his **Origin of Species**, was unable to describe how heritable changes were passed on to subsequent generations, or how new adaptations arose. Mutations provided answers to problems of the appearance of novel adaptations. The patterns of Mendelian inheritance explained the perseverance of rare traits in organisms, all of which increased variation, as you recall that was a major facet of Darwin's theory.

Mendel's work was published in 1866 but not recognized until the early 1900s when three scientists independently verified his principles, more than twenty years after his death. Ignored by the scientific community during his lifetime, Mendel's work is now a topic enjoyed by generations of biology students (;))

Genetic Terms

Definitions of terms. While we are discussing Mendel, we need to understand the context of his times as well as how his work fits into the modern science of genetics.

Gene - a unit of inheritance that usually is directly responsible for one trait or character.

Allele - an alternate form of a gene. Usually there are two alleles for every gene, sometimes as many a three or four.

Homozygous - when the two alleles are the same.

Heterozygous - when the two alleles are different, in such cases the dominant allele is expressed.

Dominant - a term applied to the trait (allele) that is expressed irregardless of the second allele.

Recessive - a term applied to a trait that is only expressed when the second allele is the same (e.g. short plants are homozygous for the recessive allele).

Phenotype - the physical expression of the allelic composition for the trait under study.

Genotype - the allelic composition of an organism.

Punnett squares - probability diagram illustrating the possible offspring of a mating.

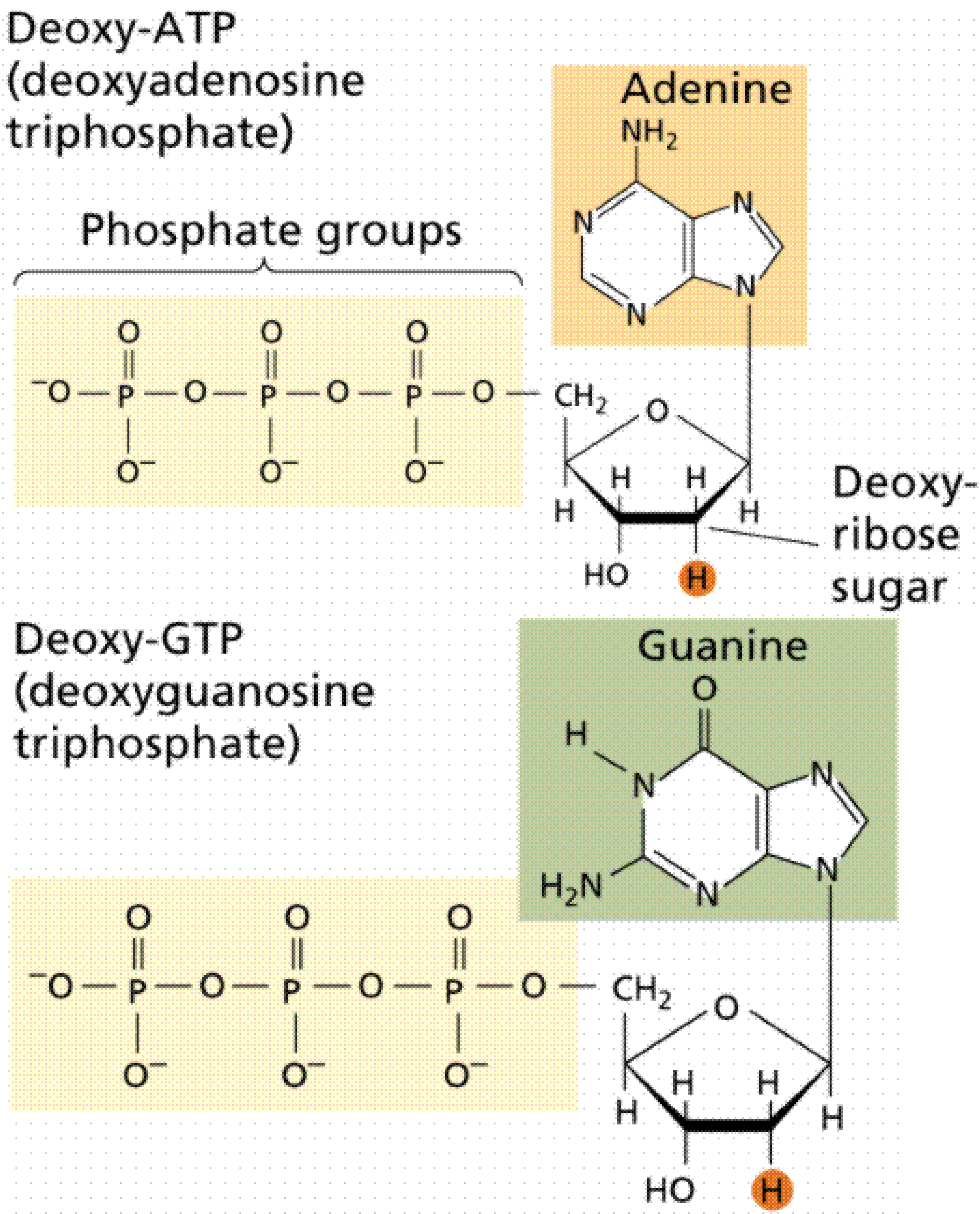
DNA AND MOLECULAR GENETICS

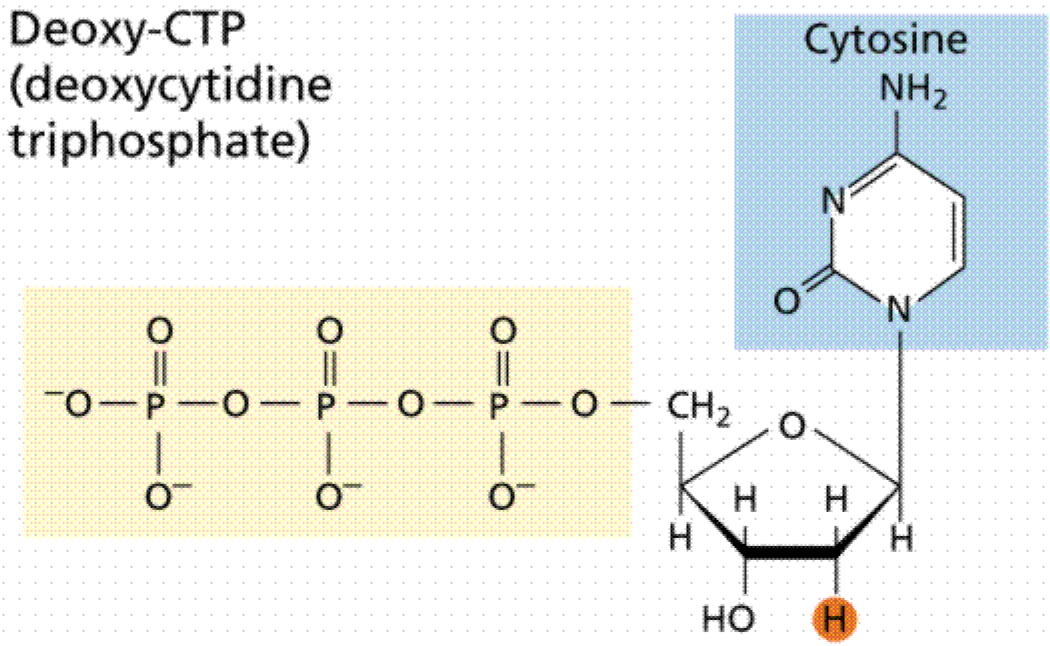
The physical carrier of inheritance

While the period from the early 1900s to World War II has been considered the "golden age" of genetics, scientists still had not determined that DNA, and not protein, was the hereditary material. However, during this time a great many genetic discoveries were made and the link between genetics and evolution was made.

Friedrich Meischer in 1869 isolated DNA from fish sperm and the pus of open wounds. Since it came from nuclei, Meischer named this new chemical, nuclein. Subsequently the name was changed to nucleic acid and lastly to deoxyribonucleic acid (DNA). Robert Feulgen, in 1914, discovered that fuchsin dye stained DNA. DNA was then found in the nucleus of all eukaryotic cells.

During the 1920s, biochemist P.A. Levene analyzed the components of the DNA molecule. He found it contained four nitrogenous bases: cytosine, thymine, adenine, and guanine; deoxyribose sugar; and a phosphate group. He concluded that the basic unit (nucleotide) was composed of a base attached to a sugar and that the phosphate also attached to the sugar. He (unfortunately) also erroneously concluded that the proportions of bases were equal and that there was a tetranucleotide that was the repeating structure of the molecule. The nucleotide, however, remains as the fundemantal unit (monomer) of the nucleic acid polymer. There are four nucleotides: those with cytosine (C), those with guanine (G), those with adenine (A), and those with thymine (T).





Molecular structure of three nirogenous bases. In this diagram there are three phosphates instead of the single phosphate found in the normal nucleotide. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

During the early 1900s, the study of genetics began in earnest: the link between Mendel's work and that of cell biologists resulted in the chromosomal theory of inheritance; Garrod proposed the link between genes and "inborn errors of metabolism"; and the question was formed: what is a gene? The answer came from the study of a deadly infectious disease: pneumonia. During the 1920s Frederick Griffith studied the difference between a disease-causing strain of the pneumonia causing bacteria (*Streptococcus peumoniae*) and a strain that did not cause pneumonia. The pneumonia-causing strain (the S strain) was surrounded by a capsule. The other strain (the R strain) did not have a capsule and also did not cause pneumonia. Frederick Griffith (1928) was able to induce a nonpathogenic strain of the bacterium *Streptococcus pneumoniae* to become pathogenic. Griffith referred to a transforming factor that caused the non-pathogenic bacteria to become pathogenic. Griffith injected the different strains of bacteria into mice. The S strain killed the mice; the R strain did not. He further noted that if heat killed S strain was injected into a mouse, it did not cause pneumonia. When he combined heat-killed S with Live R and injected the mixture into a mouse (remember neither alone will kill the mouse) that the mouse developed pneumonia and died. Bacteria recovered from the mouse had a capsule and killed other mice when injected into them!

Hypotheses:

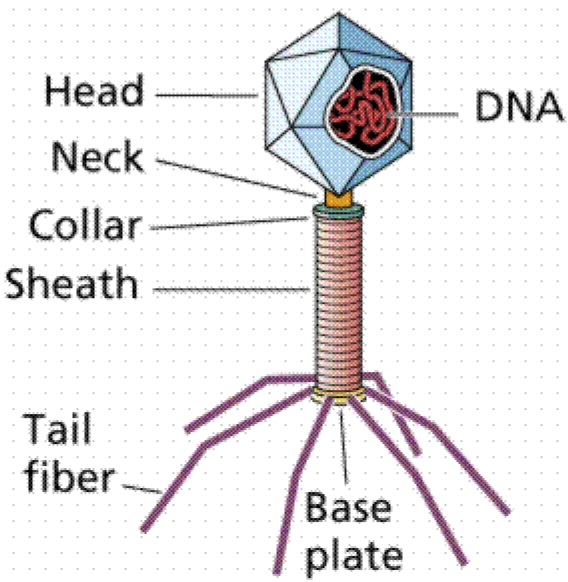
1. The dead S strain had been reanimated/resurrected.

2. The Live R had been transformed into Live S by some "transforming factor".

Further experiments led Griffith to conclude that number 2 was correct.

