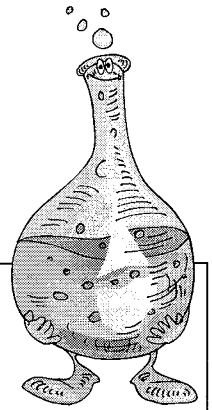
Evolutionary Theory

Section 13.1

Spontaneous Generation and Biogenesis



Pre-View 13.1

- **Spontaneous generation** – the idea that living organisms are created from nonliving matter
- **Francesco Redi** – one of the first scientists to disprove spontaneous generation by showing that flies come from other flies and are not created from meat
- **John Needham** – scientist who believed he proved spontaneous generation occurs for microorganisms because he did not realize that microorganisms could be found in the air
- **Lazzaro Spallanzini** – scientist who believed he disproved spontaneous generation by designing an experiment that kept heated broth from being re-contaminated by air
- **Louis Pasteur** – scientist who finally disproved spontaneous generation by designing an experiment that confirmed that microorganisms can be found in the air
- **Biogensis** – a scientific law that states that living organisms only come from other living organisms

Current ideas and beliefs about living things, such as how they came to exist, how they change, and how they should be classified, have been developed over many years by many different scientists. Before we look at current theory, let's review some key scientists who contributed to the current view of biology.

Let's go back in human history for a while. For hundreds of years, people believed in **spontaneous generation**, the idea that life is continually created from nonliving things. After all, if you took a handful of hay and a handful of corn, wrapped them in an old t-shirt, and threw the wad in the corner of a shed, you could come by in a few days and see mice! Did the mice come from the t-shirt, the corn, or the hay? Of course not, but it took a lot of work to disprove this idea of spontaneous generation to many people.

Francesco Redi

Since the time of Aristotle, people had believed that life came from a combination of nonliving things such as water, fire, and air. One of the first scientists to disprove spontaneous generation was **Francesco Redi** in 1668. He hypothesized that flies come from other living flies and not from meat as was commonly believed. He tested his hypothesis by placing raw meat in several containers. Some of the containers were covered, and the others were left open. Redi saw that only the open containers where flies entered had developed maggots. He kept the maggots until they turned into flies. The closed containers had no maggots and no flies.

Redi is often given credit as the first scientist to develop a controlled experiment. He may not have actually been the first person to use controls or to understand the need for a control group. However, his simple experiment successfully used a control group and an experimental group to prove his hypothesis. His experiment may have looked something like the illustrations in figure 13-1.

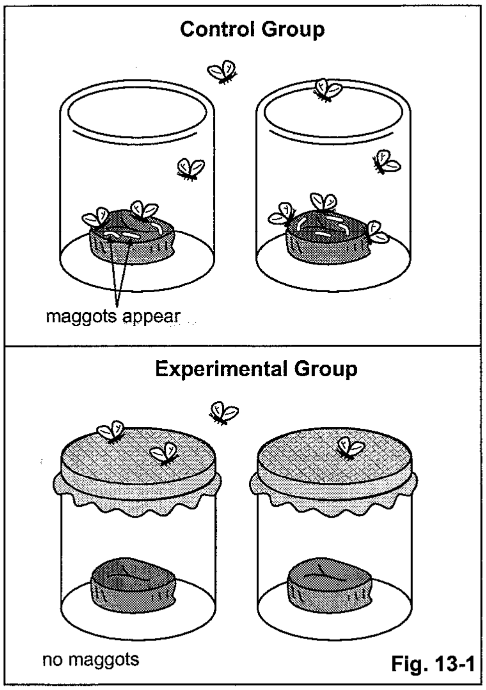


Fig. 13-1

John Needham and Lazzaro Spallanzani

Francesco Redi's experiment proved to most that large living organisms, like flies, did not come from nonliving things. But about 100 years after Redi, the question over spontaneous generation was still debated, especially when it came to organisms that could now be observed with a microscope.

In 1745, **John Needham** attempted to prove spontaneous generation does occur with microscopic organisms. At the time, it was known that heat kills living organisms. In an experiment, Needham heated chicken broth in a flask to kill all living microscopic organisms. He then let the flask and broth cool and sit. After some time, the broth became cloudy with microorganisms. This experiment gave Needham "proof" that microorganisms were created by the broth.

Another scientist, **Lazzaro Spallanzani,** repeated Needham's experiment, but Spallanzani suspected that the microorganisms were coming from the air. Spallanzani's experiment removed the air from the flask by creating a partial vacuum after the broth had been heated. In Spallanzani's experiment, no microorganisms grew, so he believed his experiment disproved spontaneous generation of microorganisms.

Spallanzani's experiment did not convince everyone because many believed that air was necessary for spontaneous generation to occur. Some believed that all Spallanzani proved was that spontaneous generation could not occur without air.

