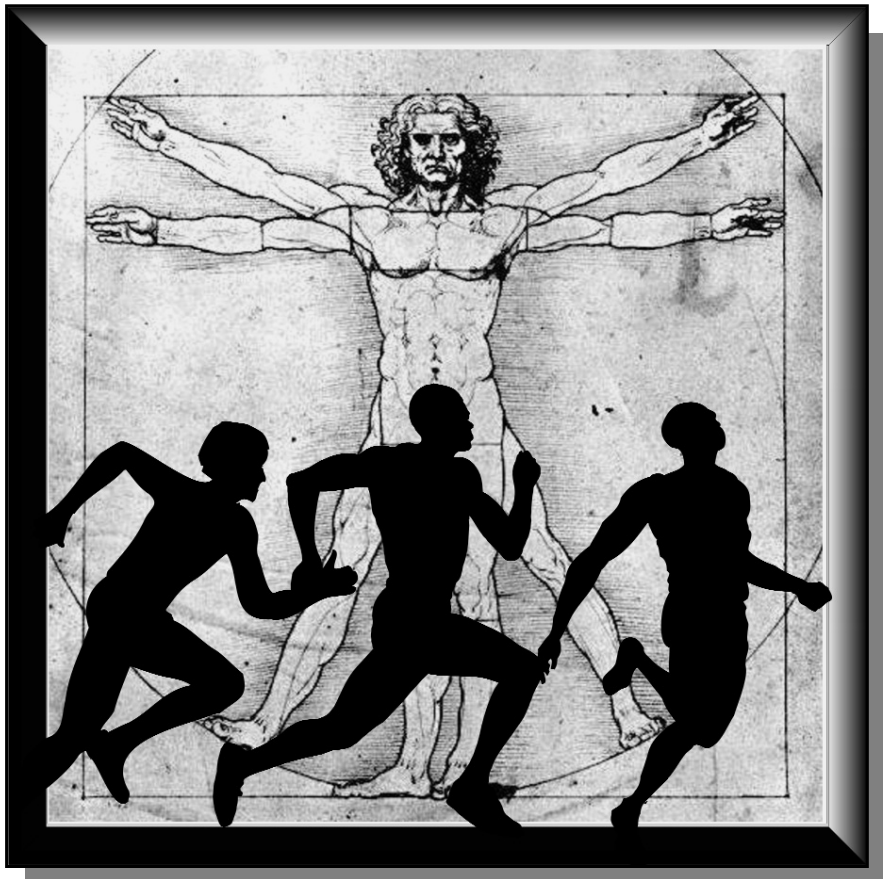
# *The Principles, Theories & Precepts of Biology*

**This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.**



## *Chapter 1*

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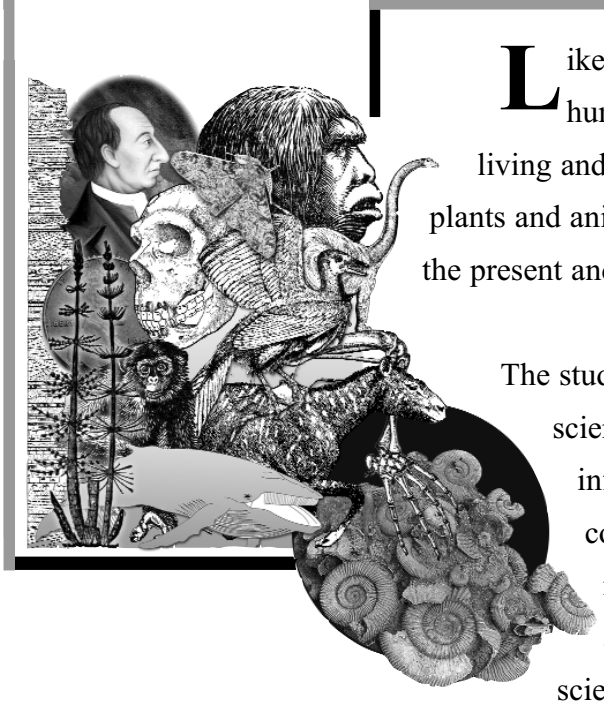
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# *The Principles, Theories & Precepts of Biology*
# INTRODUCTION



Like other sciences, the study of Biology is humanity's quest to understand life. Organisms, living and dead, are considered in assessment of humans, plants and animals in an effort to understand the past, occupy the present and project the future.

The study of Biology is not without controversy among scientists whose personal belief systems may influence interpretation of data. Scientists draw conclusions and proclaim theories according to research and personal beliefs. This course attempts to present information based on the scientific method of observation of data with admission that some theories simply cannot be subjected to the scientific method due to the absence of complete living or dead organisms with which to conduct comprehensive studies. Consequently, this Biology course focuses on the marvelous and astonishing evidence that life is a wonderful mystery to be explored and appreciated.



As you read the text and respond to activity questions, you will begin to embrace awareness that you are an intricate and special being. You will enjoy this course because it allows you to challenge theories, discuss precepts, question principles and engage in open dialog about the *Principles, Theories and Precepts of Biology*.

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DNA



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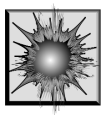
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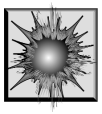
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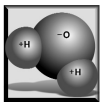
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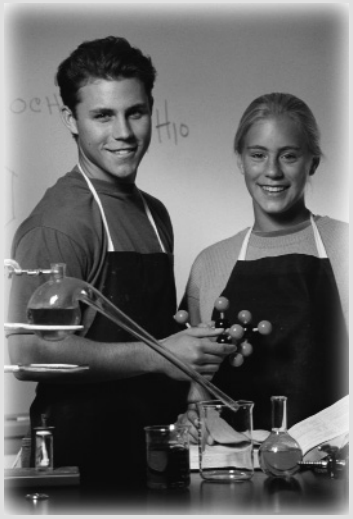
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"Biology is man's attempt to understand who he is, where he came from, why he is here, and where he is going."

—Ronald E. Johnson, C.Ph.D.



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*Life*

**Lesson 1**

# *Chapter 1*

## *A LOOK AT LIFE—THE STUDY OF BIOLOGY*

## Section 1

***Lessons 1-5***







Most teenagers ask serious questions about life. Perhaps you have wondered how to define life. Maybe you have wondered what makes a frog and a rock different, or what makes a plant different from dirt. Of course, many differences can be listed. A rock cannot breathe, nor can it reproduce. Dirt certainly cannot produce green leaves and fruit.



A living thing may move or breathe, but not all living things do breathe or move. Plants do not move from place to place, but they do breathe in their own way. Organisms such as some yeast can live without air! Living things reproduce themselves, but then again—so can some non-living things such as crystals. A crystal put into a saturated solution of the same substance, can actually act as a seed and cause many more crystals to be "born."

A flame of fire has many properties which living things also possess; it moves, it grows, it consumes, and it could even be said to reproduce itself! But fire cannot fit into the category of "living things." Common sense observations of this kind are clear to us all. However, what is obvious in ordinary life is not always obvious in the world of science.

For example, if you were to compare the chemical composition of a rock to that of the frog, you might find many similarities. You would also find many differences! Not all of the naturally occurring elements that you might find in a rock are of particular importance to living organisms. However, six

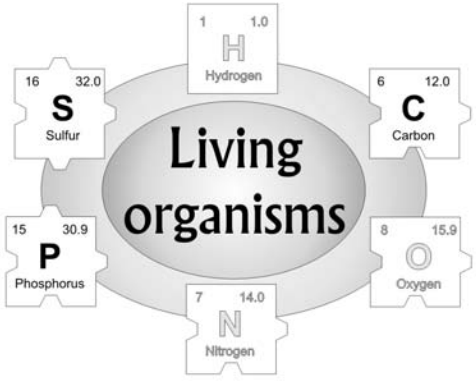
## VOCABULARY

***Biology:*** the study of living beings and life processes
***Intricate:*** having many complexly integrated parts that are difficult to analyze or track; highly complicated
***DNA:*** the molecular basis of or code of life in living (or once living) organisms
***Pale:*** to appear dim, feeble, deficient or inferior

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elements play a most important role: hydrogen, carbon, oxygen, nitrogen, phosphorus and sulfur. These occur in all living creatures and are absolutely necessary for life as we know it.

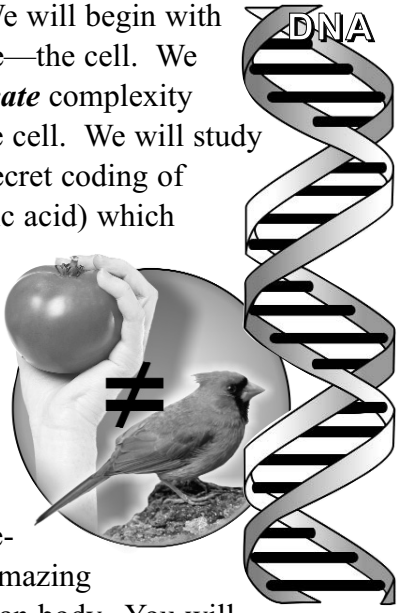



So, we can begin to define life by the type of elements present in living organisms. Certain elements are abundant in life while other elements are not.

The next logical step in your observations would be to determine the difference between a dead frog and a live frog. A dead frog cannot breathe, reproduce or grow. A dead frog will decompose; a living frog will continue to grow and require energy from food. However, immediately after death, no differences remain between the two in composition. All the necessary chemicals for life are present in the dead frog. However, something is missing: the breath of life.

The breath of life remains a mystery in the scientific world. No one has been able to create life from the six basic elements. Many scientists have tried; all have failed. At this time in history, no formula or solution exists in the physical world that can bring a dead creature back to life. Furthermore, physical life ceases when the breath of life leaves an organism.

This study of ***biology*** and living organisms will take you on a most fascinating journey. We will begin with the smallest unit of life—the cell. We will examine the ***intricate*** complexity and organization of the cell. We will study the most remarkable secret coding of ***DNA*** (deoxyribonucleic acid) which defines who you are! We will study why a bird is not a tomato, and why a tomato is not a fish. We will learn about living creatures of all kinds, from the simple, single-celled bacteria to the amazing complexity of the human body. You will find that even the *least* complicated living things have internal machinery that shows incredible engineering. The most intricate man-made machines ***pale*** in comparison!




This entire course is all about life; yet when you have completed this study, you will probably still lack a good definition of life. You will, however, have a much deeper appreciation for, and understanding of, being alive.

**In the next lesson, we will discuss the importance of the scientific method.**



## LIFE PRINCIPLE

**"There is no part of life that does not contain its lessons. If you are alive, there are lessons to be learned."**

—Chérie Carter-Scott in *The Rules for Being Human*.

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Scientific Laws

**Lesson 2**

# *Chapter 1*

## SCIENTIFIC METHOD

## Section 1

***Lessons 1-5***




Often when we think of scientists, we imagine mysterious, undercover proceedings in a sterile laboratory. Perhaps we picture strange but brilliant men and women dressed in white who spend all their waking hours in the laboratory—inventing and discovering.

The ***scientific method***, the process by which discoveries are validated, is actually a simple, logical, step-by-step procedure that we all use daily to make decisions. Very simply stated, we use observations in the natural world as well as in the experimental world to draw conclusions. In the world of science, we begin with a given *premise* called a ***hypothesis*** based on some initial observations. Next, we try to prove or test the hypothesis by collecting data, then designing and performing experiments. When enough test evidence is collected to validate the hypothesis, a ***theory*** is established. Over time, and supported by much experimental evidence without exception, the theory gains enough acceptance from the scientific community to become a ***scientific law*** because no exceptions to the theory have been found.