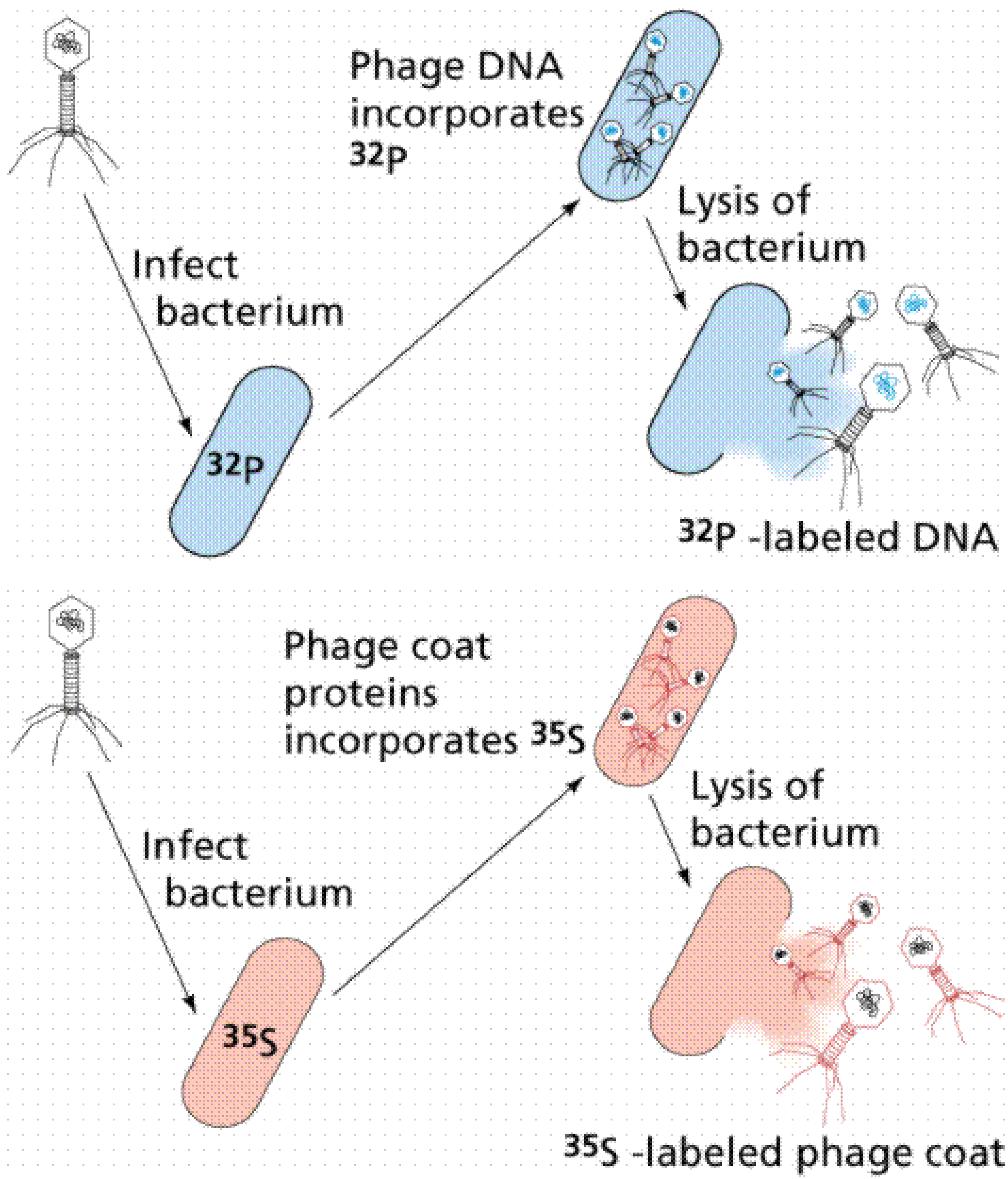
In 1944, Oswald Avery, Colin MacLeod, and Maclyn McCarty revisited Griffith's experiment and concluded the transforming factor was DNA. Their evidence was strong but not totally conclusive. The then-current favorite for the hereditary material was protein; DNA was not considered by many scientists to be a strong candidate.

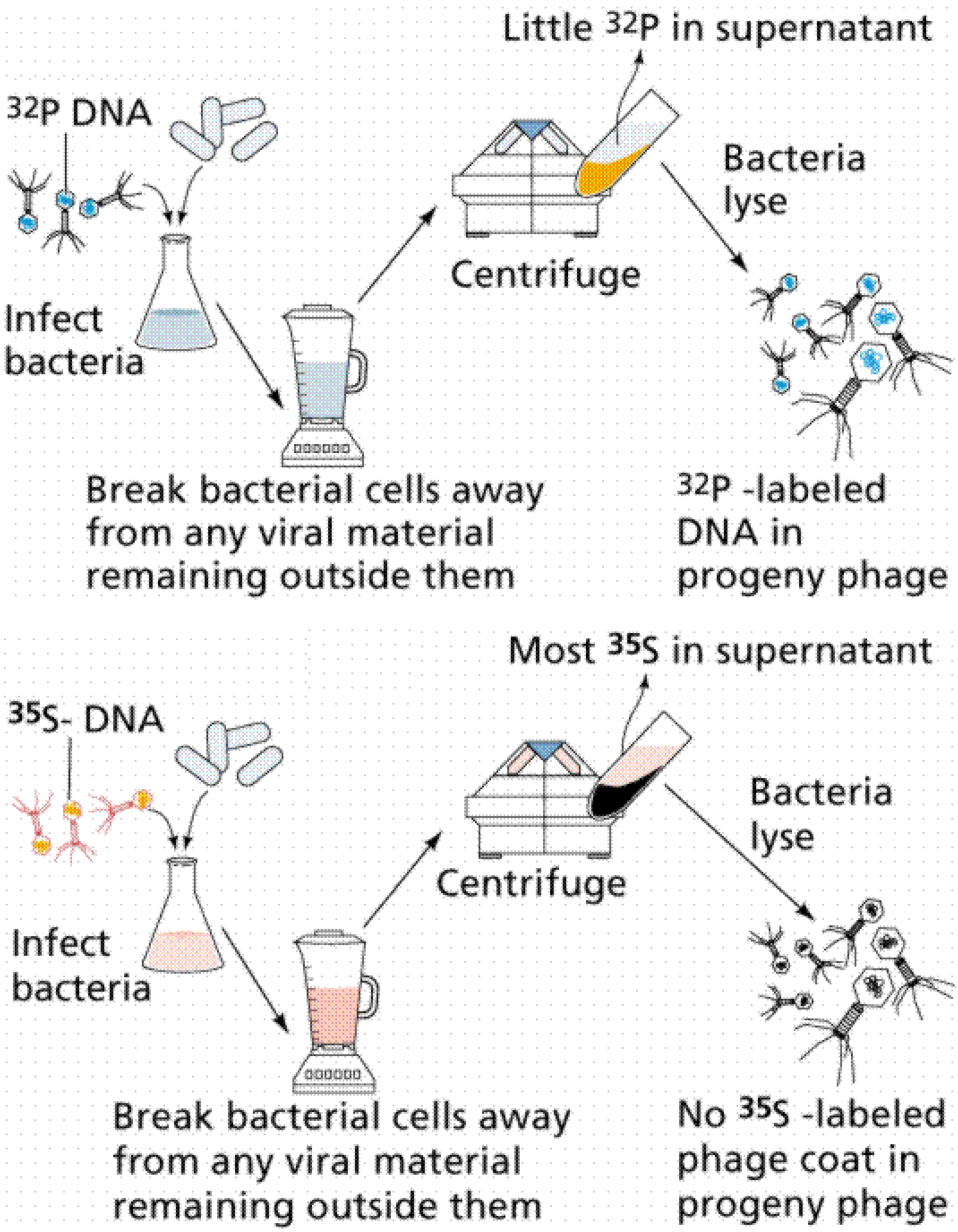
The breakthrough in the quest to determine the hereditary material came from the work of Max Delbruck and Salvador Luria in the 1940s. Bacteriophage are a type of virus that attacks bacteria, the viruses that Delbruck and Luria worked with were those attacking *Escherichia coli*, a bacterium found in human intestines. Bacteriophages consist of protein coats covering DNA. Bacteriophages infect a cell by injecting DNA into the host cell. This viral DNA then "disappears" while taking over the bacterial machinery and beginning to make new virus instead of new bacteria. After 25 minutes the host cell bursts, releasing hundreds of new bacteriophage. Phages have DNA and protein, making them ideal to resolve the nature of the hereditary material.



Structure of a bacteriophage virus. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

In 1952, Alfred D. Hershey and Martha Chase (click the link to view details of their experiment) conducted a series of experiments to determine whether protein or DNA was the hereditary material. By labeling the DNA and protein with different (and mutually exclusive) radioisotopes, they would be able to determine which chemical (DNA or protein) was getting into the bacteria. Such material must be the hereditary material (Griffith's transforming agent). Since DNA contains Phosphorous (P) but no Sulfur (S), they tagged the DNA with radioactive Phosphorous-32. Conversely, protein lacks P but does have S, thus it could be tagged with radioactive Sulfur-35. Hershey and Chase found that the radioactive S remained outside the cell while the radioactive P was found inside the cell, indicating that DNA was the physical carrier of heredity.


Phage DNA
incorporates
32P
Infect
bacterium
32P
Lysis of
bacterium
32P -labeled DNA
Phage coat
proteins
incorporates 35S
Infect
bacterium
35S
Lysis of
bacterium
35S -labeled phage coat

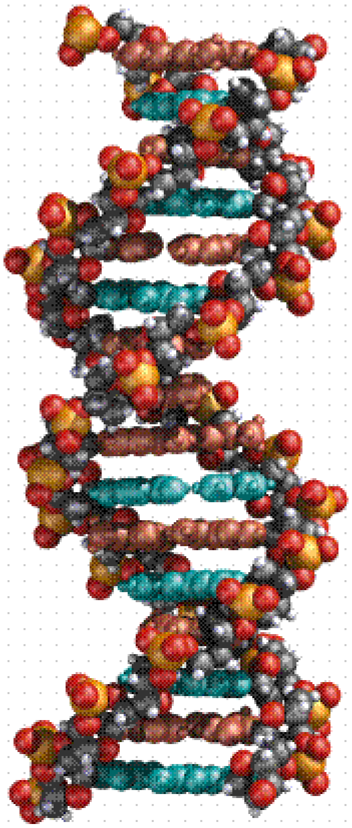


Diagrams illlustrating the Hershey and Chase experiment that supported DNA as the hereditary material while it also showed protein was NOT the hereditary material. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

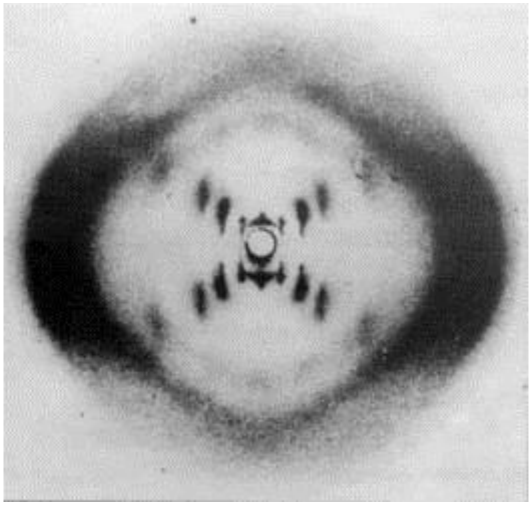
The Structure of DNA | Back to Top

Erwin Chargaff analyzed the nitrogenous bases in many different forms of life, concluding that the amount of purines does not always equal the amount of pyrimidines (as proposed by Levene). DNA had been proven as the genetic material by the Hershey-Chase experiments, but how DNA served as genes was not yet certain. DNA must carry information from parent cell to daughter cell. It must contain information for replicating itself. It must be chemically stable, relatively unchanging. However, it must be capable of mutational change. Without mutations there would be no process of evolution.