Louis Pasteur

Another hundred years passed by before **Louis Pasteur** finally designed an experiment that disproved spontaneous generation once and for all. In the late 1850s, Pasteur performed a variation of Needham's and Spallanzani's experiments. Pasteur sterilized broth by heating it, but he designed and used a special flask. See figure 13-2. The swan-like neck of the flask allowed air to enter, but it trapped microorganisms and other contaminants so that they could not reach the broth. Using this specially-designed flask, Pasteur was able to show that microorganisms lived in the air, but they were not formed by the air. He proved that microorganisms come from other microorganisms, not broth and air.

Pasteur's Swan-necked Flask

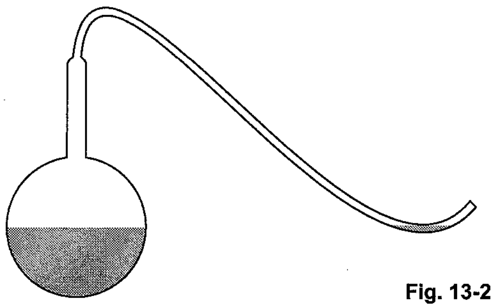


Fig. 13-2

Disproving the idea of spontaneous generation was just one of Pasteur's contributions to science. He is considered the father of microbiology and of immunology. Pasteur was the first to determine that yeast were responsible for fermentation, an important process in the making of beer and wine. He also developed the germ theory, the idea that diseases are caused by microorganisms, and he created vaccines for rabies and anthrax. Pasteur created the process of pasteurization, the heating of milk or other liquids to kill harmful bacteria. His discoveries in microbiology led to antiseptic techniques still used by doctors and nurses today to prevent the spreading of diseases.

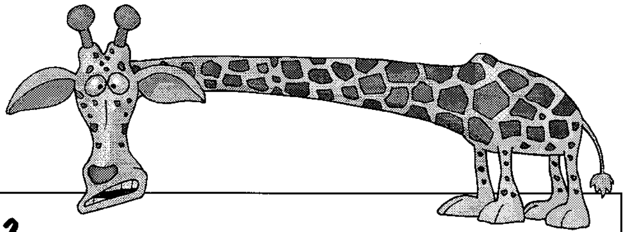
Biogenesis

Pasteur's broth experiment led to the widely-accepted belief that living organisms come only from other living organisms. This belief became known as the law of **biogenesis**, a law that has been firmly established. A scientific law is a general fact of nature. Gravity, for example, is another scientific law.

Evolutionary Theory

Section 13.2

The Theory of Evolution



Pre-View 13.2

- **Theory of evolution** – theory that states that organisms have changed gradually over a long period of time to form new organisms
- **Organic evolution** – the theory of evolution that states gradual changes in living organisms have resulted in more complex organisms
- **Jean-Baptiste de Lamarck** – scientist who is credited with one of the first theories of evolution; believed that organisms changed over time from simple to more complex by passing on acquired traits to offspring
- **Charles Darwin** – "the father of evolution" who believed that a process called natural selection explains how organisms evolved over time
- **Natural selection** – the idea that organisms better suited for their environment will survive and reproduce
- **Thomas Malthus** – scientist who believed human population growth would lead to poverty and famine
- **Charles Lyell** – geologist who believed that natural processes over a long period of time were responsible for changes to the earth's surface
- **Alfred Russel Wallace** – scientist who came up with a theory of evolution by means of natural selection at the same time that Darwin was developing his theory
- **Mutations** – changes in the genetic code
- **Neo-Darwinism** – a revision of Darwin's original theory of evolution to include modern genetics

Hundreds of years ago, people recognized that living organisms changed in appearance over time. Since it was evident that organisms vary from simple to complex, scientists wondered if one organism might have evolved from another organism. Have living organisms evolved in complexity from a single-celled organism to an organism that contains multiple complex organ systems?

The **theory of evolution** is scientists' best modern explanation of how living organisms came into existence and how they may have changed into more complex organisms. This theory, also called **organic** (or biologic) **evolution**, states that living organisms have changed gradually over time to form new organisms. Let's look at some of the historical scientists that helped to form this theory and how this theory has been modified over time.

Jean-Baptiste de Lamarck

Jean-Baptiste de Lamarck (1744-1829) was a French scientist who lived before Pasteur disproved the idea of spontaneous generation. Lamarck believed that new organisms were continually created from nonliving material and that organisms had a tendency to become more complex over time.

Lamarck believed that as the environment changed, organisms changed their behavior in order to survive. He believed that as an organism used a body part or organ to adapt to the environmental change, the body part or organ would grow or improve. On the other hand, if the organism disused a body part or organ, he believed it would shrink or lose function. Lamarck called this idea of use and disuse his "First Law." Lamarck assumed, as others during his time, that organisms passed on acquired characteristics to their offspring, and he called this belief of heredity his "Second Law." Through these two "laws," Lamarck believed organisms changed over time from simple to increasingly more complex.