During the process of collecting data, the scientist must be willing to alter or even abandon his most cherished generalizations when they are contradicted by new facts. The scientist's question must always be: "What is the evidence?"

Unfortunately, because scientists are human, they are not always objective, open-minded people. Some scientists cling to old ideas simply because the scientific community generally rejects radically new ideas. On the other hand, a scientific discovery may be accepted well

## VOCABULARY

***Scientific Method:*** the process by which a general statement (a hypothesis) is written and tested through experimentation in order to reach a conclusion regarding the hypothesis

***Hypothesis:*** an assumption made in order to test and prove a logical conclusion

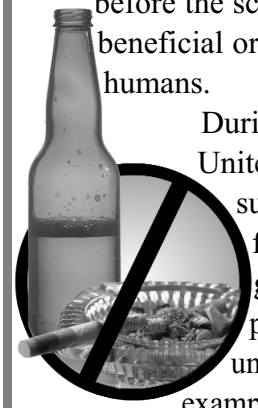
***Theory:*** a scientifically acceptable and tested hypothesis offered to explain observed facts

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before it is thoroughly tested. The history of science is full of scientific ***dogmas*** that turned out to be wrong, although for a time they were widely accepted by other scientists. This is one reason why the cautious society—and biology student—will not place too much faith or invest heavily in any theory until it clearly withstands the test of time.

Often, the scientists who make discoveries have no influence on how their discoveries are applied by organizations or individuals in society. Unfortunately, some scientific discoveries have been used carelessly. Certain products and practices have been endorsed and promoted by governmental agencies and large corporations before the scientific method verified beneficial or harmful effects on humans.



During World War II, the United States was so anxious to support military recruiting films that the public gullibly accepted advertised products which had not undergone testing. For example, smoking tobacco and drinking alcoholic beverages were habits promoted and glamorized in Hollywood films which were financed by tobacco and alcohol industries. Years later, both habits were proven to be devastating to human health.

During the 1950s and 1960s, the drug *Thalidomide* was prescribed for morning sickness for pregnant women before physicians recognized that the drug caused terrible birth defects. Fortunately, it was never approved in the United States for this use, but it was used extensively in Europe. The drug was never thoroughly tested by the pharmaceutical industry because industry professionals assumed that the mother's uterine wall would filter out all harmful chemicals.

These examples illustrate how the scientific method can be ignored for the sake of convenience or financial benefit. Fortunately, the public is beginning to take more responsibility for their health by demanding that medical suppliers validate claims of health products. With the Internet and other resources, a wealth of information about any health issue is now available to the consumer. The public is now encouraged to apply their own method of scientific reasoning.

Unfortunately, only during recent decades has the consumer begun to demand scientific proof about products or theories. The following story sadly illustrates how devastating the results can be to life and health if the scientific method is not applied properly.

### VOCABULARY

***Scientific Law:*** a theory supported by experimental evidence and many years of successful observations with no exceptions
***Dogma:*** a point of view put forth as authorative but lacking evidence
***Renaissance:*** (ren·e·säns) a French word for the intellectual/cultural revival and beginning of modern science during 1300–1600

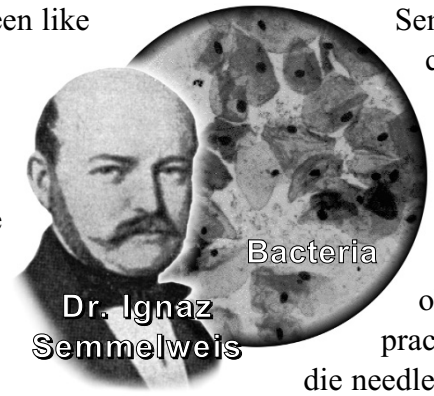
## THE STORY OF DR. IGNAZ SEMMELWEIS

Throughout history mankind has suffered billions of deaths due to infections from microscopic germs. Germs from a dead

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human body are more dangerous to a living human than the germs from an animal's body because of the greater likelihood of transmission of infection between like species. Sadly, mankind's ignorance of deadly microscopic germs has caused much suffering and death. Only since the late 1800's have medical professionals understood the importance of sanitary procedures in hospitals, homes and military campsites.




In 1845, a brilliant Hungarian medical doctor, Dr. Ignaz Semmelweis, observed that the death by infection of women who gave birth in hospitals was between 15-30 percent. This tragic situation was considered normal at the time. Dr. Semmelweis noted that every morning the young medical interns first examined the bodies of patients who had died; and then, without washing their hands, went to the next ward to examine expectant mothers. This astonishing behavior was considered normal medical practice in the 1800s because the existence of microscopic germs was unknown. As a result, thousands of women died needlessly.




Dr. Semmelweis insisted that the doctors under his supervision follow his new orders to wash their hands vigorously in water and chlorinated lime prior to examining living patients. Immediately, the death rate caused by infection among the expectant mothers fell to less than 2 percent. Despite these incredible improvements, the senior hospital staff rejected Semmelweis' hypothesis and eventually fired him! His unconventional ideas were ridiculed by colleagues because they refused to believe that infections could be caused by something invisible to the naked eye. Dr. Semmelweis continued trying to convince doctors in other hospitals in North America and Europe of the need for hospital sanitation, but the medical establishment continued to ignore the obvious benefits of sanitation practices. Patients continued to die needlessly of infectious diseases while in hospitals. Finally, in the late 1800s, indisputable evidence became overwhelming, and Dr. Semmelweis' techniques were finally accepted and implemented in hospitals.

History reveals that the scientific community is rarely in a hurry to embrace new concepts at variance with accepted ideas. True to pattern, scientists of that day rejected the new, radical idea of clean hands, even when the data was overwhelmingly in favor of Dr. Semmelweis' hypothesis. Today, sanitation is of utmost importance in medical procedures. Scientists no longer doubt that microscopic germs cause disease. We no longer have to test this hypothesis. It is no longer theory; it has become a scientific law.

## Limitations of the Scientific Method

As a hypothesis is being tested through experimentation, certain limits or boundaries are reached. For example, spiritual, mental, and emotional events, feelings, and concepts cannot be tested physically, and therefore cannot be evaluated by science. Science can measure certain occurences that are ascribed to God, such as

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gravity, the speed of light or the intensity of a storm. The existence of God, however, cannot be proved or disproved by laboratory experiment.




Science cannot make value judgments: it cannot prove that a painting is beautiful. Science cannot make moral judgments: it cannot say that war is immoral. Science can, however, analyze the human response to paintings, and it can analyze the biological, social and cultural implications of war.

Scientists are fond of saying that science is never good or bad; only society's use of science has moral consequences. From a purist's point of view, this is true. The discovery that the atom could be split was merely a scientific discovery with no moral implications. It was society's decision to use this knowledge to build an atom bomb that produced the moral dilemma of whether or not mankind was justified to use such a devastating weapon of war.

However, with new discoveries being made—especially in the field of biology—some scientists now feel that they must become involved in society's moral decisions about science. A few scientists are promoting human cloning. Some scientists contend that parents should have the option to choose the genetic character of an unborn child. Moral judgments have become a necessary part of science. The debate will escalate when society attempts to define the value system which will guide scientists in moral decisions.

Galileo Galilei (1564-1642) is generally considered to have established the modern scientific method, as demonstrated in his famous investigation of falling bodies at the Leaning Tower of Pisa, Italy. According to legend, he simultaneously dropped from the tower two cannon balls, one 10 times heavier than the other. When he observed that they struck the ground at the same time, he concluded that all objects fall at the same rate of speed regardless of weight. His emphasis on experimentation as the logical way to prove the validity of ideas was part of the broader movement of free thought and skepticism that was characteristic of the period of history known as the *European* ***Renaissance*** during the 1500s to 1600s.

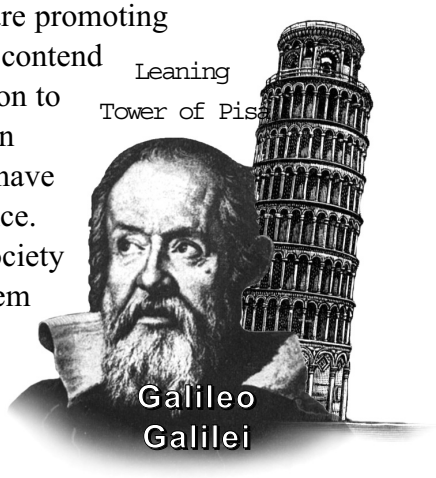
**In the next lesson, we will highlight the rise of modern science.**



## LIFE PRINCIPLE

**"Man will occasionally stumble over the truth, but usually manages to pick himself up, walk over or around it and carry on."**

—Winston Churchill
(1875-1965)
British Statesman




WATCH VIDEO:
Hammer & Feather

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Discoveries

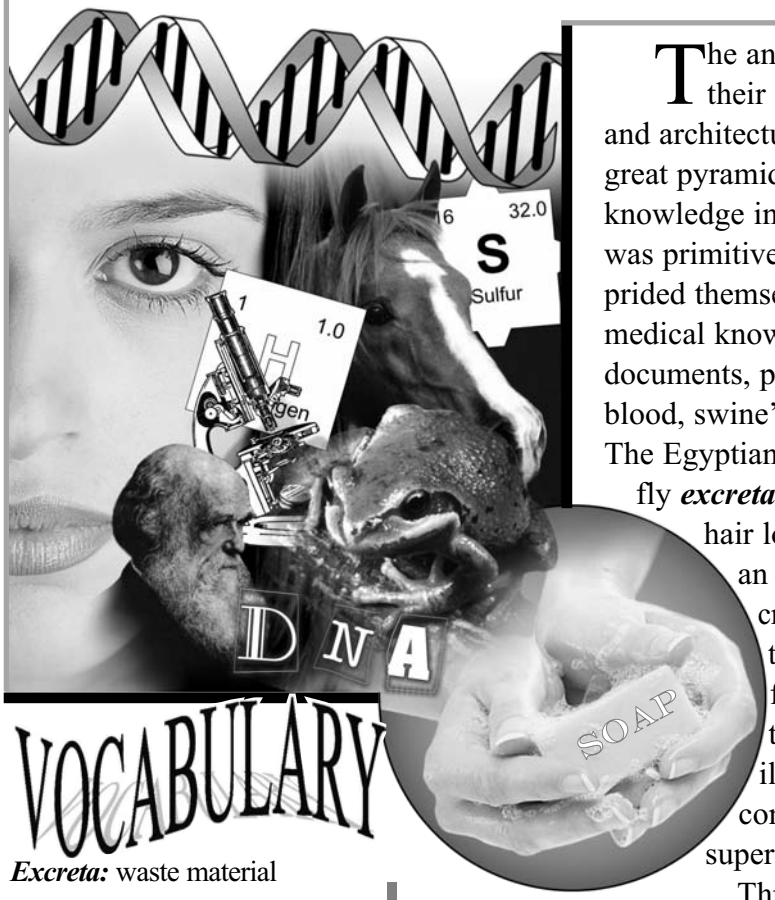
**Lesson 3**

# *Chapter 1*

## Section 1

***Lessons 1-5***

## *PUTRID MEAT AND STINKING FAT—EARLY HISTORY OF SCIENCE*




The ancient Egyptians were well known for their advanced astronomical knowledge and architectural engineering, as evidenced by the great pyramids. However, the Egyptian level of knowledge in biological and medical practices was primitive and dangerous. Nevertheless, they prided themselves on their presumed great medical knowledge. According to ancient documents, popular prescriptions included lizard's blood, swine's teeth, putrid meat and stinking fat. The Egyptian's remedy for a painful tumor was fly ***excreta*** mixed with sycamore juice. For hair loss, Egyptian doctors recommended an application of fats from a horse, a crocodile, a cat, a snake, or a donkey's tooth crushed in honey. Despite the fact that these "remedies" failed and that many people died of serious illnesses, the Egyptian doctors continued applying these crude, superstitious procedures.