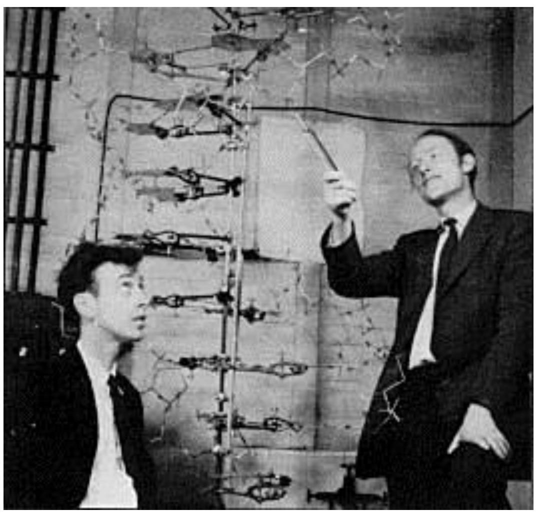
Many scientists were interested in deciphering the structure of DNA, among them were Francis Crick, James Watson, Rosalind Franklin, and Maurice Wilkens. Watson and Crick gathered all available data in an attempt to develop a model of DNA structure. Franklin took X-ray diffraction photomicrographs of crystalline DNA extract, the key to the puzzle. The data known at the time was that DNA was a long molecule, proteins were helically coiled (as determined by the work of Linus Pauling), Chargaff's base data, and the x-ray diffraction data of Franklin and Wilkens.



Ball and stick model of DNA. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

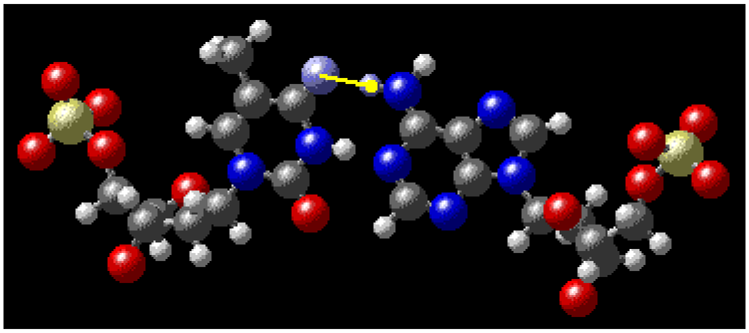


X-ray diffraction photograph of the DNA double helix. Image from the Internet.

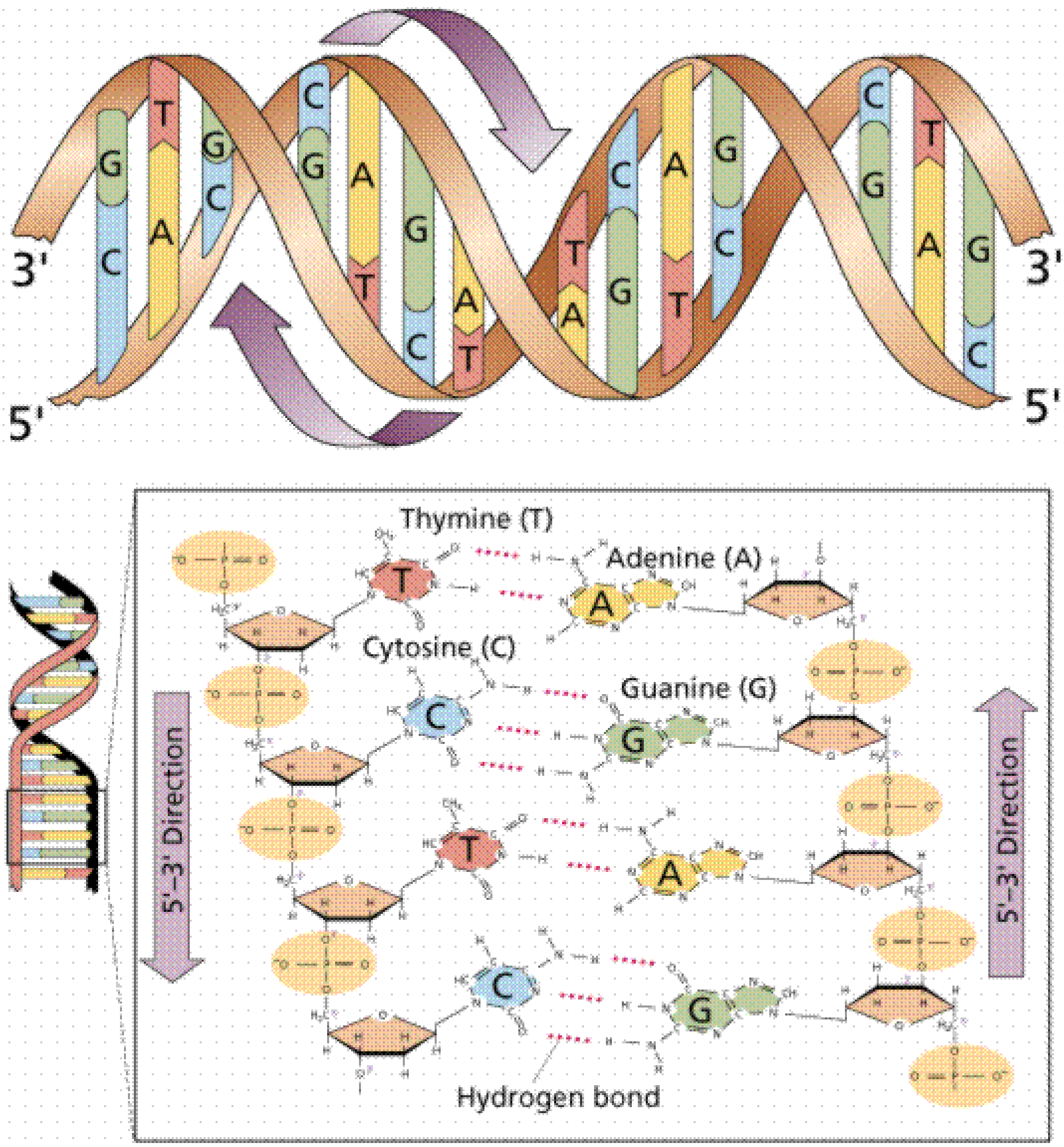


James Watson (L) and Francis Crick (R), and the model they built of the structure of DNA. Image from the Internet.

DNA is a double helix, with bases to the center (like rungs on a ladder) and sugar-phosphate units along the sides of the helix (like the sides of a twisted ladder). The strands are complementary (deduced by Watson and Crick from Chargaff's data, A pairs with T and C pairs with G, the pairs held together by hydrogen bonds). Notice that a double-ringed purine is always bonded to a single ring pyrimidine. Purines are Adenine (A) and Guanine (G). We have encountered Adenosine triphosphate (ATP) before, although in that case the sugar was ribose, whereas in DNA it is deoxyribose. Pyrimidines are Cytosine (C) and Thymine (T). The bases are complementary, with A on one side of the molecule you only get T on the other side, similarly with G and C. If we know the base sequence of one strand we know its complement.



Rendering of two complementary bases on a DNA molecule. Image prepared using MacMolecule.

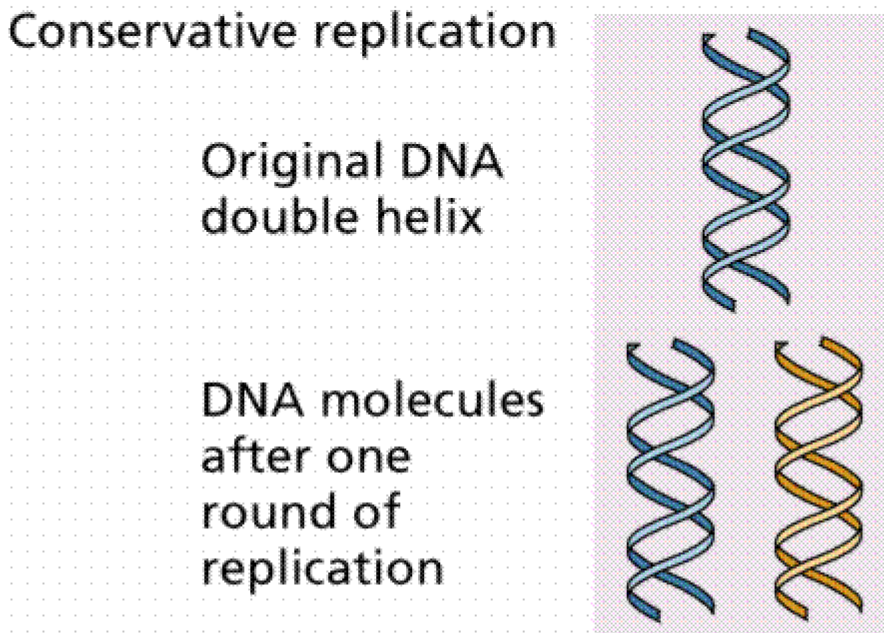


The ribbon model of DNA. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

DNA Replication

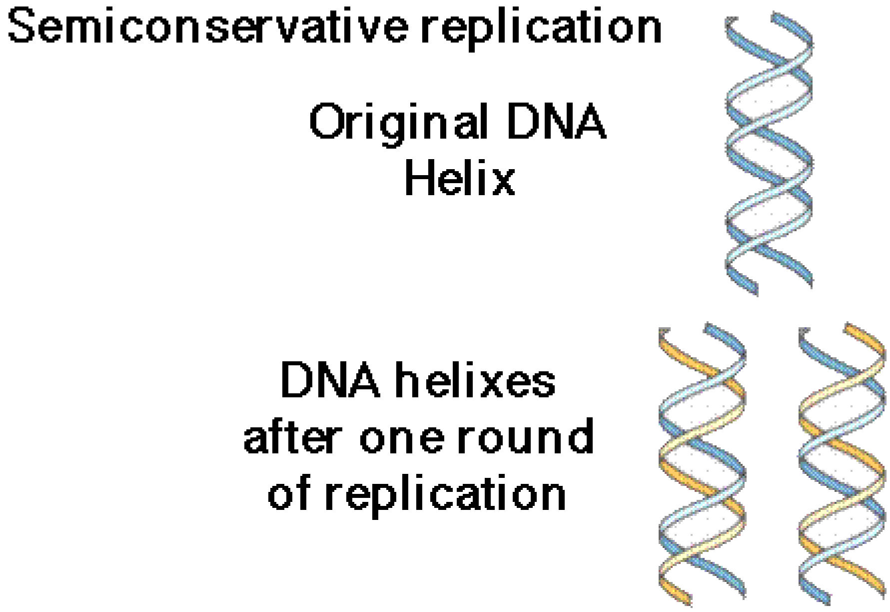
DNA was proven as the hereditary material and Watson et al. had deciphered its structure. What remained was to determine how DNA copied its information and how that was expressed in the phenotype. Matthew Meselson and Franklin W. Stahl designed an experiment to determine the method of DNA replication. Three models of replication were considered likely.