Example 1: Perhaps Lamarck's most famous explanation of evolution involved the necks of giraffes. How did Lamarck believe that giraffes acquired longer and longer necks?

Lamarck believed that giraffes needed to acquire longer necks in order to eat leaves found in tall trees. By stretching their necks, Lamarck believed that giraffes could cause their necks to grow longer and that the longer necks would then be passed on to their offspring.

Lamarck didn't know anything about genetics, so he didn't know that an acquired characteristic does not make a change in genes. Once scientists had an understanding of how genes affect heredity, Lamarck's mechanism for evolution was considered disproved. However, he is still credited as being one of the first people to suggest a theory of evolution.

Charles Darwin

Charles Darwin (1809-1882) is considered the father of evolution. In 1831, Darwin boarded a ship called the H.M.S. *Beagle* and started a five-year journey that gave him the foundation for the ideas he would later publish. During those five years, Darwin collected an incredible number of specimens and made detailed observations and drawings of the organisms that he saw.

Darwin spent a lot of time in the Galapagos Islands where he was especially intrigued by the different types of birds he saw there. According to the scientific theories of that time, if the birds had migrated from the mainland, then they would be exactly the same as the birds on the mainland. If the birds had been created specifically for the environment found on the islands, they would be completely different from the mainland birds. Darwin found that the birds were not completely different from the mainland birds, but they were not exactly the same either. Darwin began developing the idea that these birds had evolved to survive the tough environmental conditions on the islands.

Darwin used his own observations and combined them with ideas from other scientists, some who lived before him, to form his theories. He published his ideas in his book *On the Origin of Species*. Darwin's most important ideas given in his book can be summed up by the following list:

Summarizing On The Origin of Species

- All populations show the ability to change from one generation to the next. These changes are seen as variations or modifications in a species. (A **species** is defined as a group of very similar organisms that can interbreed and produce fertile offspring. A **population** is made of organisms of the same species that live in the same place at the same time.)
- Competition and variation lead to **natural selection**. Organisms that have variations that are more suited for their environment make them more able to survive and reproduce. Since organisms must compete for limited resources, only the "strongest" survive (the idea of "**survival of the fittest**"). This idea is called the theory of natural selection.
- The process of natural selection can lead to extinction in some species, it can lead to vestigial organs (organs that no longer serve a purpose), and it can lead to new species being formed by a steady but gradual accumulation of modifications. This last idea is known as "**descent with modification**."
- Following this logic backwards in time, Darwin concluded that all living organisms have a common ancestor that evolved over time, branched into separate species, and formed the diverse forms of life that have either become extinct or that exist today.

Lamarck's Influence on Darwin

In the preface of his book, Darwin acknowledges the few scientists before him who "believed that species undergo modification, and that the existing forms of life are the descendants by true generation of pre-existing forms." He credits Lamarck as being the "first man whose conclusions on the subject (of evolution) excited much attention." Although Darwin did not necessarily adopt Lamarck's ideas as his own, many of Darwin's ideas were similar to Lamarck's. Like Lamarck, Darwin believed that organisms changed over time and that these changes resulted in new organisms (or species). Larmarck and Darwin both believed that all living things have a common ancestor. Darwin, however, went much further in trying to give scientific evidence and explanations for his theories.

Lamarck believed that organisms had the ability to change during their lifetimes and then could pass on those modifications to their offspring. Darwin, on the other hand, recognized that organisms changed from one generation to the next, but he had no understanding or explanation for how these changes occurred. Darwin simply stated that natural selection determined which changes were passed on to offspring. Remember, neither Lamarck nor Darwin had knowledge of genes and genetics.

Thomas Malthus's Influence on Darwin

Thomas Malthus (1766-1834) lived around the same time as Lamarck, and he studied population growth. Malthus recognized that plants and animals reproduced more offspring than could survive, and he applied this example to the human population. He lived in England during a time when living conditions were deteriorating, so he theorized that poverty and famine would be the natural outcome of unchecked human population growth. In other words, the rate of reproduction in humans would one day be greater than the resources (especially food supply) to sustain them.

Malthus's ideas showed a struggle for existence that greatly influenced Darwin. Darwin especially recognized in his own studies that plants and animals had more offspring than could survive. Although Malthus concentrated on the human population, Darwin used the struggle for existence to develop and support the ideas of natural selection and survival of the fittest. Darwin believed since all organisms struggle for existence, a slight modification might give an organism a better chance at surviving. He believed the modification would therefore be naturally selected, and the organism would pass this modification to its offspring.

Charles Lyell's Influence on Darwin

Charles Lyell (1797-1875) was a geologist and amateur paleontologist. Around 1830 Lyell published his ideas that natural geological forces transformed the surface of the earth into its present appearance over a long period of time. He had evidence that the earth was much older than most people thought. Lyell's ideas about geology became known as **uniformitarianism**.