Throughout history, every age had its own set of false ideas and assumptions. We read about the example of when the medical community refused to accept simple hand washing as a mandatory sanitary technique. History records many other examples of what seems foolishness to us in the twenty-first century. For hundreds of years, people believed that the Sun and other planetary bodies revolved around the Earth. This idea was known as the ***geocentric theory*** and was alleged in the 1500s to be false. During the seventeenth and eighteenth centuries, another theory was universally accepted and taught as fact. This theory was




## VOCABULARY

***Excreta:*** waste material eliminated from an organism
***Geocentric Theory:*** the theory that the sun and other planetary bodies revolve around the earth
***Phlogiston Theory:*** theory that every substance contains an imagined ingredient, *phlogiston*, which causes combustion
***Dark Ages:*** a period of barbarism and cultural decline from the fall of the Roman Empire (476 A.D.) to about 1000 A.D.
***Rigor:*** strict precision; exactness

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known as the ***phlogiston theory***. It supposed that every substance contained an imagined ingredient called *phlogiston*, which allegedly caused matter to burn. Later, the French chemist, Antoine Lavoisier, demonstrated conclusively that *oxygen* was the combustible substance found in all matter.

Many other historical blunders of science could be mentioned. What we need to keep in mind is that scientists are human beings. The assumption that they are completely objective, error-free, impartial, "cold machines" dressed in white coats is, of course, absurd.

Like everyone else, scientists are influenced by prejudice and preconceived ideas. You should also remember that just because most people believe a particular thing does not necessarily make it true. Majorities can be, and often have been, completely wrong. This truth is very important to remember in any study of science.

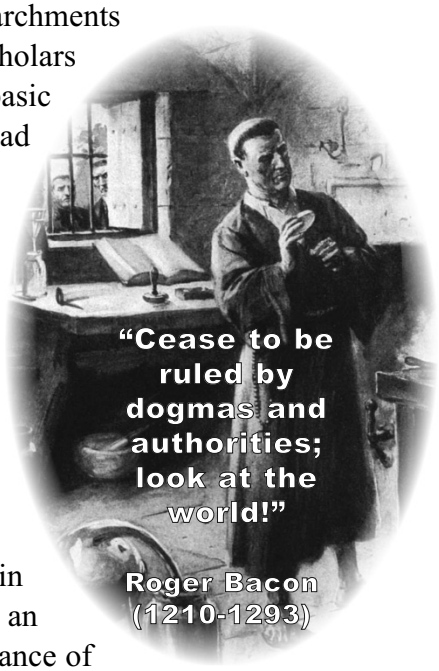
## The Rise of Modern Science

The scientific approach discussed in the previous lesson is of relatively recent origin. It may seem obvious to you that the way to learn about nature is to look at it, to seek evidence by observation. However, for many centuries, observation was not the obvious procedure for men and women seeking answers. Even though major scientific discoveries were made in several of the ancient civilizations such as Babylonia and Greece, these early activities were very limited. The world experienced a steady decline in scientific learning a century or so before the birth of Christ. Between about 200 and 1200 A.D., virtually no important discoveries were made, and much of what had been discovered was lost or forgotten during the period of time called the ***Dark Ages***. Instead, superstition reigned along with greater reliance on Roman church dogma. "Scholars" were more likely to haggle over the exact meaning of a sentence in one of Aristotle's books on plants than actually studying the plants themselves. Most ancient scholars never even entertained the idea of conducting experiments, or that revered authorities might have been in error on some assertions.

VOCABULARY

***Treatise:*** (tre·tes) a written exposition or argument including facts, principles and conclusion presented methodically

Then came a period of intellectual awakening in Europe. Scientists began studying ancient parchments used by Hebrew scholars who accepted the basic premise that God had established the universe and put certain laws into existence. Therefore, man was merely discovering the laws of God. Roger Bacon (1210-1293), at Oxford University in England, called for an end to blind acceptance of traditional teachings such as those of Aristotle. Bacon said, "Cease to be ruled by dogmas and authorities; look at the world!" Francis Bacon (1561-1626), three centuries later, championed the experimental approach

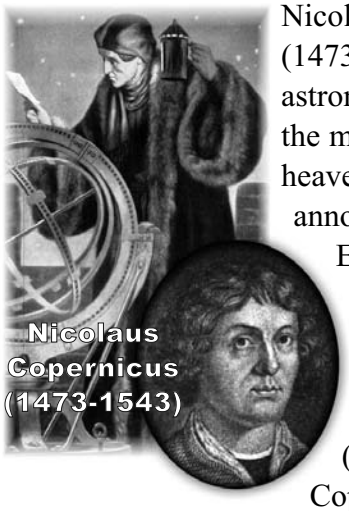


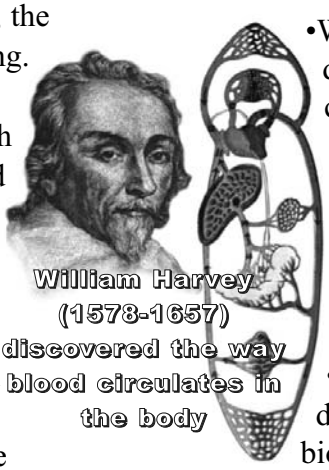

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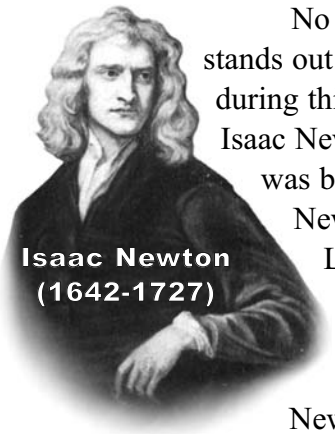
to science, urging all men to trust no statements without verification and to test all things with ***rigor***.

Within the physical sciences, the intellectual climate also was changing. Nicolaus Copernicus (1473-1543), a Polish astronomer, analyzed the movements of heavenly bodies and announced that the Earth moves around the Sun rather than the Sun around the Earth! Galileo Galilei (1564-1642) embraced Copernicus' theory, but was forced to retract his belief under threat of excommunication from the Church of Rome. Despite Galileo's retraction, educated men could no longer be suppressed. They began to question accepted theories and to express new ideas. The knowledge explosion had begun!



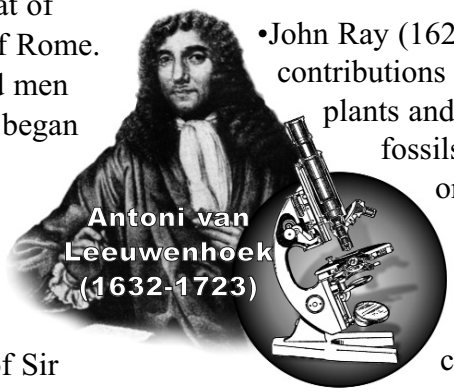




No other name stands out so prominently during this period as that of Sir Isaac Newton (1642-1727), who was born the year Galileo died. Newton's discovery of the Law of Gravitation and the movements of the planets brought physical science into a new era. Newton's mathematical and astrological achievements and scientific laws were based primarily on biblical concepts.




Simultaneously, biological science was advancing at its own rapid pace:

- Andreas Vesalius (1514-1564) described in greater detail than ever before the anatomy of the human body.
- Ulisse Aldrovandi (1522-1605) published three large books on birds and a huge ***treatise*** on insects.
- William Harvey (1578-1657) discovered the way blood circulates in the body.
- Marcello Malpighi (1628-1694) extended Harvey's work and made major contributions to the understanding of the way the embryo develops.
- Robert Hooke (1635-1703) first detected the presence of cells in biological material.
- Antoni van Leeuwenhoek (1632-1723) studied and described many microscopic organisms.




- John Ray (1627-1705) made major contributions to the knowledge of plants and correctly explained fossils as the remains of once-living organisms.
- Carolus Linnaeus (1707-1778) founded the modern system of classifications of living organisms.

Even though the discoveries by these men were important, their work during this time (1600-1700) did not spark the sort of explosive growth of biological science, as did Newton's work in the field of physical science. The explosion of biological science did not begin until 1859 when British naturalist Charles Darwin (1809-1882) introduced his book: *On The Origin of Species by Means of Natural Selection or The Preservation of Favored Races in The Struggle for Life*.

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**In the next lesson, we will explore the life of Charles Darwin.**

# LIFE PRINCIPLE



**"In questions of science, the authority of a thousand is not worth the humble reasoning of a single individual."**

—Galileo Galilei (1564-1642)
Italian scientist and mathematician

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Theories

**Lesson 4**

# *Chapter 1*

## Section 1

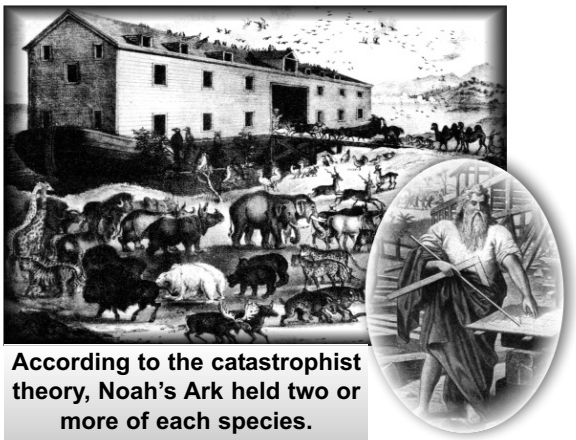
***Lessons 1-5***

## *DARWIN AND THE THEORY OF EVOLUTION*




In Charles Darwin's book, *On the Origin of Species by Means of Natural Selection or the Preservation of Favored Races in The Struggle for Life*, Darwin proposed his theory of ***evolution*** by ***natural selection***. His book caused an ongoing explosive debate in the scientific community.

At the time his work was published in 1859, most scientists adhered to the "catastrophist theory," also known as *creationist theory*. The ***tenents*** of this theory state that the Earth experienced a succession of creations of plant and animal life, as well as mankind, which, centuries later, were largely destroyed by a sudden ***catastrophe***. According to this theory, a world-wide catastrophe called Noah's Flood destroyed all life except two or more of each species taken into a large ship called an *ark*. Since the flood, the remains of life have been visible only in the form of fossils. Also in the view of catastrophist theory, all species had been individually created and changed very little, if at all, over time.



**According to the catastrophist theory, Noah's Ark held two or more of each species.**

Although the theory of evolution had been introduced to the scientific community prior to Darwin's work, his ideas on natural selection sparked heated debates between the catastrophists and the evolutionists. Whether to prove or disprove Darwin's theory, biologists began to search diligently for new information. Darwin's work is responsible for creating a rapid growth in

## VOCABULARY

***Evolution:*** the theory that higher forms of life have gradually evolved by chance from inorganic elements and lower life forms into the complex diversity of life that exists today

***Natural selection:*** the process which results in the survival of individuals or groups best suited for their environment

***Tenents:*** beliefs or principles held to be true by a group or organization

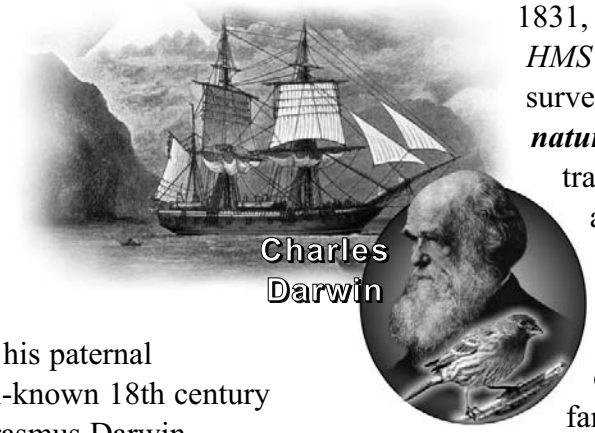
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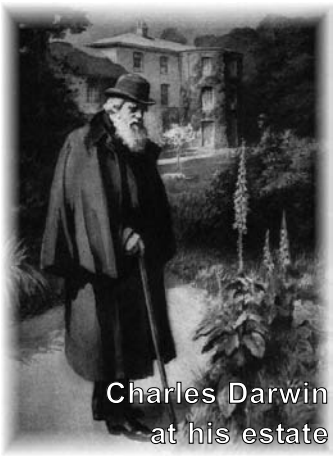
biological research. Darwin's book greatly accelerated speculation and research to discover and test new information in the field of biology.