1. **Conservative replication** would somehow produce an entirely new DNA strand during replication.



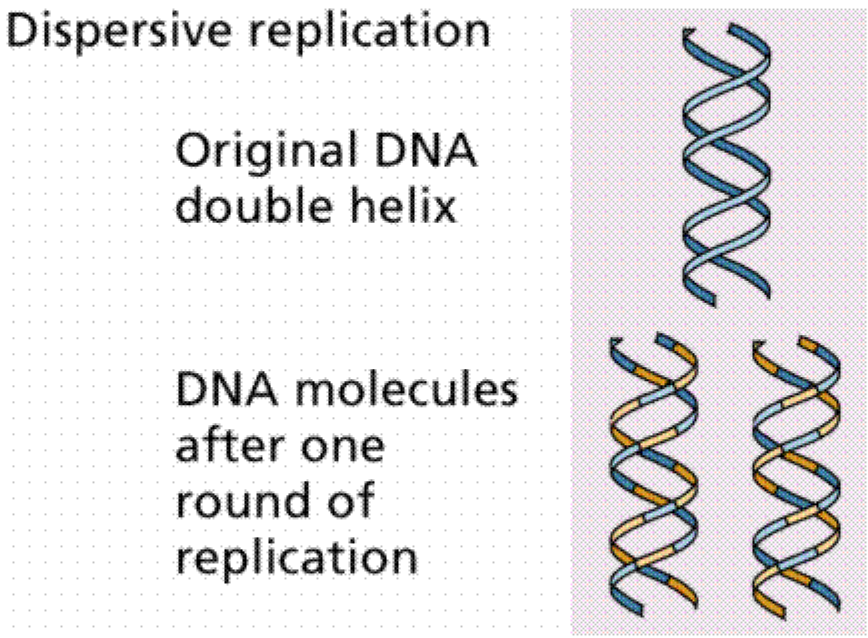
Conservative model of DNA replication. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

2. **Semiconservative replication** would produce two DNA molecules, each of which was composed of one-half of the parental DNA along with an entirely new complementary strand. In other words the new DNA would consist of one new and one old strand of DNA. The existing strands would serve as complementary templates for the new strand.



The semiconservative model of DNA structure. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

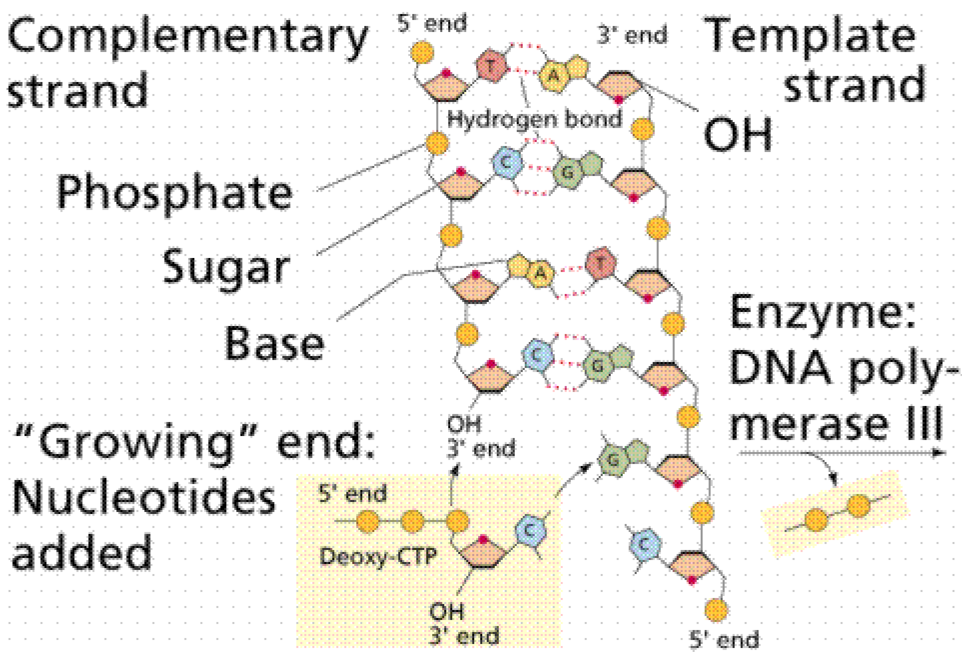
3. **Dispersive replication** involved the breaking of the parental strands during replication, and somehow, a reassembly of molecules that were a mix of old and new fragments on each strand of DNA.

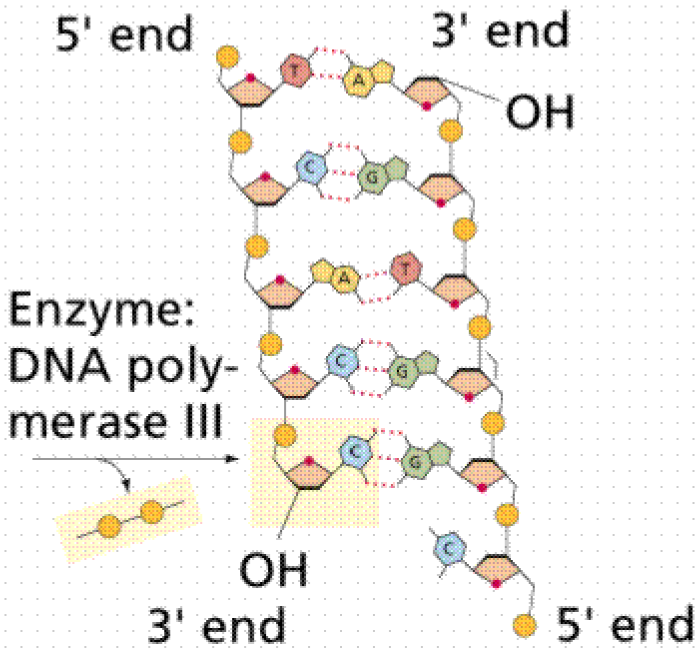


The dispersive replication model of DNA replication. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

The Meselson-Stahl experiment involved the growth of *E. coli* bacteria on a growth medium containing heavy nitrogen (Nitrogen-15 as opposed to the more common, but lighter molecular weight isotope, Nitrogen-14). The first generation of bacteria was grown on a medium where the sole source of N was Nitrogen-15. The bacteria were then transferred to a medium with light (Nitrogen-14) medium. Watson and Crick had predicted that DNA replication was semi-conservative. If it was, then the DNA produced by bacteria grown on light medium would be intermediate between heavy and light. It was.

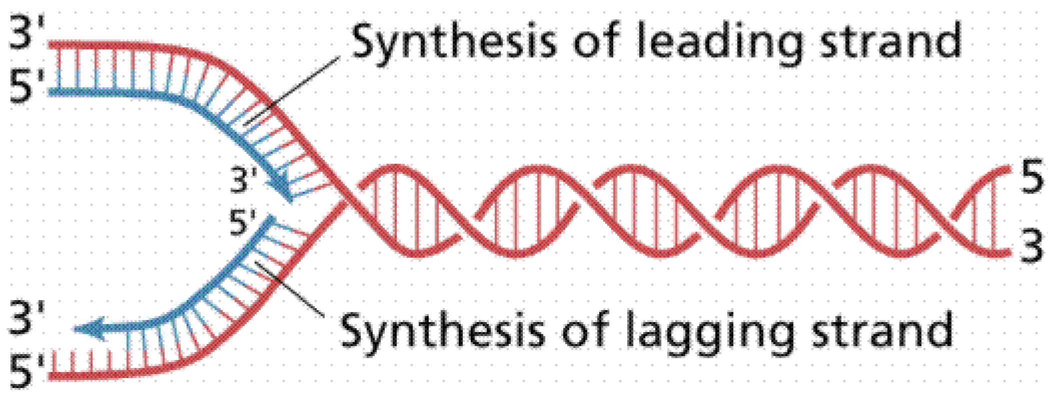
DNA replication involves a great many building blocks, enzymes and a great deal of ATP energy (remember that after the S phase of the cell cycle cells have a G phase to regenerate energy for cell division). Only occurring in a cell once per (cell) generation, DNA replication in humans occurs at a rate of 50 nucleotides per second, 500/second in prokaryotes. Nucleotides have to be assembled and available in the nucleus, along with energy to make bonds between nucleotides. DNA polymerases unzip the helix by breaking the H-bonds between bases. Once the polymerases have opened the molecule, an area known as the replication bubble forms (always initiated at a certain set of nucleotides, the origin of replication). New nucleotides are placed in the fork and link to the corresponding parental nucleotide already there (A with T, C with G). Prokaryotes open a single replication bubble, while eukaryotes have multiple bubbles. The entire length of the DNA molecule is replicated as the bubbles meet.

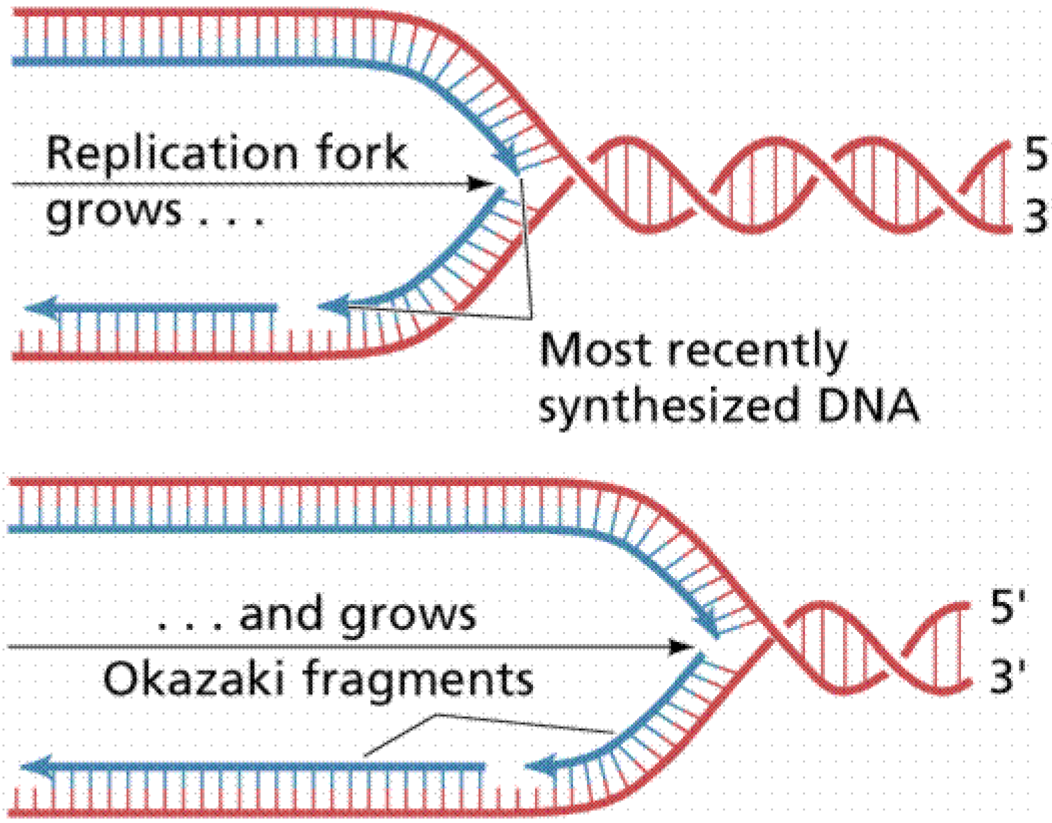




The roles of DNA polymerases in DNA replication. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Since the DNA strands are antiparallel, and replication proceeds in the 5' to 3' direction on EACH strand, one strand will form a continuous copy, while the other will form a series of short Okazaki fragments.