Lyell's book, *Principles of Geology,* also influenced Darwin. Since evolution would need a very long period of time to make the changes from one organism to another, Darwin embraced Lyell's ideas. Darwin also used Lyell's idea that the earth changed slowly over time by natural processes and applied that same idea to living organisms.

Alfred Russel Wallace

Unknown to Darwin, another scientist, **Alfred Russel Wallace**, had been working on the same idea of evolution by natural selection. Darwin had been collecting data for twenty years when he found out that Wallace had a paper ready to be published on the same idea. Darwin contacted Wallace, and together they published a paper on natural selection. A year later Darwin published the first edition of *On the Origin of Species.* Although Wallace had the same ideas, Darwin received the recognition.

Neo-Darwinism

Charles Darwin and Gregor Mendel lived at the same time, but Darwin never read about Mendel's discoveries about genetics. We now know that the "variations" Darwin saw and described from one generation to another were actually genetic traits passed on by dominant and recessive genes.

The only mechanism that Darwin had for evolution was natural selection. You'll see much more about natural selection in Section 14. For now, remember that natural selection chooses the most advantageous traits for an organism so that those traits are passed on to future generations. But where did these genes come from and how were different forms of a gene created? We now understand that natural selection does not actually create new genes.

The only way scientists have observed changes in genes is by **mutations**. You saw the different types of mutations in Section 12.4. In order for evolution to occur, scientists believe that accumulated mutations in the genetic code must account for the variety of life found today. Random mutations coupled with natural selection are actually believed to be the driving force behind evolution and not natural selection alone.

Darwin's original theory of evolution has since been modified to include our new understanding of genetics. The revised theory is often called **neo-Darwinism**.

Current Research

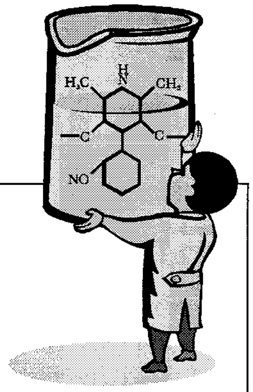
Some modern scientists question whether random mutations can cause the type of new variations needed for evolution to occur. For example, they question whether small, random genetic changes were able to produce complex structures, such as organs, limbs, or wings. Many scientists have looked for alternative pathways to explain how organisms increase in complexity.

Two modern biologists Marc W. Kirschner and John C. Gerhart have proposed a new theory called "facilitated variation." This new theory refers to a few "core" processes that are largely the same in all living organisms. They suggest that small changes in these core processes may have resulted in large-scale changes found in different organisms. Their ideas are published in the book *The Plausibility of Life: Resolving Darwin's Dilemma* (Yale University Press).

Evolutionary Theory

Section 13.3

Ideas on the Origin of Life



Pre-View 13.3

- **Chemical evolution** – the gradual formation of life from nonliving chemicals
- **Oparin-Haldane hypothesis** – the combined ideas of Alexander Oparin and J. B. S. Haldane of how life on earth could have formed gradually from nonliving chemicals
- **Stanley Miller** and **Harold Urey** – scientists who formed amino acids and other simple organic compounds in a laboratory experiment by reacting ammonia, methane, and hydrogen gases mixed with water vapor
- **Sidney Fox** – scientist who heated amino acids to form protein-like spheres

Now let's back up. If the theory of evolution suggests that all living organisms evolved from a common ancestor, where did the common ancestor come from? To answer this question, let's look at a different type of evolution.

Louis Pasteur showed that life was not spontaneously created from nonliving material, but is it possible that living organisms did indeed emerge from nonliving material by means of some natural process? After all, living organisms can be broken down into nonliving components. Scientists have tried to determine how these nonliving chemicals may have reacted and combined to form the first life on planet earth. The formation of life from nonliving chemicals is called **chemical evolution**.

The Oparin-Haldane Hypothesis

Alexander Oparin (1894-1980) suggested that the atmosphere of early earth was very different than it is today. He believed the early atmosphere contained water vapor, ammonia, hydrogen gas, and methane, but no free oxygen (O_2). Because free oxygen is so reactive, it would destroy organic molecules as fast as they could be formed. Around 1924, Oparin came up with a hypothesis of how life evolved from this early atmosphere. With energy from lightning and heat from volcanoes, he believed these simple chemicals could combine to form increasingly more complex organic compounds. In 1928, another scientist **J. B. S. Haldane** came up with a similar hypothesis. Haldane believed that energy from the sun could cause these same atmospheric gases to react and form organic compounds. As the earth cooled, the early oceans would have been filled with these organic compounds. Haldane described the ocean as a "hot dilute soup," and he believed these organic chemicals in the ocean combined gradually over a long period of time (perhaps millions of years) into virus-like organisms, which then evolved into the first living cells. Oparin and Haldane had very specific and detailed ideas on the steps involved for life to evolve from chemicals, and these ideas are called the **Oparin-Haldane hypothesis** (and sometimes referred to as the Oparin hypothesis). However, neither of these scientists performed experiments to test their ideas.