## DARWIN'S STORY

Born in England in 1809, Darwin was the fifth child of a very wealthy and sophisticated family. His maternal grandfather was the successful china and pottery entrepreneur, Josiah Wedgewood, and his paternal grandfather was the well-known 18th century physician and genius, Erasmus Darwin. After graduating from an elite school at Shrewsbury in 1825, young Charles Darwin was sent by his father to the University of Edinburg in Scotland to study medicine, in which Darwin had little interest. He dropped out two years later and was sent to Cambridge University in England to prepare for becoming a clergyman, a "last resort" for failures in many rich families of that time.




When Darwin graduated in 1831, he was taken aboard the *HMS Beagle*, an English survey ship, to serve as a ***naturalist***. Darwin was not a trained naturalist, but had always been more interested in animal pursuits than in his studies, much to the embarrasment of his family. During the five year voyage, Darwin made many observations in nature, with a special emphasis on a particular type of bird called a *finch*.




After returning to England in 1836, Darwin began to develop his theory of evolution through natural selection. For the next two decades, Darwin refined his theory and worked on other natural history projects. Darwin inherited wealth, thus he had time to pursue development of his theory. In 1839, he married his wealthy first cousin, Emma Wedgwood, and soon after moved to Downe House, a small estate outside of London. There, he and his wife had ten children, three of whom died in infancy.

Darwin's theory was first announced in 1858 in a ***paper*** presented at the same time as one by Alfred Russel Wallace, a young naturalist who, independently, had also

### VOCABULARY

***Catastrophe:*** a sudden, violent change in features of Earth by means of a global flood, upheaval or convulsion of the earth's surface.
***Naturalist:*** a student of nature, specifically plants and animals.
***Paper:*** a formal, written composition often designed for publication
***Catalyst:*** something that prompts a dramatic change
***Skeptics:*** persons having a doubting state of mind, especially concerning religion
***Aryan:*** referring to white, Northern Europeans and a white-supremacy philosophy
***Regime:*** (ray·zheem) a socialist form of government

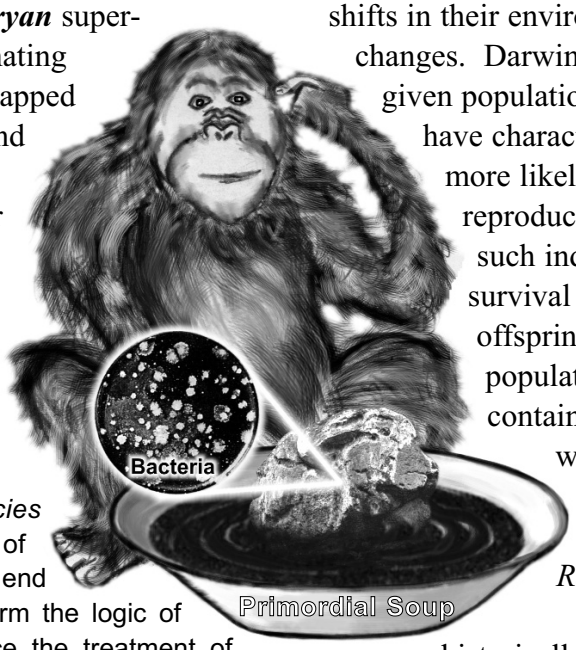
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proposed the theory of evolution via natural selection. Both men introduced their theories at a time when some European scholars were doubting church leadership. Hence, the theory of evolution offered a ***catalyst*** for ***skeptics*** to reject Biblical concepts. Fearful that Wallace would publish his work first, Darwin rushed to publish his own work in 1859: *On The Origin of The Species by Means of Natural Selection or The Preservation of Favored Races in The Struggle for Life*. This book is often referred to as "the book that shook the world." The title was later referred to only as *The Origin of Species*, partly due to the racial overtones of the full title. This concept not only "shook the world" in Darwin's time, but would shake it again 60 years later when Adolf Hitler, a proponent of Darwinism and "favored races", attempted to build an ***Aryan*** super-race of people by eliminating Jews, Christians, handicapped persons, homosexuals and all others considered to be of inferior quality for Hitler's Nazi ***regime***. According to noted liberal educator John Dewey in *The Influence of Darwin on Philosophy*:




> The *Origin of Species* introduced a mode of thinking that in the end was bound to transform the logic of knowledge, and hence the treatment of morals, politics, and religion.




Darwin's theory consisted of two major parts: the concept of evolutionary change and the concept of natural selection. First, Darwin rejected the catastrophist theory, which holds that living creatures are basically unchanging products of sudden, purposeful creation that exist now very much as they have since their creation. Darwin insisted, on the contrary, that change is the rule, and that organisms living today have evolved by chance and gradual change from ancient ancestors quite unlike modern beings.

Secondly, Darwin maintained that *natural selection* determines the course of biological change. Life, he believed, is a competitive struggle to survive and often under conditions of limited resources: living things must compete for food and space; they must evade the dangers of predators and disease while dealing with unpredictable shifts in their environment, such as climatic changes. Darwin suggested that within a given population, certain individuals have characteristics that make them more likely to survive and reproduce. Darwin believed that such individuals passed critical, survival characteristics to their offspring; therefore, the population would gradually contain only those individuals with characteristics critical for survival—or *The Preservation of Favored Races*.

A central and historically controversial component of evolutionary theory is that all living organisms, from microscopic bacteria to

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plants, insects, birds and mammals, share a common ancestor. Species that are closely related ostensibly share a recent common ancestor, while distantly related species supposedly have a common ancestor further in the past. The animal most closely related to humans, for example, might be the chimpanzee. By projecting into the far distant past, evolutionary theory allows humans to have bacteria as a common ancestor. The theory maintains that bacteria arose from a "primordial soup", consisting of non-living materials. Therefore, Darwinism claims that humans gradually and mysteriously evolved from non-living materials. Some critics humorously claim that evolution proposes a philosophy of "from goo to you by way of the zoo."

Darwin's theory has been periodically modified and updated to reflect new biological and geological discoveries; consequently, many changes have been made to Darwin's original theory. However, the debates between the evolutionary theorists and catastrophist theorists still rage. Evolutionists insist that their theory must be right and that missing fossil evidence is merely the result of a flawed fossil record; the catastrophists insist that evolutionists have not exercised the scientific method of discovery and therefore have little real scientific evidence to prove their theory.

In a later chapter we will be taking a much closer look at evolution and the scientific evidence that is available. Until we arrive at that lesson, consider the statement of British biologist L. Harrison Matthews in the foreword to the 1971 edition of Darwin's *The Origin of Species:*

> The fact of evolution is the backbone of biology; and biology is thus in the peculiar position of being a science founded on unproved theory—is it then a science or a faith? Belief in the theory of evolution is thus exactly parallel to belief in special creation—both are concepts which believers know to be true but neither, up to the present, has been capable of proof.

**In the next lesson, we will examine characteristics that define life.**

## LIFE PRINCIPLE



**". . . .There is more evidence to suggest an abrupt arrival of man rather than a gradual process of evolving . . . ."**

—Richard Leakey,
Leading paleoanthropologist
in a 1990 PBS documentary

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**Lesson 5**

# *Chapter 1*

## FEATURES OF LIFE

## Section 1

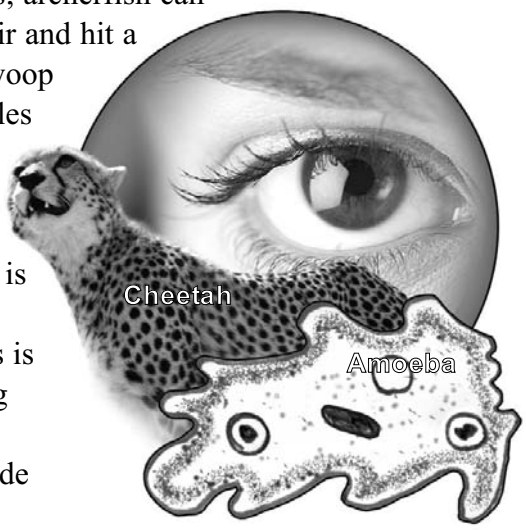
***Lessons 1-5***




As we discussed in the first section of this chapter, life is quite difficult to define. Living organisms are distinguished by numerous features not found in most non-living systems; yet none of these characteristics is unique to life. For each identified characteristic in living organisms, the same property can be found in some non-living system. Even though a clear definition of life may be difficult to formulate, scientists have been able to identify the main features of living organisms.

1 **Living systems are highly ordered and complex.** The chemicals that make up living organisms are much more ordered and organized on a ***molecular*** level than are the chemicals that make up most non-living systems. Nature is teaming with countless examples of remarkable order and complexity. From the lowly, one-celled ***amoeba*** to the human eye, the list of biological wonders is practically endless. The cheetah can run 70 miles per hour; some insects can sleep for 17 years; ink-shooting octopuses can eat their own arms and grow new ones; archerfish can shoot water 15 feet into the air and hit a bug; peregrine falcons can swoop down on their prey at 150 miles per hour.

Without doubt, however, the most amazing and complex living organism is the human body. One of the biggest mysteries to scientists is the human eye. This amazing organ is more complex and dependable than any man-made




## VOCABULARY

***Molecular:*** pertaining to the tiniest, most basic components of life in living organisms
***Amoeba:*** a simple, single-celled organism
***Inborn:*** inherited; present at birth
***Symbiotic relationship*** or ***Symbiosis:*** a friendly relationship between organisms of two different species that live together in direct contact; each receives benefit from the other.

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camera. The eye produces stereoscopic pictures and is fully automatic. The eye can see in total darkness and in very bright sunlight. The eye can focus on a tiny bug at very close range or it can take in the beauty of a distant, snow-capped mountain. The human eye is constantly at work and even has its own maintenance routine.

Scientists admit they do not fully understand the way the human eye operates. Many scientists realize that the eye would be of no use if it were not fully functional all at once; therefore scientists do not agree that the eye structure developed in a gradual, trial and error manner. Even Charles Darwin found the concept of evolution of the human eye to be absurd:

> To suppose that the eye, with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the corrections of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest possible degree.... The belief that an organ as perfect as the eye could have formed by natural selection is more than enough to stagger anyone.

2 **Living things take things from their environment.** Most organisms depend directly or indirectly on energy from the sun. Green plants use solar energy to make food that supports virtually all other organisms on Earth. All organisms gain energy from food to maintain body orderliness, to grow and to reproduce. Some organisms are very creative in collecting their food. An example is the decoy-fish, which lives in the waters near Oahu, Hawaii. This fish uses its dorsal fin as a lure to attract other fish on which to prey. The decoy-fish raises its fin, which appears to be a separate, smaller fish. This decoy appears to have a "mouth" and an "eye"! The decoy-fish enhances its deception by stopping all gill and breathing movements. Then the lure becomes a deep red color, while the part attached to the decoy-fish's body becomes clear, so that the lure appears to be a small, singular fish. An unsuspecting victim approaches the trap thinking it is food, but the victim soon becomes dinner for the decoy-fish.