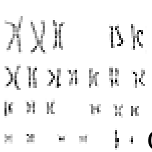


Growth of replication forlks as DNA is replicated base by base. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

HUMAN GENETICS

The human karyotype

There are 44 autosomes and 2 sex chromosomes in the human genome, for a total of 46. Karyotypes are pictures of homologous chromosomes lined up together during Metaphase I of meiosis. The chromosome micrographs are then arranged by size and pasted onto a sheet.

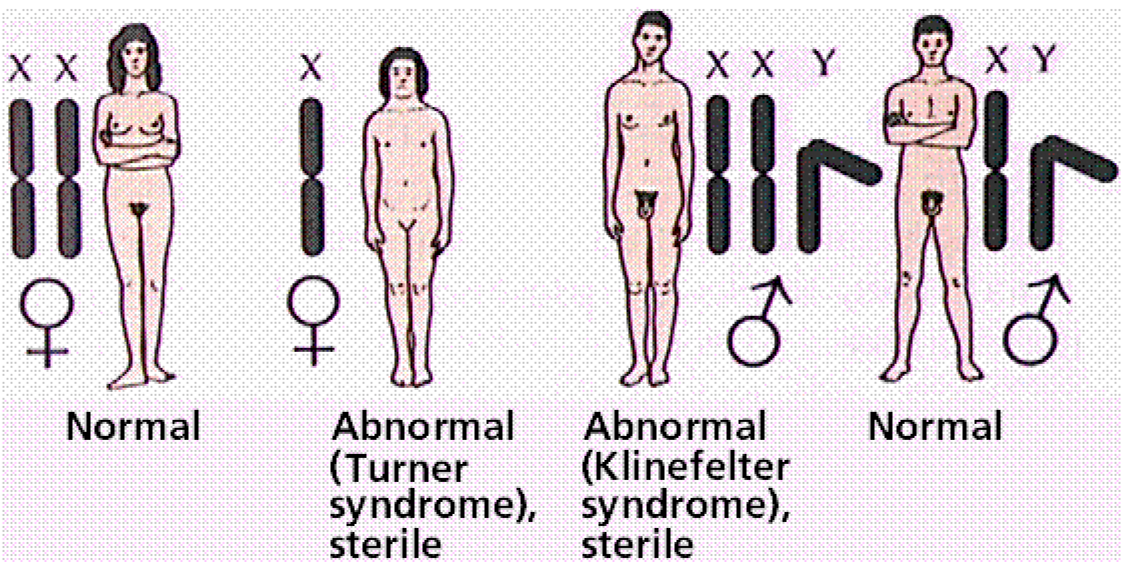
 Click here for a larger picture. This picture is from The Primate Cytogenetics Network at (http://www.selu.com/~bio/cyto/karyotypes/Hominidae/Hominidae.html).

Human chromosomal abnormalities

A common abnormality is caused by nondisjunction, the failure of replicated chromosomes to segregate during Anaphase II. A gamete lacking a chromosome cannot produce a viable embryo. Occasionally a gamete with n+1 chromosomes can produce a viable embryo.

In humans, nondisjunction is most often associated with the 21st chromosome, producing a disease known as Down's syndrome (also referred to as trisomy 21). Sufferers of Down's syndrome suffer mild to severe mental retardation, short stocky body type, large tongue leading to speech difficulties, and (in those who survive into middle-age), a propensity to develop Alzheimer's Disease. Ninety-five percent of Down's cases result from nondisjunction of chromosome 21. Occasional cases result from a translocation in the chromosomes of one parent. Remember that a translocation occurs when one chromosome (or a fragment) is transferred to a non-homologous chromosome. The incidence of Down's Syndrome increases with age of the mother, although 25% of the cases result from an extra chromosome from the father. Click here to view a drawing (from Bioweb) of a karyotype of Down's syndrome.

Sex-chromosome abnormalities may also be caused by nondisjunction of one or more sex chromosomes. Any combination (up to XXXXY) produces maleness. Males with more than one X are usually underdeveloped and sterile. XXX and XO women are known, although in most cases they are sterile. What meiotic difficulties might a person with Down's syndrome or extra sex-chromosomes face?



Human sex chromosome abnormalities. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Kleinfelter's syndrome (click here to view a karyotype from Bioweb) How does this differ from the normal karyotype?

Turner's syndrome (click here to view a karyotype from Bioweb) How does this differ from the normal karyotype?

Chromosome deletions may also be associated with other syndromes such as Wilm's tumor.

Prenatal detection of chromosomal abnormalities is accomplished chiefly by amniocentesis. A thin needle is inserted into the amniotic fluid surrounding the fetus (a term applied to an unborn baby after the first trimester). Cells are withdrawn have been sloughed off by the fetus, yet they are still fetal cells and can be used to determine the state of the fetal chromosomes, such as Down's Syndrome and the sex of the baby after a karyotype has been made.

Human Allelic Disorders (Recessive)

The first Mendelian trait in humans was described in 1905 (brachydactly) by Dr. Farabee (no relation to your author). Now more than 3500 human genetic traits are known.

Albinism, the lack of pigmentation in skin, hair, and eyes, is also a Mendelian human trait. Homozygous recessive (aa) individuals make no pigments, and so have face, hair, and eyes that are white to yellow. For heterozygous parents with normal pigmentation (Aa), two different types of gametes may be produced: A or a. From such a cross 1/4 of the children could be albinos. The brown pigment melanin cannot be made by albinos. Several mutations may cause albinism: 1) the lack of one or another enzyme along the melanin-producing pathway; or 2) the inability of the enzyme to enter the pigment cells and convert the amino acid tyrosine into melanin.

Phenylketonuria (PKU) is recessively inherited disorder whose sufferers lack the ability to synthesize an enzyme to convert the amino acid phenylalanine into tyrosine Individuals homozygous recessive for this allele have a buildup of phenylalanine and abnormal breakdown products in the urine and blood. The breakdown products can be harmful to developing nervous systems and lead to mental retardation. 1 in 15,000 infants suffers from this problem. PKU homozygotes are now routinely tested for in most states. If you look closely at a product containing Nutra-sweet artificial sweetener, you will see a warning to PKU sufferers since phenylalanine is one of the amino acids in the sweetener. PKU sufferers are placed on a diet low in phenylalanine, enough for metabolic needs but not enough to cause the buildup of harmful intermediates.

Tay-Sachs Disease is an autosomal recessive resulting in degeneration of the nervous system. Symptoms manifest after birth. Children homozygous recessive for this allele rarely survive past five years of age. Sufferers lack the ability to make the enzyme N-acetyl-hexosaminidase, which breaks down the GM2 ganglioside lipid. This lipid accumulates in lysosomes in brain cells, eventually killing the brain cells. Although rare in the general population (1 in 300,000 births), it was (until recently) higher (1 in 3600 births) among Jews of eastern central European descent. One in 28 American Jews is thought to be a carrier, since 90% of the American Jewish population emigrated from those areas in Europe. Most Tay-Sachs babies born in the US are born to non-Jewish parents, who did not undergo testing programs that most US Jewish prospective parents had.

Sickle-cell anemia is an autosomal recessive we have discussed in other sections. Nine-percent of US blacks are heterozygous, while 0.2% are homozygous recessive. The recessive allele causes a single amino acid substitution in the beta chains of hemoglobin. When oxygen concentration is low, sickling of cells occurs. Heterozygotes make enough "good beta-chain hemoglobin" that they do not suffer as long as oxygen concentrations remain high, such as at sea-level.

Human Allelic Disorders (Dominant)

Autosomal dominants are rare, although they are (by definition) more commonly expressed.

Achondroplastic dwarfism occurs, even though sufferers have reduced fertility.

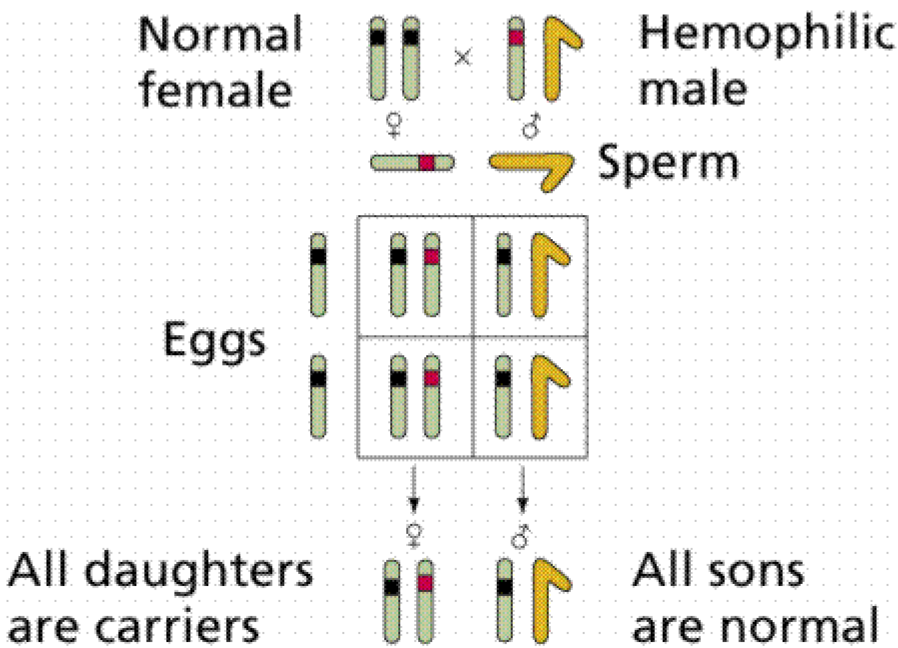
Huntington's disease (also referred to as Woody Guthrie's disease, after the folk singer who died in the 1960s) is an autosomal dominant resulting in progressive destruction of brain cells. If a parent has the disease, 50% of the children will have it (unless that parent was homozygous dominant, in which case all children would have the disease). The disease usually does not manifest until after age 30, although some instances of early onset phenomenon are reported among individuals in their twenties.