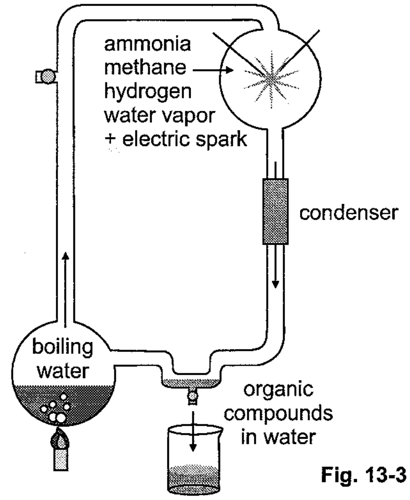


Fig. 13-3

The Miller-Urey Experiment

Stanley Miller and **Harold Urey** tested part of the Oparin-Haldane hypothesis in 1953. These scientists used an experimental set-up similar to the one shown in figure 13-3. First, the system was flushed so that no oxygen was present. Then they boiled water to form water vapor and introduced ammonia, methane, and hydrogen gases into the system. Notice that these are the same gases that Oparin and Haldane believed were present in the early atmosphere. An electric spark simulated lightning. The resulting chemicals were cooled through a condenser and collected. From that chemical mixture, Miller and Urey found several amino acids that are found in proteins.

The Miller-Urey experiment indicated that if, indeed, the early atmosphere was made up of ammonia, methane, hydrogen, and water vapor, then natural processes could form some of the organic compounds found in living cells.

Alternative Ideas

Was Oparin correct about earth's early atmosphere? We can't know for sure, and modern scientists do not agree with one another. More recent research leads some scientists to believe the early earth contained mainly carbon dioxide, nitrogen, and water vapor. Others believe it likely contained carbon dioxide and high levels of hydrogen. If these new ideas are correct, organic molecules could not have formed in the way Oparin predicted. Similar to free oxygen, the carbon dioxide and/or nitrogen would have destroyed the organic molecules as soon as they were formed. Scientists have come up with two alternative explanations.

Perhaps the chemical reactions needed to form basic organic compounds occurred in deep sea vents where hot volcanic gases are released. Scientists have been able to form amino acids in experiments that simulate this environment. However, other scientists believe it is highly unlikely that sea vents could form a meaningful amount of organic molecules. The heat would destroy the molecules as quickly as they were formed.

Panspermia is a belief that life originated in outer space, and this idea has been around for thousands of years. In 2008, organic compounds were found in a meteorite that landed in Australia. This meteorite gave scientists new ideas of how space debris may have been responsible for bringing organic compounds or even life, itself, to earth. In other words, if the conditions for creating organic compounds were not favorable here on earth, maybe those conditions existed somewhere else in space.

Sidney Fox

If amino acids were present in the early earth, they would have to react together in just the right way to form proteins, one of the essential components of life. In the 1950s and 1960s, **Sidney Fox** performed experiments to see if he could form proteins. He heated dry, purified amino acids to cause them to combine. Instead of forming a linear chain of amino acids as is found in a true protein, his experiments formed branched amino acids that he called "proteinoid." When Fox dissolved these protein-like compounds in water, they self-organized into spherical membranes that are semi-permeable and have the ability to grow and divide. These structures created by Fox and other scientists are called proteinoid microspheres or protocells. Fox and other scientists believe that perhaps these types of structures were the beginnings of forming a living cell.

Overcoming Obstacles to Chemical Evolution

The steps needed to form life from nonliving materials are largely unknown and yet to be discovered. Even the most basic single-celled organism alive today is extremely complex. The cell membrane, as you saw in Section 7, is made up of a phospholipid bilayer with specialized protein molecules, a structure that is much more complex than the protocells that scientists have been able to form in a laboratory.

In addition to a cell membrane, even the simplest of cells has genetic material in the form of DNA. How did DNA form? Remember that DNA contains the blueprint that allows a cell to form proteins. Scientists have been unable to cause amino acids to form proteins without enzymes (a special type of protein) and DNA. The double-helical structure of DNA is much too complex to form by natural processes.

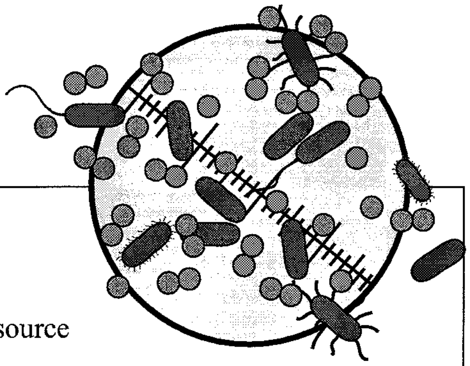
To solve the DNA problem, some scientists have suggested that RNA may have been formed first. RNA can act as an enzyme and can carry instructions for making a protein. Some viruses, which are not really considered living, contain RNA surrounded by protein. Viruses can reproduce inside a living cell, so perhaps one step toward life was a virus-like organism. Scientists, however, have been unable to determine how RNA could have formed by natural processes.