VOCABULARY

***DNA (deoxyribonucleic acid):*** the molecule responsible for heredity; found in the cell nucleus

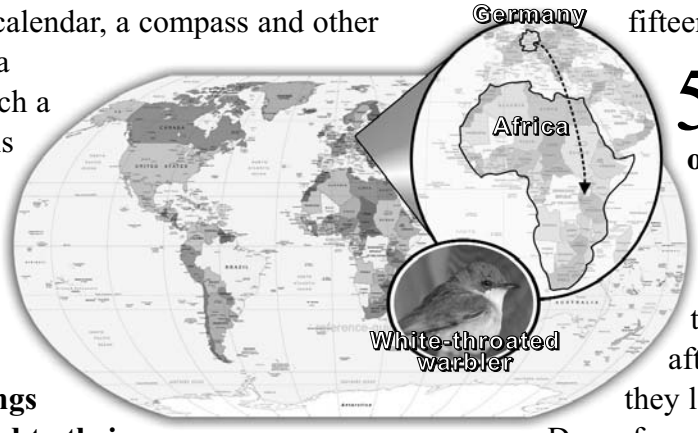
3 **Living things respond actively to their environment.** A stone may move passively when it is pushed. An animal that is pushed may respond actively by running away, bending towards you, or rolling up into a ball. The stem of a plant bends toward light, while the roots will grow downward. Some living things are programmed to adjust to climatic changes by growing thick fur for winter or losing long hair during the summer. Other creatures simply fly elsewhere to avoid cold climates.

Migratory instincts illustrate a different way living things respond to their environment. For example, a small bird, the white-throated warbler, spends its summers in Germany and its winters in warmer Africa, below the equator near Lake Victoria (the second largest lake in the world). At the end of summer, the parent birds fly off to Africa, over 5,000 miles away, without the newly hatched youngsters. Several weeks later, the young birds are able to leave Germany and

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fly instinctively across thousands of miles of unfamiliar territory in order to join their parents. The young birds seem to be blessed with an ***inborn*** calendar, a compass and other navigational data necessary for such a flight. All of this enables them to fly unguided to the exact location of their parents!




**4 Living things are adapted to their environments.** Living organisms are well suited to their environment. Fish, earthworms and frogs are all designed in such a way that we can generally predict certain things about them just by observation. Additionally, many organisms have ***symbiotic relationships*** or ***symbiosis*** in response to an environment. For example, the environment of the Bull's Horn Acacia tree of Central and South American jungles makes a great home for ants. The tree is furnished with large hollow thorns that are inhabited by a species of ferocious stinging ants. Small bumps on the tree also supply food to the ants. As a result, the ants get food and shelter from the tree. The tree, for its part of the bargain, receives complete protection from all animal predators and plant competitors. The ants will viciously attack any and all intruders. Additionally, they regularly bite off every green shoot that comes up near "their" tree. As a result, this particular tree always has plenty of sunlight and space, which is quite unusual in a tropical jungle. Experiments have shown that when the ants are removed, the tree dies within two to fifteen months.

**5 Living things reproduce offspring of like kind.** New animals and plants arise only through the process of reproduction. Living things produce offspring after their own kind so that they look like their parents. Dogs, for example, reproduce dogs, not cats. Eagles reproduce eagles. Bees reproduce bees. Oak trees reproduce oak trees. Each kind continues to reproduce its own kind, generation after generation.

**6 The information that each organism needs to survive, develop and reproduce is segregated within the organism and passed from each organism to its offspring.** Every living thing contains genetic material in an information store known as ***DNA (deoxyribonucleic acid)***.

Reproduction and the transmission of hereditary or inherited information are




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directed by the highly complex DNA molecule. All life, from the most basic bacteria to man is dependent on this awesome DNA. DNA acts as a blueprint for all of your personal characteristics such as your hair, eyes, skin type and height. DNA "programs" every cell in your 206 bones, 600 muscles, more than 100 billion nerves, about 2,500 kilometers (or 1,562 miles) of blood vessels, and even your hair. Your DNA alone stores much more information than any super computer ever designed; yet, the DNA of all organisms which have ever lived could be held in less than a teaspoon! In fact, your DNA stores more information than could be contained in all the books ever written! Truly, the complexity, sophistication and perfection of DNA and its ability to duplicate itself so readily are wonders in the scientific world. Later in this course, you will learn more fascinating details about the incredible DNA molecule.

**The next lesson will introduce some basic concepts of chemistry, which are necessary for an understanding of biology.**



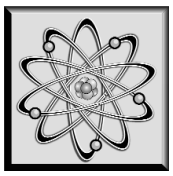
## LIFE PRINCIPLE

**"Chance favors the prepared mind."**

—Louis Pasteur (1822-1895)
French chemist and founder of microbiology

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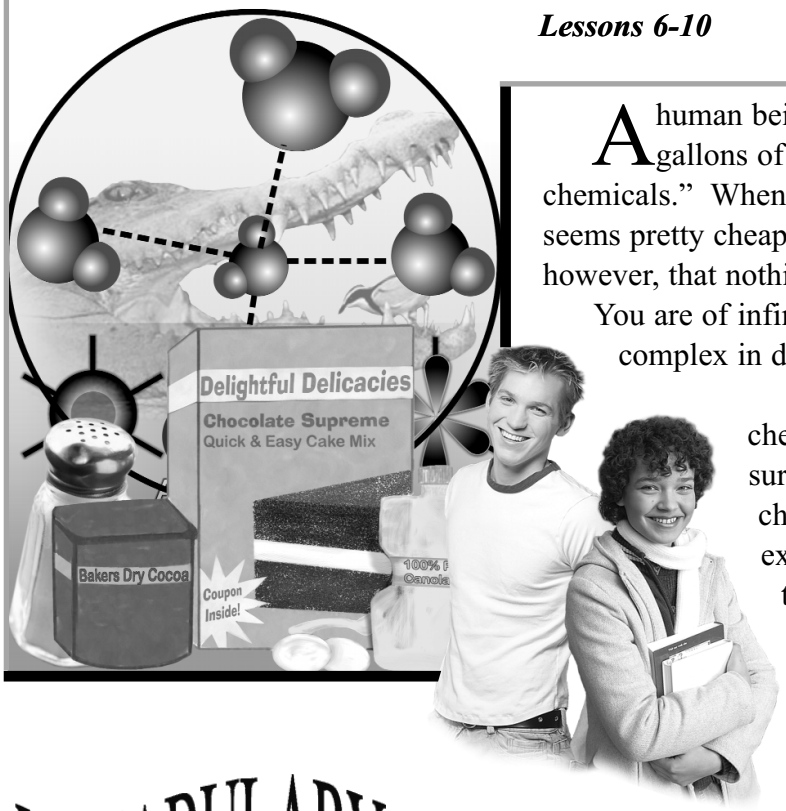

**Lesson 6**

# *Chapter 1*

## *ELEMENTS AND ATOMS—THE FOUNDATION OF LIFE*

## Section 2

***Lessons 6-10***




A human being has been defined as "twenty gallons of water and $5.00 worth of assorted chemicals." When expressed in those terms, life seems pretty cheap and simple. You will discover, however, that nothing could be further from the truth. You are of infinite value in many ways and very complex in design.

All organisms are composed of chemicals; moreover, the environment surrounds organisms with additional chemicals. In this section, we will examine some aspects of chemistry that are essential to the study of biology. This lesson may be a challenge to your concentration, but it reveals the intricate complexity of this wonderful world which you are beginning to understand.

## VOCABULARY

***Element***: a substance that cannot be broken down into other, smaller substances by ordinary chemical means

***Myriad:*** innumerable; too many to count

***Atom***: the smallest unit of an element that still retains the properties of its element

***Nucleus***: the dense core at the center of the atom. Most of the mass of the atom is concentrated here with all of the protons and neutrons

### CHEMICAL ELEMENTS OF LIFE

A chemical ***element*** is a basic substance that cannot be reduced to other kinds of substances during ordinary chemical reactions. Some familiar examples are copper, oxygen, and carbon. Each element is designated by a chemical symbol of either one or two letters that stand for its English or Latin name. Thus, H is the symbol for hydrogen, O for oxygen, C for carbon, Cl for chlorine, Mg for magnesium, K for potassium (the Latin name is *kalium*) and Na for sodium (the Latin name is *natrium*). You may remember your previous study of the periodic element chart as seen on the next page.

Chemists have discovered 113 chemical elements, but living organisms contain only about 20 elements. However, these are not the 20 most common elements. For example, silicon, the most common element in the Earth's crust, is over 300 times more abundant (by weight) than carbon, yet silicon

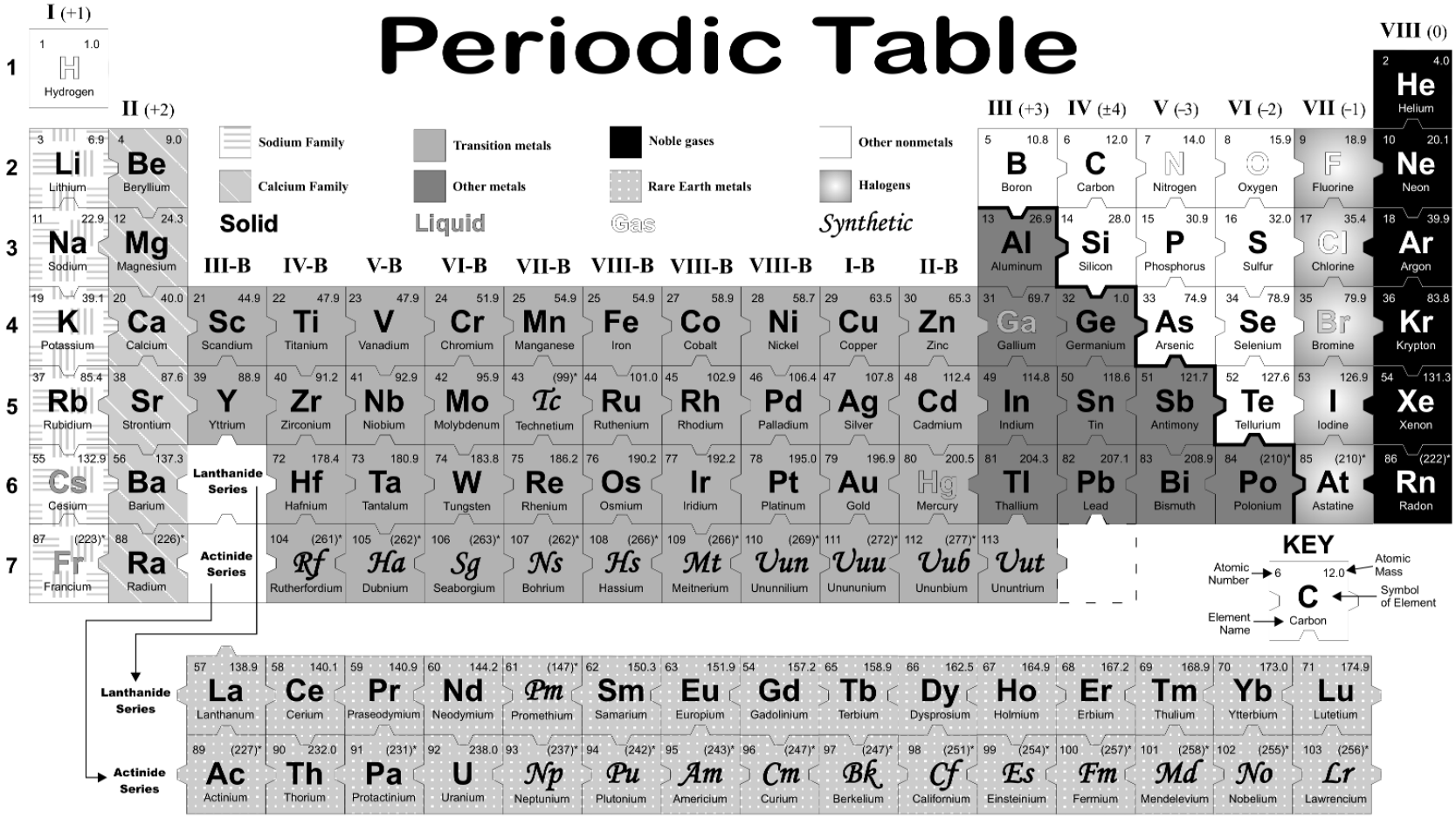
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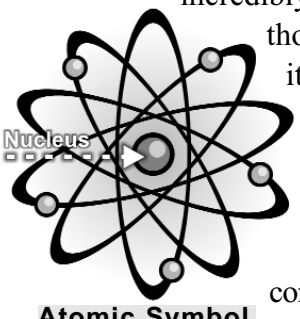
is rarely a major element in life. By contrast, carbon is a critical component of every living thing because carbon has unique properties that make it peculiarly suitable for biological structures.