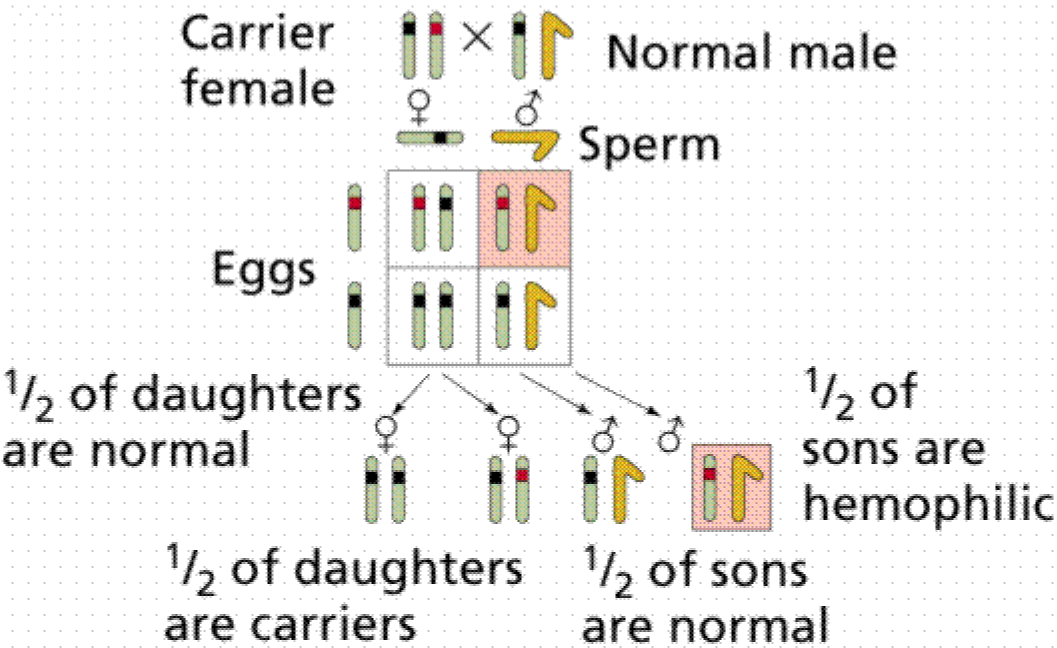
Polydactly is the presence of a sixth digit. In modern times the extra finger has been cut off at birth and individuals do not know they carry this trait. One of the wives of Henry VIII had an extra finger. In certain southern families the trait is also more common. The extra digit is rarely functional and definitely causes problems buying gloves, let alone fitting them on during a murder trial.

Sex-linked Traits

Color blindness afflicts 8% of males and 0.04 % of human females. Color perception depends on three genes, each producing chemicals sensitive to different parts of the visible light spectrum. Red and green detecting genes are on the X-chromosome, while the blue detection is on an autosome.

Hemophilia is a group of diseases in which blood does not clot normally. Factors in blood are involved in clotting. Hemophiliacs lacking the normal Factor VIII are said to have Hemophilia A, the most common form. Normal Factor VIII can be supplied at a high dollar and health risk cost, although the development of biotechnologically engineered Factor VIII produced by bacteria lessens the health risk. England's Queen Victoria was a carrier for this disease. The allele was passed to two of her daughters and one son. Since royal families in Europe commonly intermarried, the allele spread, and may have contributed to the downfall of the Russian monarchy (Czar Nicholas' son Alexei suffered from hemophilia A inherited from his mother who carried Victoria's genetic secret).





Inheritance of a human sex-linked trait. Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

Muscular dystrophy is a term encompassing a variety of muscle wasting diseases. The most common type, Duchenne Muscular Dystrophy (DMD), affects cardiac and skeletal muscle, as well as some mental functions. DMD is an X-linked recessive occurring in 1 in 3500 newborns. Most sufferers die before their 20th birthday. In 1987, Louis Kunkel claimed to have isolated a protein, dystrophin, present in normal individuals (about 0.002 % of their muscle protein) but absent in two individuals with DMD. The lack of dystrophin is accompanied with a condition of muscle hardening known as fibrosis, which restricts blood supply to the muscle which then die. The gene technologies discussed in an earlier chapter have been employed to sequence and clone the dystrophin gene, which is the largest known human gene (some 2-3 million base pairs), with 60 exons and many large introns.

Diagnosis of Human Genetic Diseases

Restriction enzymes, such as *Hpa* I were used in a study on sickle-cell anemia. The probe hybridized in normal hemoglobin with two fragments 7000 or 7600 nucleotides long. Sickle-cell hemoglobin had hybridization with a 13,000 nucleotide single sequence. A similar result has been obtained from amniocentesis studies, providing a tool to screen fetus and adult for sickle-cell. The markers where hybridization occurred are referred to as RFLPs (restriction-fragment-length polymorphisms). The longer fragment in sickle-cell individuals is interpreted as evidence of a mutation in the recognition sequence. Two nucleotide sequences close together on the same DNA molecule tend to stay together. In the sickle-cell DNA the beta-chain hemoglobin gene has become linked with another gene that somehow alters the recognition sequence at which *Hpa* I hybridizes. Heterozygotes will have both long and short fragments, while a single type (short or long) will occur in homozygous dominant and recessive, respectively.

Huntington's disease was studied by James F. Gusella and his research team, who used RFLPs to identify a marker. Testing a large library of human DNA fragments, Gusella et al. found the needle in the haystack. The enzyme used was *Hind* III. Four fragments have been identified in an American family that has members suffering from the disease. The presence of fragment A has been identified in individuals who suffer from (or will suffer from) Huntington's. Pattern A occurs in 60 percent of the population, as well as the Huntington's sufferers. A Venezuelan family of 3000 members is descended from a German sailor who had Huntington's. This family had a strong correlation between Fragment C and the disease. Pattern C is much less common among the general population in this country. Many individuals do not wish to know if they will develop this disease; Woody Guthrie's children have chosen not to be tested.

Cystic fibrosis (CF) has also been studied with RFLP technology. CF is the most common genetic disease in Caucasians.

Radioactive probes

Hemophiliacs suffer from defective Factor VIII, which can be detected in fetuses 20 weeks old. A more accurate test, which can also be administered earlier during pregnancy, involves the use of a radioactive probe (36 nucleotide RNA fragment) which hybridizes restriction fragments. The gene for hemophilia is 186,000 base pairs, and has 26 exons separated by 25 introns. Mutations in the gene can be detected by RFLPs. This technology has also been used to detect the single base-pair difference between normal and mutated beta-chains, a screen for sickle-cell anemia. A DNA probe has been developed that hybridizes with the gene for dystrophin. The previous screening for Duchenne Muscular Dystrophy was a sex screen, with option to abort a male. The new technique allows differentiation between the healthy and diseased male fetus, so parents have more information with which to make an informed choice (if they chose). The hybridization only occurs if the normal dystrophin gene is present, no hybridization occurs in the DMD sufferer.

ANIMAL ORGAN SYSTEMS AND HOMEOSTASIS

Body Systems and Homeostasis

We are all familiar with many of the organ systems that comprise the body of advanced animals: such as the circulatory system, nervous system, etc. More of us are aware of the essential nature of the immune system in these days of HIV, AIDS, and emergent viral diseases such as Ebola and Hanta. Later chapters will focus on animals, such as sponges that have no organs at all, and other organisms that lack many of the organ systems we take for granted. Recall that in the Introduction chapter we discussed the levels of organization we see in biology, from atoms to organ systems that makeup a multicellular organism. We have also seen somewhat of the myriad cells and tissues that occur in humans (and by extension in other animals). This chapter will introduce you to the eleven organ systems that function within our own bodies, and how they coordinate to keep us functioning within a dynamic range of internal conditions we refer to as homeostasis.

Animal organs are usually composed of more than one cell type. Recall that the stomach contains all four animal tissue types: epithelium to line the stomach and secrete gastric juices; connective tissues to give the stomach flexibility to expand after a large meal; smooth muscle tissues to churn and digest that meal without the need for conscious thought (indeed, we are aware of that action only when we burp or suffer some sort of gastric distress!); and nervous tissues to monitor the progress of food as it is worked on by the stomach, and to direct secretion and muscle activity. Each organ typically performs a given function set. The stomach is an organ composed of tissues that aid in the mechanical and chemical breakdown of food. Most organs have functions in only one organ system. The stomach is involved only in the digestion of food as part of the digestive system. Organ systems, such as the digestive system, are collections of organs that perform a major function for the organism.

Homeostasis

Homeostasis is the maintenance of a stable internal environment. Homeostasis is a term coined in 1959 to describe the physical and chemical parameters that an organism must maintain to allow proper functioning of its component cells, tissues, organs, and organ systems.

Recall that enzymes function best when within a certain range of temperature and pH, and that cells must strive to maintain a balance between having too much or too little water in relation to their external environment. Both situations demonstrate homeostasis. Just as we have a certain temperature range (or comfort zone), so our body has a range of environmental (internal as well as external) parameters within which it works best. Multicellular organisms accomplish this by having organs and organ systems that coordinate their homeostasis. In addition to the other functions that life must perform (recall the discussion in our Introduction chapter), unicellular creatures must accomplish their homeostasis within but a single cell!

Single-celled organisms are surrounded by their external environment. They move materials into and out of the cell by regulation of the cell membrane and its functioning. Most multicellular organisms have most of their cells protected from the external environment, having them surrounded by an aqueous internal environment. This internal environment must be maintained in such a state as to allow maximum efficiency. The ultimate control of homeostasis is done by the nervous system. Often this control is in the form of negative feedback loops. Heat control is a major function of homeostatic conditions that involves the integration of skin, muscular, nervous, and circulatory systems.

The difference between homeostasis as a single cell performs it and what a multicelled creature does derives from their basic organizational plan: a single cell can dump wastes outside the cell and just be done with it. Cells in a multicelled creature, such as a human or cat, also dump wastes outside those cells, but like the trash can or dumpster outside my house/apartment, those wastes must be carted away. The carting away of these wastes is accomplished in my body by the circulatory system in conjunction with the excretory system. For my house, I have the City of Phoenix sanitation department do that (and get to pay each month for their service!).

The ultimate control of homeostasis is accomplished by the nervous system (for rapid responses such as reflexes to avoid picking up a hot pot off the stove) and the endocrine system (for longer-term responses, such as maintaining the body levels of calcium, etc.). Often this homeostatic control takes the form of negative feedback loops. There are two types of biological feedback: positive and negative. Negative feedback turns off the stimulus that caused it in the first place. Your house's heater (or cooler for those of us in the Sun Belt) acts on the principle of negative feedback. When your house cools off below the temperature set by your thermostat, the heater is turned on to warm air until the temperature is at or above what the thermostat is set at. The thermostat detects this rise in temperature and sends a signal to shut off the heater, allowing the house to cool of until the heater is turned on yet again and the cycle (or loop) continues. Positive feedback causes an amplification of the stimulus by the reaction. Examples of each will be presented below.

The Internal Environment

There are two types of extracellular fluids in animals:

the extracellular fluid that surrounds and bathes cells

plasma, the liquid component of the blood.

Internal components of homeostasis:

Concentration of oxygen and carbon dioxide

pH of the internal environment

Concentration of nutrients and waste products

Concentration of salt and other electrolytes

Volume and pressure of extracellular fluid

Control Systems

Open systems are linear and have no feedback, such as a light switch. Closed Systems has two components: a sensor and an effector, such as a thermostat (sensor) and furnace (effector). Most physiological systems in the body use feedback to maintain the body's internal environment.

Extrinsic

Most homeostatic systems are extrinsic: they are controlled from outside the body. Endocrine and nervous systems are the major control systems in higher animals.

The nervous system depends on sensors in the skin or sensory organs to receive stimuli and transmit a message to the spinal cord or brain. Sensory input is processed and a signal is sent to an effector system, such as muscles or glands, that effects the response to the stimulus.