Even when scientists extract the contents from a living cell, they have not yet been able to cause those components to form back into a cell. Scientists have much still to learn when it comes to the origin of life. As scientists continue to study the components of cells, perhaps they will be able to figure out more specifically how nonliving materials came together to form the first living organism.

Evolutionary Theory

Section 13.4

The Evolution of Cells



Pre-View 13.4

- **Anaerobic** – existing without oxygen
- **Heterotrophic** – unable to make food; requiring food from an outside source
- **Prokaryote** – a cell that contains no nucleus
- **Autotrophic** – able to make food from either the sun's energy or from other chemicals
- **Aerobic** – existing with oxygen
- **Eukaryote** – a cell that contains a nucleus and other membrane-bound organelles
- **Endosymbiotic theory** – theory that explains the origin of mitochondria and chloroplasts in eukaryotic cells
- **Symbiotic relationship** – a relationship between two organisms where at least one benefits

The First Cell(s)

If the first cell(s) evolved from something like the protocells that you just saw, what would they have been like? They would have been very simple, much simpler than the most simple cell alive today. Scientists believe that the first cell must have been an anaerobic, heterotrophic prokaryote. You should know each of those terms, but let's review what they mean in terms of a cell.

Anaerobic: Since oxygen would have destroyed the organic compounds needed to form the first cell, many scientist believe that earth's early atmosphere contained little or no free oxygen. Therefore, the first cell must have been **anaerobic**, which means it was able to get energy without using oxygen. (Review Section 8.2 if needed.)

Heterotrophic: Organisms that cannot make their own food are called **heterotrophic**. Heterotrophs must take in food from their environment. Scientist believe that the first cell(s) absorbed or "ate" organic compounds around them for food.

Prokaryote: Remember from Section 6.1 that a **prokaryote** is a small cell that has no nucleus or other membrane-bound organelles. Since the first cell would have to be structurally very simple, it would have to be a prokaryote.

Today, what are all prokaryotes called? They are bacteria cells. These first cells would be classified as bacteria. Not all bacteria are anaerobic and heterotrophic, but some are.

Autotrophic Cells

It is commonly believed that some prokaryotic (bacteria) cells eventually evolved to create their own food. These types of cells are called **autotrophic**, which means they are able to make their own food. There are two types of autotrophic bacteria found today; one uses photosynthesis, and the other uses chemosynthesis. As you probably already know, photosynthetic bacteria use sunlight to convert carbon dioxide and water into glucose. Chemosynthetic bacteria, on the other hand, usually live in extreme environments, such as hot vents found deep undersea. These bacteria use inorganic chemicals, such as hydrogen sulfide, to convert carbon dioxide and water into glucose.

The byproduct of photosynthesis is free oxygen, so many scientists believe that the presence of photosynthetic bacteria helped to form the atmosphere as we know it today.

Aerobic Cells

If photosynthetic prokaryotic cells produced the free oxygen now found in the atmosphere, the earth would then have become more hostile to life. Remember that oxygen is very reactive and destructive. In order for life to continue, the prokaryotic cells exposed to oxygen must evolve to protect themselves against destruction. Scientists reason that these prokaroytic cells must have evolved to use the oxygen to produce energy. Anaerobic prokaryotes must have evolved into aerobic prokaryotes. **Aerobic** cells use oxygen to produce energy as you saw in Section 8.2.