Organisms select and take in the chemicals they need, rejecting others that are present but are unnecessary for life processes. The roots of a plant, for example, take up certain minerals but exclude others. Animals have complex behavior patterns that allow them to obtain necessary chemicals. Some animals are known to travel miles to visit salt deposits where they can replenish their supplies of sodium.

Scientists have searched to understand why certain life forms depend on other life forms to survive. As a rather unique example, a bird called the *Egyptian plover* boldly walks right into the mouth of the Nile crocodile to get needed nutrients from parasites living in the crocodile's mouth. The bird remains unharmed because it helps to clean up the crocodile's mouth, illustrating another wonderful example of *symbiosis*—a cooperative relationship of mutual benefit between two unlike organisms.



Over time, then, scientists have come to understand that every living organism shares certain elements common to all life. Scientists have also observed that living things depend on each other and that life is incredibly complex, yet orderly, as though the entire Earth and its inhabitants are the result of a master design.



Atomic Symbol

## ATOMIC STRUCTURE

All living things consist of their unique designs and properties. Even though the world is filled with millions of living things

## VOCABULARY

***Proton***: a particle found in the nucleus which carries a positive charge and has a mass of one atomic mass unit (amu)

***Neutron***: like the proton, a neutron is a particle found in the nucleus and has a mass of one atomic unit. However, a neutron bears no charge

***Mass***: the amount of matter an object contains (Matter is defined as anything that takes up space.)

***Electron***: a negatively charged particle which resides outside the nucleus of the atom and has very little mass

***Electron orbitals:*** the region of the atom around the nucleus where electrons are found (also called energy levels or electron shells)

***Atomic number:*** a number representing the amount of protons in an atom

***Atomic mass:*** a number representing the sum of the protons and the neutrons in an atom

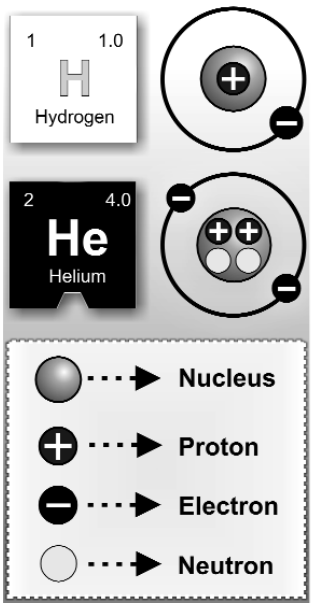
***Isotopes***: different forms of the same element, having the same number of protons but a different number of neutrons; thus, having the same atomic number but a different atomic mass

***Valence***: the number of electrons an atom must gain or lose in order to become stable

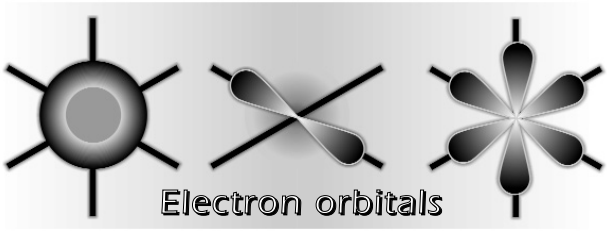
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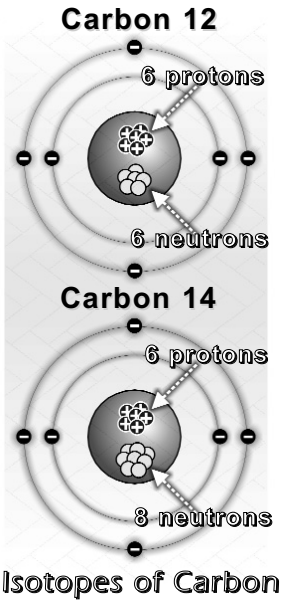
that appear very different from each other, each one has a ***myriad*** of small units called ***atoms***. According to atomic theory, an atom is the smallest unit of an element that retains all the properties of the element. As you study atomic theory, keep in mind that no one has ever actually seen an atom to be able to describe it. Science author and physics professor Alfred Romer, in his book, *The Restless Atom*, stated, "The atom is an idea, a theory, a hypothesis . . .to account for the facts of experience." Scientists regard the various atomic models as tools to help us visualize how atoms may function, and to provide a structure for understanding chemical reactions.




In the center of an atom is the ***nucleus***, which contains ***protons*** and ***neutrons***. (To get an idea of the relative size of the nucleus to the entire atom, imagine that a football field is the atom and the nucleus is a marble.) Protons and neutrons both have a mass of about 1 atomic ***mass*** unit. Each proton bears one positive electric charge, whereas a neutron has no charge. A third type of atomic particle is called the ***electron***. Electrons are so light that their mass is usually considered to be zero. Each electron bears one negative electric charge. Electrons move rapidly around the area surrounding the nucleus and this space is referred to as the atom's ***electron orbitals***. This region can be described in terms of its distance from the nucleus and its shape. Because opposite charges attract, the strong positive charges from the protons in the nucleus help to hold the electrons in their orbitals.




The number of protons and the number of electrons are the same in each atom, so that the atom has a net electric charge of zero. The smallest atom (an atom of hydrogen) consists of one proton and one electron. An atom of a particular element has a unique number of protons in its nucleus. This number is called the ***atomic number***. For example, hydrogen has one proton so it has an atomic number of one. Helium has two protons so it has an atomic number of two. In fact, the key difference between the atoms of different elements is the number of protons and electrons they contain. Notice how these elements are recorded in the periodic element chart.




The ***atomic mass*** is determined by adding the number of its protons and the number of its neutrons, because they each have the same mass. Some elements occur in two or more different forms, called ***isotopes***. Two isotopes of the same element have different numbers of neutrons, but the same number of protons. Thus, they have the same atomic number but a different atomic mass.

Although atoms are too small to be examined directly, chemists and physicists have identified many atomic properties and

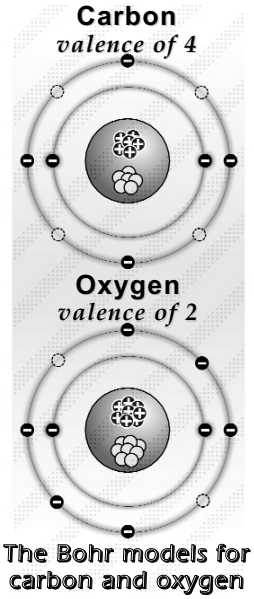
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developed models of their structure. The atomic structure model was first introduced in 1913 by physicist Niels Bohr of Denmark.

Because electrons are negatively charged, they are attracted to the positively charged nucleus. Bohr visualized electrons as moving in spherical spaces or orbitals, called *electron shells* or *energy levels*, around the nucleus. The innermost shell can hold only two electrons. In the common elements, the next outer shells can hold a maximum of eight electrons each. Atoms tend to fill their outer shells during chemical reactions in which they gain, lose or share electrons.

For example, carbon has six protons, six neutrons and six electrons. Hence, it has two electrons in its first energy level but only four in the second energy level, although there is room for eight. In fact, carbon "wants" to have a total of eight electrons to become stable and "looks" for them during reactions. Electrons should be envisioned as particles in constant, random motion.



The Bohr models for carbon and oxygen

The number of electrons that an element must share, lose or gain to complete a stable outer electron shell is known as its ***valence***. Thus, carbon has a valence of four and oxygen has a valence of two. The valence of an atom determines how many connections an atom can form when it combines with other atoms. Valence electrons are those electrons which occupy the outer shell of an atom. The orbitals of an atom define *electron charge clouds*, which is the volume of space in which the electrons can move.

**The next lesson will take us into the way elements bond together to make life possible.**

# LIFE PRINCIPLE



**"The things that exist are formed . . . from things which our eyes do not see."**

—David Engles
Poet and musician

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## TABLE 1-7 CHEMICAL ELEMENTS FOUND IN HUMANS AND ANIMALS, THEIR APPROXIMATE ABUNDANCE BY WEIGHT AND THEIR ATOMIC MASSES

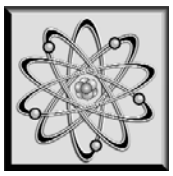
| ELEMENT | SYMBOL | WEIGHT, PERCENT | ATOMIC MASS |
|---|---|---|---|
| Oxygen | O | 62 | 16.0 |
| Carbon | C | 20 | 12.0 |
| Hydrogen | H | 10 | 1.0 |
| Nitrogen | N | 3.3 | 14.0 |
| Calcium | Ca | 2.5 | 40.0 |
| Phosphorus | P | 1.0 | 31.0 |
| Sulfur | S | 0.25 | 32.0 |
| Potassium | K | 0.25 | 39.0 |
| Chlorine | Cl | 0.2 | 35.5 |
| Sodium | Na | 0.10 | 23.0 |
| Magnesium | Mg | 0.07 | 24.5 |
| Iodine | I | 0.01 | 127.0 |
| Iron | Fe | 0.01 | 56.0 |
| | | 99.59 | |
| **TRACE ELEMENTS** (needed in very small amounts) | | | |
| Copper | Cu | | 63.5 |
| Manganese | Mn | | 55.0 |
| Molybdenum | Mo | | 96.0 |
| Cobalt | Co | | 59.0 |
| Boron | B | | 11.0 |
| Zinc | Zn | | 65.5 |
| Fluorine | F | | 19.0 |
| Selenium | Se | | 79.0 |
| Chromium | Cr | | 52.0 |

[1]Each element is assigned a one or two-letter symbol that is used as a chemical "shorthand" in writing chemical formulas and equations

[2]Where atomic mass is not an integer, the mass given represents the average between commonly occuring isotopes of the elements.