The endocrine system is the second type of extrinsic control, and involves a chemical component to the reflex. Sensors detect a change within the body and send a message to an endocrine effector (parathyroid), which makes PTH. PTH is released into the blood when blood calcium levels are low. PTH causes bone to release calcium into the bloodstream, raising the blood calcium levels and shutting down the production of PTH.

Some reflexes have a combination of nervous and endocrine response. The thyroid gland secretes thyroxin (which controls the metabolic rate) into the bloodstream. Falling levels of thyroxin stimulate receptors in the brain to signal the hypothalamus to release a hormone that acts on the pituitary gland to release thyroid-stimulating hormone (TSH) into the blood. TSH acts on the thyroid, causing it to increase production of thyroxin.

Intrinsic

Local, or intrinsic, controls usually involve only one organ or tissue. When muscles use more oxygen, and also produce more carbon dioxide, intrinsic controls cause dilation of the blood vessels allowing more blood into those active areas of the muscles. Eventually the vessels will return to "normal".

Feedback Systems in Homeostasis

Negative feedback control mechanisms (used by most of the body's systems) are called negative because the information caused by the feedback causes a reverse of the response. TSH is an example: blood levels of TSH serve as feedback for production of TSH.

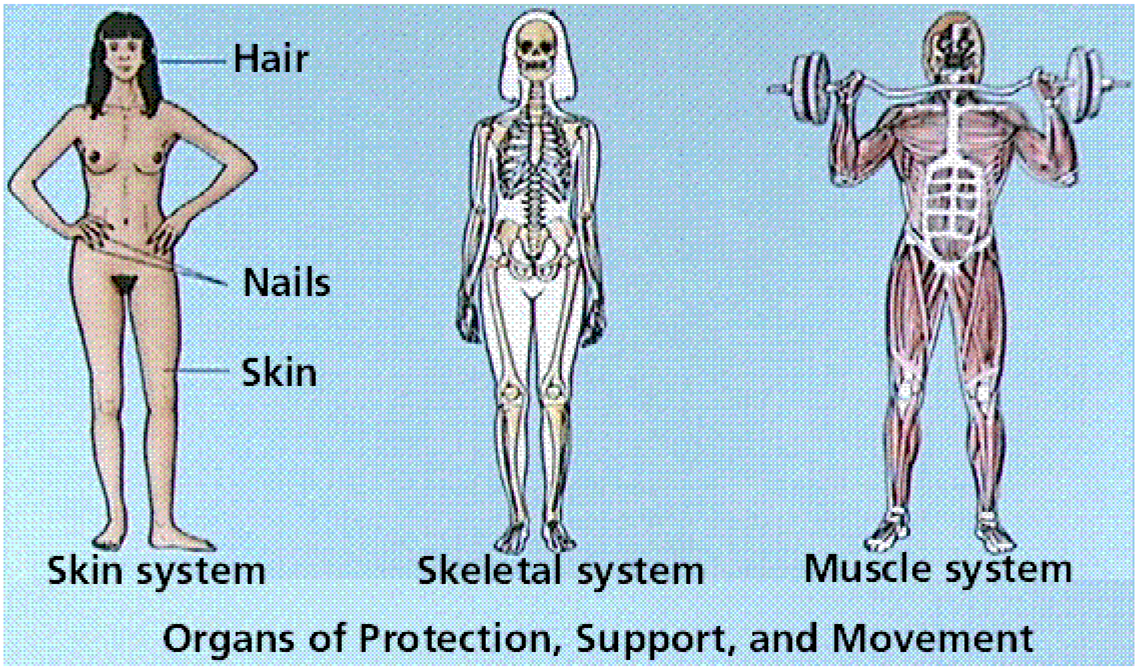
Positive feedback control is used in some cases. Input increases or accelerates the response. During uterine contractions, oxytocin is produced. Oxytocin causes an increase in frequency and strength of uterine contractions. This in turn causes further production of oxytocin, etc.

Homeostasis depends on the action and interaction of a number of body systems to maintain a range of conditions within which the body can best operate.

Body Systems and Homeostasis

Eleven major organ systems are present within animals, although some animals lack one or more of them. The vertebrate body has two cavities: the thoracic, which contains the heart and lungs; and the abdominal, which contains digestive organs. The head, or cephalic region, contains four of the five senses as well as a brain encased in the bony skull. These organ systems can be grouped according to their functions.

Figure 1. The integumentary, skeletal, and muscular systems. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

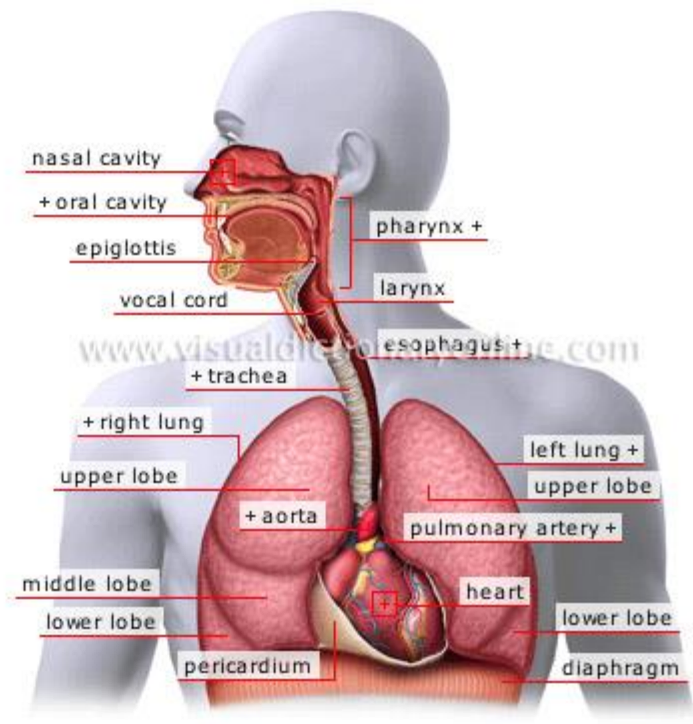


Muscular System (shown in Figure 1) facilitates movement and locomotion. The muscular system produces body movements, body heat, maintains posture, and supports the body. Muscle fibers are the main cell type. Action of this system is closely tied to that of the skeletal system.

Skeletal System (shown in Figure 1) provides support and protection, and attachment points for muscles. The skeletal system provides rigid framework for movement. It supports and protects the body and body parts, produces blood cells, and stores minerals.

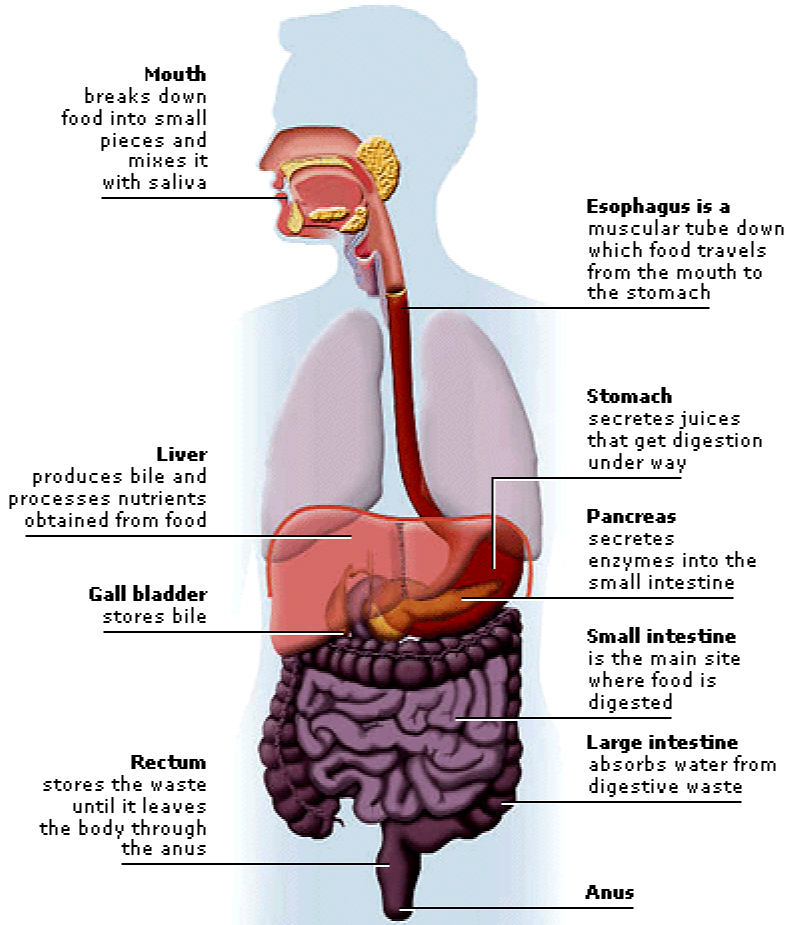
Skin or Integument (shown in Figure 1) is the outermost protective layer. It prevents water loss from and invasion of foreign microorganisms and viruses into the body. There are three layers of the skin. The epidermis is the outer, thinner layer of skin. Basal cells continually undergo mitosis. Skin is waterproof because keratin, a protein is produced. The next layer is the dermis a layer of fibrous connective tissue. Within the dermis many structures are located, such as sweat glands, hair follicles and oil glands. The subcutaneous layer is composed of loose connective tissue. Adipose tissue occurs here, serving primarily for insulation. Nerve cells run through this region, as do arteries and veins.

FIG 2



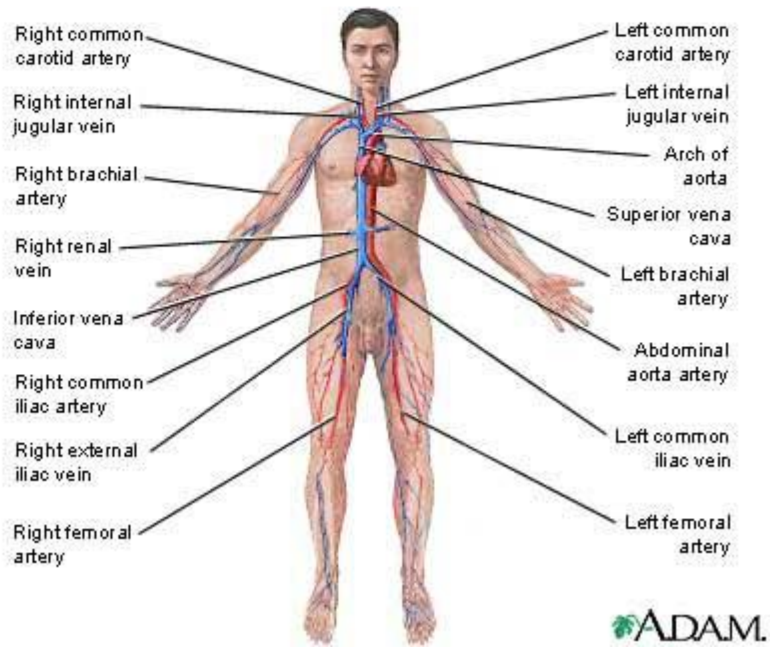
Respiratory System moves oxygen from the external environment into the internal environment; also removes carbon dioxide. The respiratory system exchanges gas between lungs (gills in fish) and the outside environment. It also maintains pH of the blood and facilitates exchange of carbon dioxide and oxygen. The system is summarized in Figure 2.