Endosymbiotic Theory

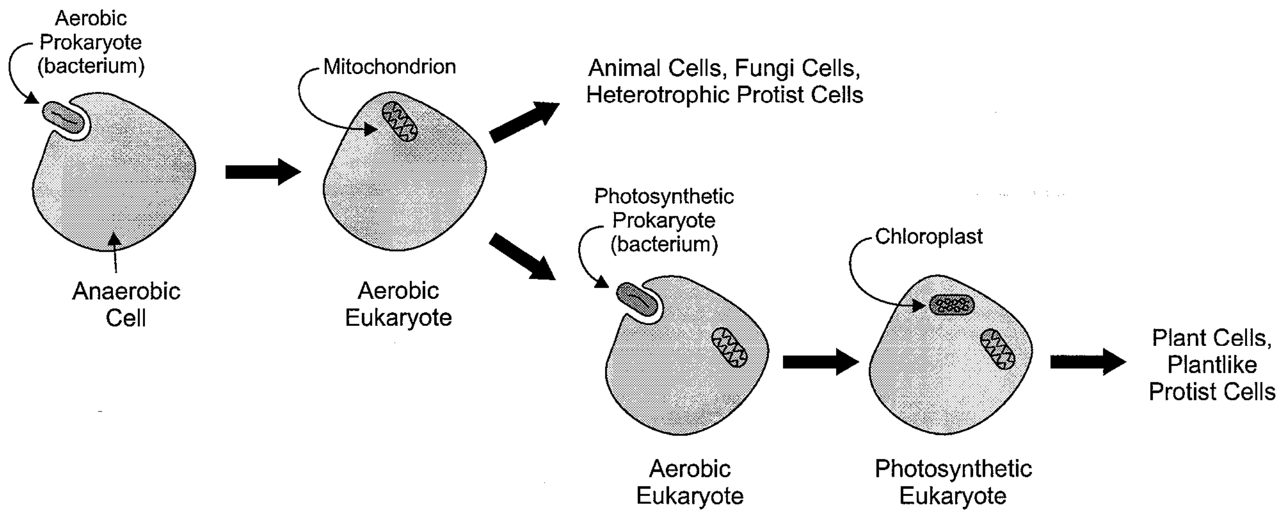
Remember that eukaryotic cells are more complex than prokaryotic cells. **Eukaryotes** are larger, have a nucleus that surrounds its DNA, and have membrane-bound organelles. How does evolution explain the formation of eukaryotic cells?

The most widely accepted theory of how eukaryotes formed is called the **endosymbiotic theory**, and it mainly explains the origin of mitochondria and chloroplasts within eukaryotic cells.

Endosymbiotic theory first explains the origin of mitochondria. Mitochondria are membrane-bound organelles that are responsible for creating most of the energy in a cell. According to endosymbiotic theory, a large anaerobic primitive cell may have engulfed an aerobic prokaryote (bacterium) to form a symbiotic relationship with it. A **symbiotic relationship** is a relationship between two organisms in which at least one benefits. Over time, this aerobic bacterium may have become a mitochondrion. To support this idea, scientists have found that mitochondria resemble prokaryotic bacteria and contain many of the same features. For example, mitochondria contain their own DNA, and they divide by binary fission. This symbiotic relationship is thought to have resulted in the first aerobic eukaryote. All other heterotrophic, eukaryotic cells would have evolved from these cells to include animal cells, fungi cells, and heterotrophic protist cells.

Next, according to endosymbiotic theory, an aerobic eukaryote may have engulfed a photosynthetic bacterium, such as a cyanobacterium, to form another symbiotic relationship. The photosynthetic bacterium would eventually evolve into a chloroplast. Again, chloroplasts and photosynthetic bacteria resemble one another. This new photosynthetic (autotrophic), eukaryotic cell would be an ancestor for plant cells and autotrophic protist cells.

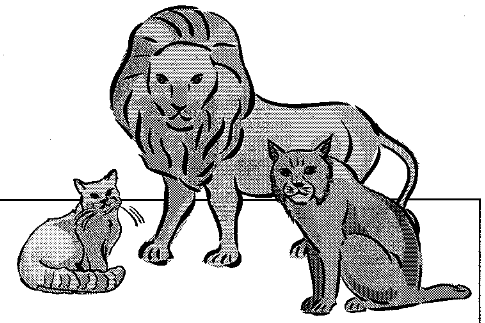
Endosymbiotic Theory



Evolutionary Theory

Section 13.5

Classification



Pre-View 13.5

- **Taxonomy** – the branch of biology that classifies organisms into taxa (from kingdom to species)
- **Carl Linnaeus** – the father of taxonomy who classified organisms in groups within groups
- **Kingdom** – the largest taxon that contains the greatest diversity of organisms
- **Species** – the smallest taxon; represents a group of organisms that can interbreed and produce fertile offspring
- **Binomial nomenclature** – a system that names each organism by giving its genus and species
- **Trinomial nomenclature** – a system that names an organism by giving its genus and species followed by its subspecies or variety

Suppose that you walked into your favorite superstore one day and found that nothing was where it was supposed to be. A can of chicken noodle soup was next to some socks. Your favorite brand of jeans was between the paper towels and the baby clothes, one row down from the dog food. It's much easier to find what you need when things are grouped together. It works the same way with living organisms.

Taxonomy is the branch of biology that specializes in classifying organisms into a series of groups called taxa (singular is taxon). **Carl Linnaeus** (1707-1778) is considered the father of taxonomy because he created these taxa and organized living organisms into them according to similarities. His classification system, although it has been modified over time, is still used today.

This modern classification system has seven taxa: kingdom, phylum, class, order, family, genus, and species. The largest classification taxon is **kingdom**, and it has more organisms in it than the taxa below it. A kingdom has the greatest diversity. The amount of diversity in each taxon is smaller than the taxon above it. **Species** is the smallest taxon and has the fewest organisms in it; species has the least diversity. A species is a group of organisms that can interbreed and produce fertile offspring.