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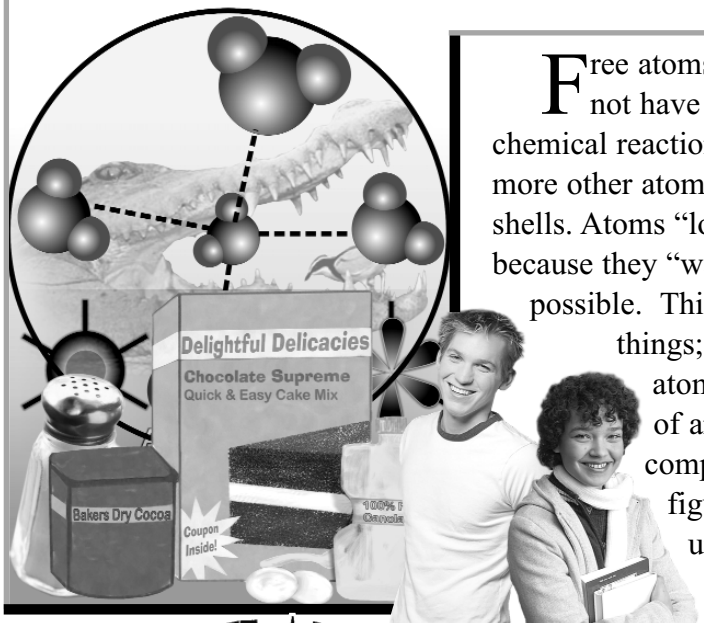

**Lesson 7**

# *Chapter 1*

## *ATOMIC BONDING— KNITTING LIFE TOGETHER*

## Section 2

***Lessons 6-10***




Free atoms are few in nature. Since most atoms do not have stable electron designs, they undergo chemical reactions in which they join, or bond, with one or more other atoms in order to attain stable outer electron shells. Atoms "look" for other atoms with which to bond because they "want" to be in the most stable condition possible. This is the critical function in all living things; bonding enables life to reproduce because atoms bond to perpetuate the specific design of an organism. This lesson on bonding is complex, but as you remain focused on the figures and the information, you will begin to understand how living things reflect a marvelous design and systematic function. You will also learn that you are wonderfully and marvelously designed. You will learn why and how you are unique, yet very much like other living beings.



## VOCABULARY

***Ionic bond:*** a chemical bond that results when one atom gives up one or more of its outermost electrons to another atom

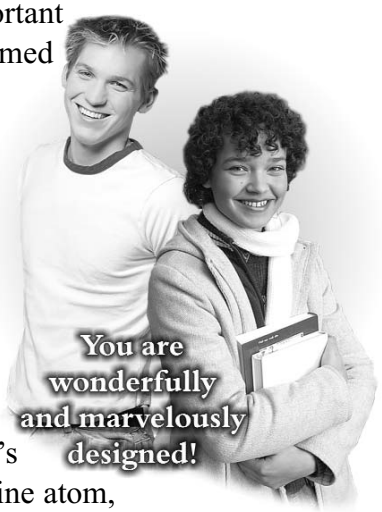
***Ion:*** a charged particle; an atom that has gained or lost an electron, thus acquiring a charge

***Covalent bond:*** the strongest bond formed by the sharing of valence electrons

***Hydrogen bond:*** a weak chemical bond formed when a partially positive hydrogen atom of a polar covalent bond in one molecule is attracted to the partially negative atom of a polar covalent bond in another molecule

### IONIC BONDING

Three types of bonds are important in living things. An ***ionic bond*** is formed when one atom gives up one or more of its outermost electrons to another atom. As a result of this atomic give-and-take, both atoms end up with stable, outermost energy shells. For example, sodium has one electron in its outermost shell. If that electron leaves, the atom will then have a new stable outer shell containing eight electrons. If sodium's outermost electron is given to a chlorine atom, which contains seven electrons in its outer shell, the chlorine atom will also become stable with eight electrons in its




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outermost shell. As a result of gaining or losing an electron, each newly formed particle now carries an electric charge and is known as an ***ion***. The sodium ion has 11 protons but only 10 electrons, for a net charge of $^{+}1$. The ionic form of chlorine is called a *chloride ion*; it has 18 electrons and only 17 protons, for a net charge of $^{-}1$. The strong attraction between oppositely charged ions is called an ionic bond.



The ionic bond between sodium and chlorine

A sodium ion with its positive charge and a chlorine ion with its negative charge tend to attract each other, since opposite charges attract. Therefore, the two ions are held together by an electrical attraction and form the compound we know as *table salt*, or *sodium chloride*, NaCl.

## VOCABULARY

***Electronegative:*** charged with negative electricity; an atom having the tendency to pull electrons toward itself

***Ionized:*** when ionic bonds of compounds dissociate into separate ions

***Acid:*** a substance that increases the hydrogen ion concentration in a solution

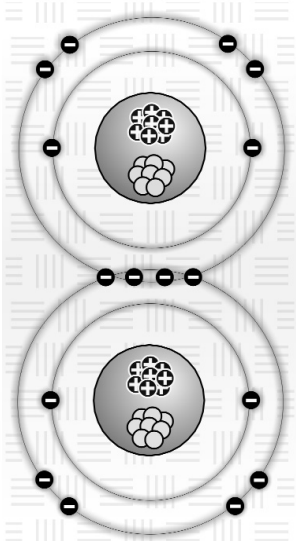
***Base:*** a substance that decreases the hydrogen ion concentration in a solution

***pH scale:*** a measure of the hydrogen ion concentration which is the degree of acidity or basicity

***Buffers:*** a substance that minimizes changes in pH when acids or bases are introduced to a system

## COVALENT BONDING

In a ***covalent bond***, two atoms share a pair of electrons so that each has a stable, complete outer energy shell. Individually, each oxygen atom is surrounded by eight electrons-not a very stable arrangement. But when each atom shares two electrons with the other atom, both acquire a stable arrangement of 10 electrons. Because of the sharing, covalent bonds do not break easily. This makes covalent bonds the strongest of the bonds.


A double covalent bond between two oxygen atoms

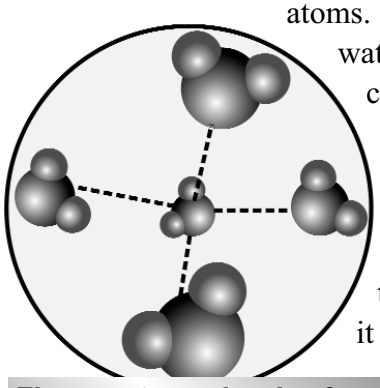
The more electrons in the covalent bond, the more strongly the two atoms are joined. A covalent bond can be formed with two electrons (called a *single bond*), four electrons (called a *double bond*), or six electrons (a *triple bond*).

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## Hydrogen Bonding

The third type of bonding between atoms that is important in the chemistry of living things is the ***hydrogen bond***. In this type of bond, a positive hydrogen atom is covalently bonded to a strongly ***electronegative*** atom, usually oxygen or nitrogen. It is a weak, low-energy bond in which a hydrogen atom acts as though it were bonded simultaneously to two other atoms. For example, water molecules are commonly linked together by hydrogen bonds between the oxygen atoms of the water, so that it is difficult to say where one water molecule ends and another begins. Also, hydrogen bonds often bind water molecules loosely to the molecules of many other compounds. We shall refer to hydrogen bonds again when we discuss important substances such as proteins and nucleic acids.

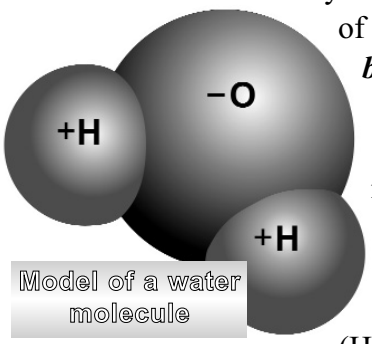


These water molecules form clusters due to the formation of hydrogen bonds.

## Ionic Compounds and pH

Substances like sodium chloride or calcium chloride ($CaCl_2$), in which bonds are ionic, tend to dissociate (break apart) into separate ions when in solution. When they are dissociated or ***ionized*** in this manner, they do not exist as molecules. In solution, NaCl forms two separate entities, a $Na^+$ ion and a $Cl^-$ ion.

Ions are charged particles and behave differently from neutral atoms or molecules in living systems. In later lessons, we shall study the effects of charge upon the movements of materials through the membranes of living cells, and how these ions set up electric potential differences important for nerve and muscle activity.

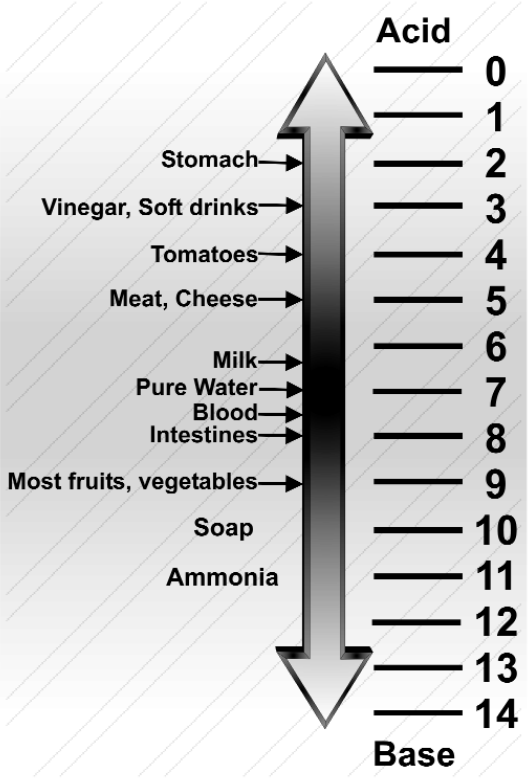



Model of a water molecule

Two classes of ionic compounds are very important in the study of biology: ***acids*** and ***bases***.

An acid is a substance that releases hydrogen ions ($H^+$) in water. For example, hydrogen chloride (HCl) produces hydrogen ions ($H^+$) and chloride ions ($Cl^-$) in solution, forming hydrochloric acid. Hydrochloric acid is very important to your digestion and is produced in your stomach.

A base is a substance that releases $OH^-$ in water, or that accepts $H^+$; thus, the base, sodium hydroxide (NaOH) dissociates (breaks apart) into sodium ions ($Na^+$) and hydroxyl ions ($OH^-$).




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The degree of acidity or basicity (usually called alkalinity) of a solution is based on the relative concentration of hydrogen ions, in the solution and is measured with the ***pH scale***. A solution with a pH of 7 is neutral (neither acid nor base). This means that the number of $H^+$ ions and the number of $OH^-$ ions are equal. Substances with a pH of less than 7 are acidic (i.e. contain a higher concentration of $H^+$ ions than that of $OH^-$ ions); the lower the pH, the more acidic the substance. Conversely, substances with a pH higher than 7 are basic (i.e. contain a higher concentration of $OH^-$ ions than $H^+$ ions); the higher the pH, the more basic the substance.

Most chemical reactions of life occur rapidly at a pH near the 7, the neutral point. In our own bodies, the blood and most body fluids have pH values of about 7.4. An empty stomach contains hydrochloric acid which dissociates readily so that the fluid in the stomach is about pH 2. In living systems, abrupt changes in pH can be harmful. ***Buffers*** are substances that are used by organisms to minimize pH changes and to help stabilize the amount of acid or base in the system.