FIG 2B



Digestive System (2B) digests and absorbs food into nutrient molecules by chemical and mechanical breakdown; eliminates solid wastes into the environment. Digestion is accomplished by mechanical and chemical means,breaking food into particles small enough to pass into bloodstream. Absorbtion of food molecules occurs in the small intestine and sends them into circulatory system. The digestive system also recycles water and reclaims vitamins from food in the large intestine. The system is summarized in Figure

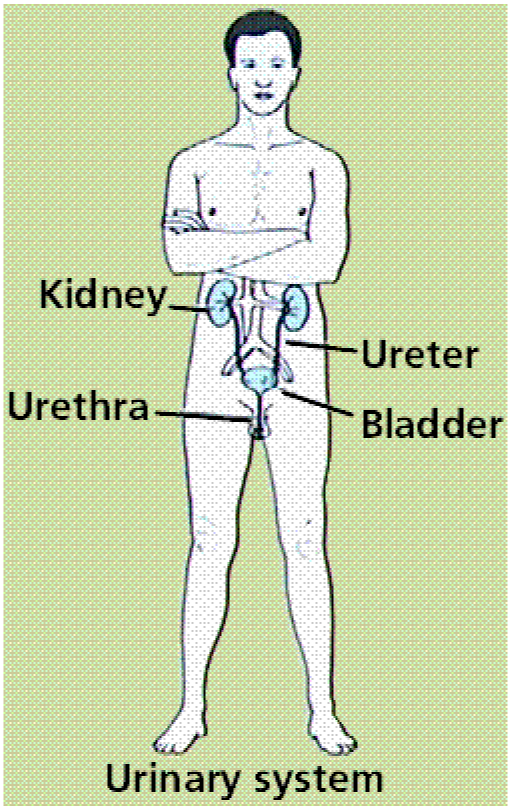
Figure 3. The circulatory and lymphatic systems. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.



Circulatory System (Figure 3) transports oxygen, carbon dioxide, nutrients, waste products, immune components, and hormones. Major organs include the heart, capillaries, arteries, and veins. The lymphatic system also transports excess fluids to and from circulatory system and transports fat to the heart.

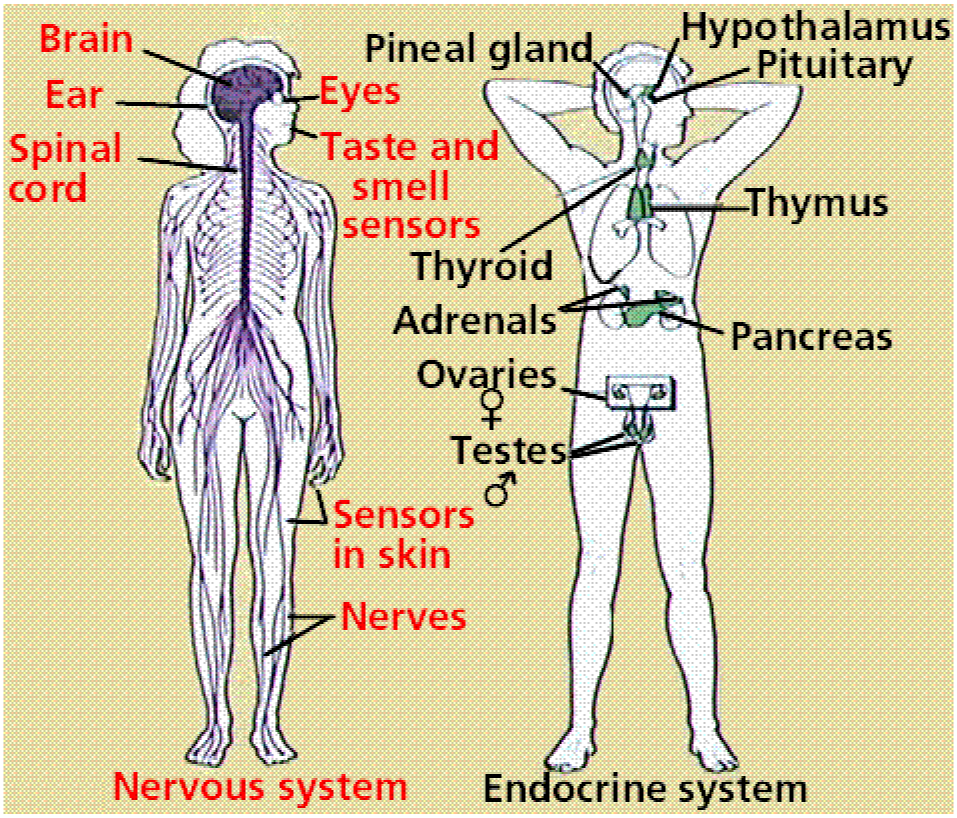
Immune System (Lymphatic system, Figure 3) defends the internal environment from invading microorganisms and viruses, as well as cancerous cell growth. The immune system provides cells that aid in protection of the body from disease via the antigen/antibody response. A variety of general responses are also part of this system.

Figure 4. The excretory system. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.



Excretory System regulates volume of internal body fluids as well as eliminates metabolic wastes from the internal environment. The excretory system removes organic wastes from the blood, accumulating wastes as urea in the kidneys. These wastes are then removed as urine. this system is also responsible for maintaining fluid levels.

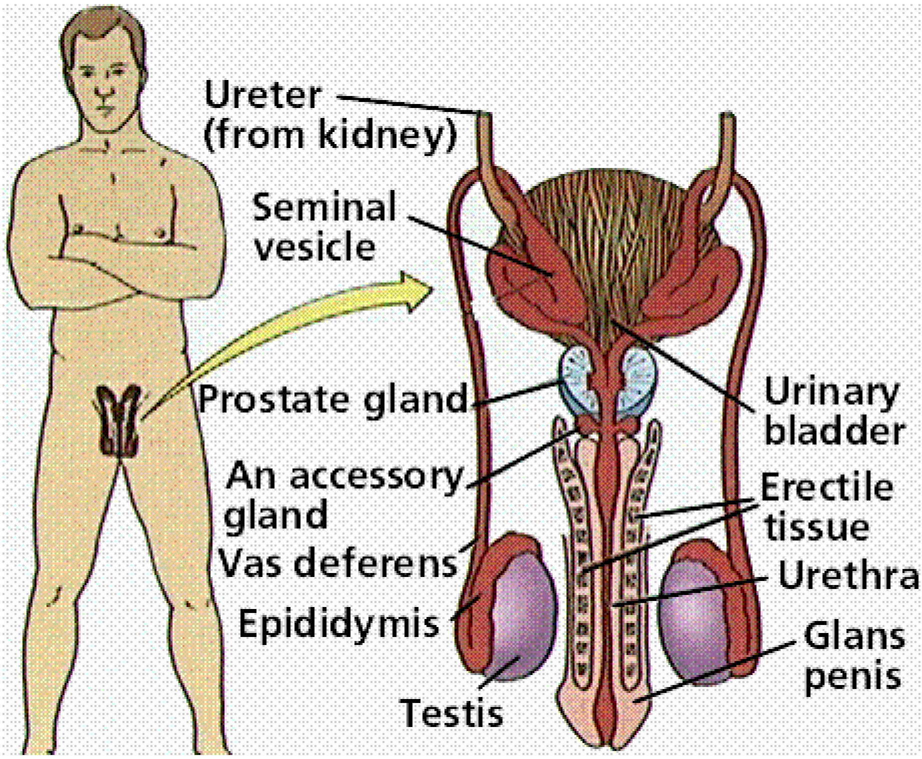
Figure 5. The nervous and endocrine systems. Image from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.

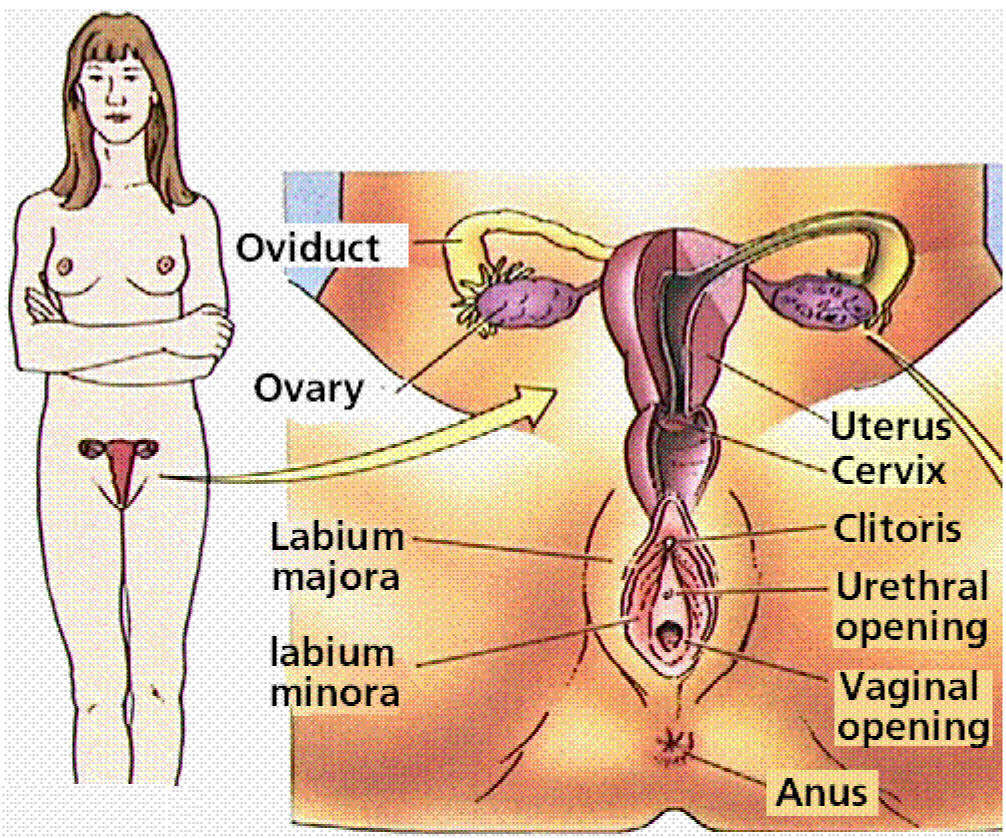


Nervous System, illustrated in Figure 5, coordinates and controls actions of internal organs and body systems. Memory, learning, and conscious thought are a few aspects of the functions of the nervous system. Maintaining autonomic functions such as heartbeat, breathing, control of involuntary muscle actions are performed by some of the parts of this system.

Endocrine System, illustrated in Figure 5, works with the nervous system to control the activity internal organs as well as coordinating long-range response to external stimuli. The endocrine system secretes hormones that regulate body metabolism, growth, and reproduction. These organs are not in contact with each other, although they communicate by chemical messages dumped into the circulatory system.

Figure 6. The urogenital and reproductive systems of males (top) and females). Images from Purves et al., Life: The Science of Biology, 4th Edition, by Sinauer Associates (www.sinauer.com) and WH Freeman (www.whfreeman.com), used with permission.





Reproductive System, shown in Figure 6, is mostly controlled by the endocrine system, and is responsible for survival and perpetuation of the species. Elements of the reproductive system produce hormones (from endocrine control) that control and aid in sexual development. Organs of this system produce gametes that combine in the female system to produce the next generation (embryo).

END TEXT