One way to remember the order of these groups is to remember the following:

most diversity

Kingdom	Ken
Phylum	Put
Class	Candy
Order	On
Family	Fred's
Genus	Good
Species	Suit

least diversity

A group of similar species forms a genus, and a genus is a larger group than species. The next larger group is a family, a taxon made of similar genera. Similar families would form a taxon called an order, and similar orders would form a class. If organisms are in the same family, then they are also in the same order, class, phylum, and kingdom — all of the taxa above family. A bobcat, a house cat, and a lion are all in the family Felidae, so they are also in the same order, class, phylum, and kingdom.

Classification

Example 1: The chart on the right shows the classification of a dog and a gorilla. What is the LOWEST taxonomic level that they have in common?

	Dog	Gorilla	
Kingdom	Animalia	Animalia	← same
Phylum	Chordata	Chordata	← same
Class	Mammalia	Mammalia	← same
Order	Carnivora	Primates	← different
Family	Canidae	Hominidae	
Genus	Canis	Gorilla	
Species	familiaris	gorilla	

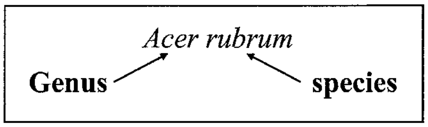
The smallest taxonomic level that the dog and the gorilla have in common is the class of Mammalia. The chart shows that they are in the same kingdom, phylum, and class, but they are in different orders.

Naming Organisms

Organisms are named using their genus name followed by their species name. The genus name is always capitalized, and the species name is always lowercase. Both the genus and the species are italicized (or underlined if handwritten). This naming system is called **binomial nomenclature**. Sometimes organisms can be even further divided into subspecies or varieties. When three scientific names are given to specify a subspecies or a variety, the naming system is called **trinomial nomenclature**. The first two names still give the genus and the species, but the third name gives a subspecies or variety. For example, *Acer rubrum* var. *drummondii* is a Drummond's red maple. *Acer* is the genus name for all maple trees, *rubrum* is the species name and means *red*, and *drummondii* gives a variety of the red maple that grows in the coastal plains area. Animals can also have subspecies. For example, the northern bald eagle has the scientific name of *Haliaeetus leucocephalus washingtoniensis. Haliaeetus* is the genus for eagles, *leucocephalus* is the species for the bald eagle, and *washingtoniensis* is the subspecies of the northern bald eagle.

Example 2: The scientific name for a red maple tree is *Acer rubrum.* Which word represents the genus name? Which word represents the species name?

Remember that genus name is always given first and then the species. *Acer* is the genus name and includes all types of maple trees. The name *rubrum* represents the specific species of maple tree, which in this case is the red maple.



Evolutionary Relationships

Evolutionary theory dictates that scientific names should indicate ancestral relationships. For example, two organisms that have the same word for the first part of the scientific name are in the same genus. Organisms in the same genus are considered very closely related.

Example 3: The scientific name for a red maple tree is *Acer rubrum.* Would it be more closely related to the tree named *Quercus rubrum* or to the tree named *Acer saccharum?*

Acer is the genus for maple trees, and *Quercus* is the genus for oak trees. *Quercus rubrum* and *Acer rubrum* are not very closely related, but *Acer rubrum* and *Acer saccharum* are closely related since they are both maple trees. They would be in the same family, order, and class. Since plant taxonomists use the term ***division*** instead of phylum, they are also in the same division and kingdom.

Scientific Name	Genus	Species	Common Name
Acer rubrum	*Acer*	*rubrum*	Red maple
Quercus rubrum	*Quercus*	*rubrum*	Red oak
Acer saccharum	*Acer*	*saccharum*	Sugar maple

more closely related

DNA Classification

When Carl Linnaeus classified living organisms, he did so mainly on the basis of physical appearance or structure. The theory of evolution, however, points to the idea that all living organisms had a common ancestor. To be consistent with this theory, scientists have tried to classify organisms based on how similar their DNA is. The logic is that the more similar the DNA sequences, the more closely related two organisms are.

One way to determine similarities in DNA is to use gel electrophoresis. Scientists collect DNA from two different organisms. Restriction enzymes are used to separate the DNA into fragments of different lengths. Gel electrophoresis separates these fragments into a pattern as you saw in Section 12.5. Remember, the more similar the pattern, the more similar the original DNA sequence. The more similar the DNA sequences, the more closely related two organisms are considered to be.

Sometimes it is surprising to learn that two organisms that seem to be very different have similar DNA. Most people wouldn't think that a raccoon and a bear have a lot in common, but they have some structural similarities and live in similar habitats. Scientists originally thought that the red panda and the giant panda were closely related. However, DNA sequencing revealed red pandas are more closely related to raccoons than they are to giant pandas.