**In the next lesson, we will study the basics of compounds and molecules.**

WATCH VIDEO:
Water: A Polar Molecule

# LIFE PRINCIPLE

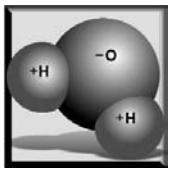


**"I never learn anything by talking. I only learn things when I ask questions."**

—Lou Holtz
NCAA college football head coach

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*Molecules*

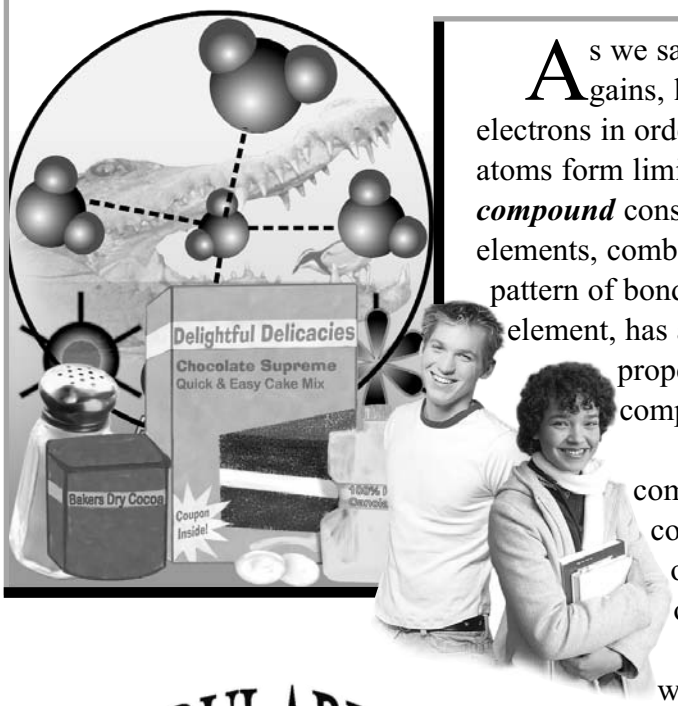
**Lesson 8**

# *Chapter 1*

## COMPOUNDS AND MOLECULES: BUILDING BLOCKS OF LIFE

## Section 2

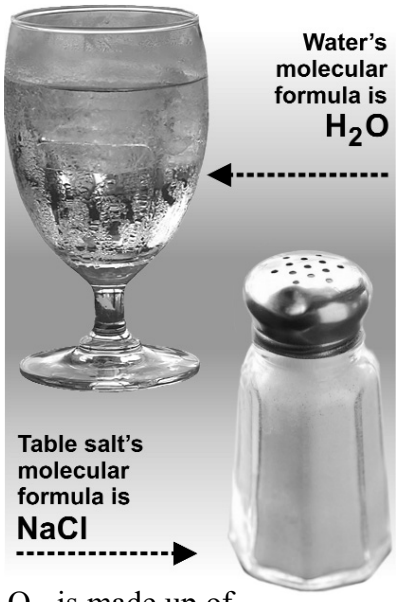
***Lessons 6-10***




As we saw in the previous lesson, each type of atom gains, loses or shares a particular number of electrons in order to attain stable energy levels. Therefore, atoms form limited and predictable types of bonds. A ***compound*** consists of two or more atoms of different elements, combined in specific proportions, with a specific pattern of bonds. Each compound, like each chemical element, has a unique formula and a unique set of properties which make it different from its component elements.

A ***molecule*** is the smallest part of a compound that retains all the properties of that compound, just as an atom is the smallest part of an element and retains all the properties of the element.

A ***molecular formula*** is a shorthand way of representing the kinds and amounts of different atoms present in a molecule, using the symbols for the elements. For example, the symbol for a helium atom, He, is also the symbol for a helium molecule since helium has a filled outer shell, making it so stable that it will not bond to other atoms. NaCl represents the compound *sodium chloride* or table salt. The molecular formula NaCl indicates that table salt contains sodium and chlorine in an equal, 1:1 ratio. Water's molecular formula is $H_20$. The subscript "2" indicates that two hydrogen atoms (H) are present for every oxygen atom (O) in a water molecule. Likewise, in $CO_2$, carbon dioxide, two oxygen atoms are present for each atom of carbon (C); a molecule of oxygen gas, $O_2$, is made up of two oxygen atoms and is called *molecular oxygen*.




## VOCABULARY

***Compound:*** a chemical combination in a fixed ratio of two or more elements

***Molecule:*** two or more atoms of one or more elements held together by ionic or covalent bonds

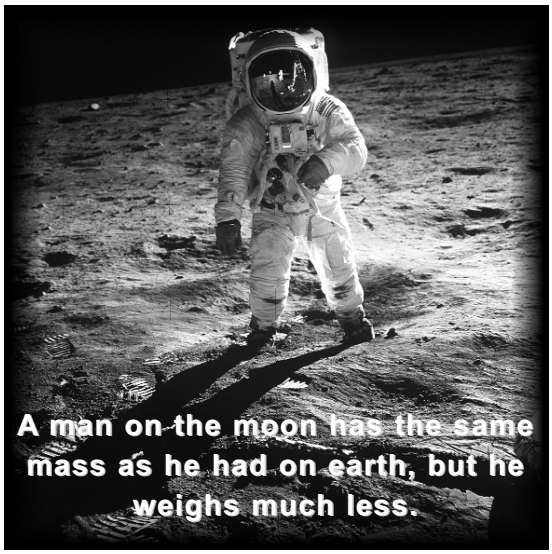
***Molecular formula:*** a molecular notation or shorthand representing the kinds and quantity of different atoms in a molecule

***Structural formula:*** a molecular notation in which the atoms within a molecule are joined by lines representing covalent bonds

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A ***structural formula*** takes up more space than a molecular formula, but it gives information about the arrangement of atoms in the molecule as well as the numbers of each type of atom. Structurally, water is written H-O-H, indicating that each hydrogen is attached to the oxygen atom, but that the hydrogens are not bonded to each other. In carbon dioxide, each oxygen is double-bonded to the carbon atom (the double bond means the carbon shares two electrons with each of the oxygen atoms) and is written O=C=O.




## VOCABULARY

***Molecular weight:*** the sum of the weights of all the atoms in a molecule of substance

***Gram Molecular Weight*** or ***Mole:*** the number of grams of a substance that equals its molecular weight. A mole contains 6.023 x $10^{23}$ number of molecules, Avagadros's number

***Avogadro's Number:*** the number of molecules in a mole: 6.023 x $10^{23}$

***Solution:*** a homogeneous, liquid mixture of two or more substances

***Solvent:*** the dissolving agent in a solution; water is the most versatile solvent

***Solute:*** a substance that is dissolved in a solution

***Molarity:*** a common measure of solute concentration, referring to the number of moles of solute in 1 liter of solution

Structural formulas are very important in cases where the molecular formulas for two different molecules are the same. For example, both dimethyl ether and ethyl alcohol have the molecular formulas $C_2H_6O$. Their structural formulas are different, though, because the same atoms can be arranged in different ways.

The ***molecular weight*** of a molecule is the sum of the atomic masses of all its atoms. [For the sake of convenience, we will consider mass and weight as equal, although this is not always the case. A man on the moon, for instance, has the same mass as he had on earth, but he weighs much less. This is because less gravity or "pushing down" occurs on the moon than on the earth. Weight depends on the force of gravity pressing down on something; mass does not take into consideration gravitational forces.] Using the atomic masses from the table found in this lesson, the molecular weight of water, $H_2O$ can be found as 2 x 1 for the hydrogens, plus 16 for the oxygen, for a total of 18 atomic mass units.

The ***gram molecular weight*** or ***mole*** of a substance is the molecular weight of the substance in grams. For example, a mole of water weighs 18 grams. A mole of any substance contains 6.023 x $10^{23}$ molecules, which is also known as ***Avogadro's number***. This number, also called *Avogadro's Law*, was named after Count Amendeo Avogadro (1776-1856), an Italian physicist who formulated the law.

The mole is a useful quantity in the study of biological reactions since it is based

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on the number of molecules; a mole of table sugar (358 grams) and a mole of ethanol (46 grams) contain the same number of molecules, although one gram of ethanol contains more than seven times as many molecules as a gram of sugar.

A ***solution*** consists of a ***solvent*** plus the substances dissolved in it, called ***solutes***. The concentration of a solution is almost invariably expressed in ***molarity*** in biological experiments. For example, a molar (1M) solution contains a mole of solutes in a total of 1 liter (1000 ml) of solution.

**In the next lesson, we will learn about chemical reactions—the processes which keep us alive.**

WATCH VIDEO:
A Water Molecule

# LIFE PRINCIPLE



**"Great works are performed not by strength but by perseverance."**

—Samuel Johnson (1709-1784)
English writer and critic

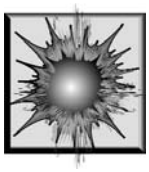
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Reactions

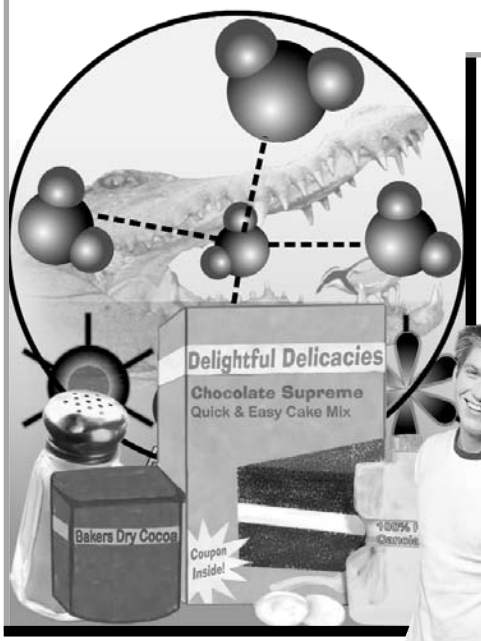
Lesson 9

# Chapter 1

## CHEMICAL REACTIONS —LIFE'S CRITICAL PROCESSES

## Section 2

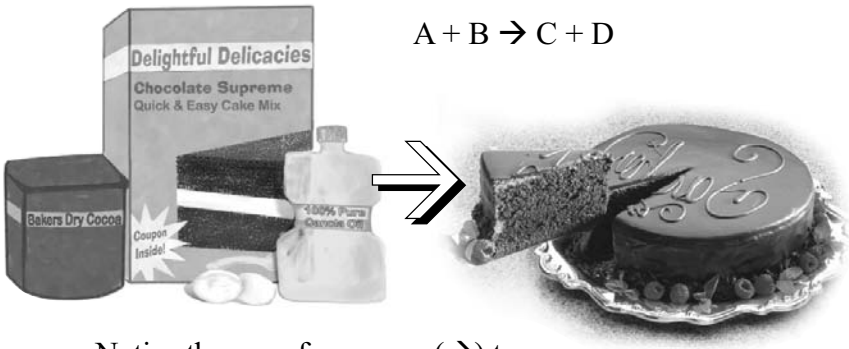
*Lessons 6-10*




If you have ever followed a recipe to bake cookies or a cake, you have added ingredients such as flour, eggs, milk and sugar together. Individually, none of these ingredients are especially delicious. However, once the ingredients have been properly measured, mixed and baked, the results are usually quite pleasing to the tongue!

In some respects, the processes involved in making cakes or cookies are similar to the processes that occur in living things. Living things take indiviual "ingredients", such as proteins or carbohydrates, and through ***chemical reactions*** turn these substances into highly organized and complex materials.

During a chemical reaction, molecules or ions interact with one another to form new substances. Here we will consider some hypothetical generalized reactions. Suppose, for example, that two substances (A and B) can react with each other to form two new substances (C and D). This process would be written:




$A + B \rightarrow C + D$

Notice the use of an arrow (→) to indicate the formation of two new substances from the two initial materials.

The initial materials, called ***reactants***, are written on the left and the ***products*** on the right, after the arrow. Many times in

## VOCABULARY

***Chemical reaction:*** the rearrangement of atoms in matter that produce a new substance

***Reactants:*** the starting materials in a chemical reaction

***Products:*** the resulting materials from a chemical reaction

***Thermal agitation:*** speeding up the motion of molecules with the use of energy

***Exergonic reaction***: a spontaneous chemical reaction in which there is a net release of free energy

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a biological experiment, we are interested in the factors that determine the rate of the reaction. First, we must recognize that if A and B are to react with each other, their molecules must encounter each other. Logically, anything that increases the likelihood of contact would increase the rate of the reaction. One obvious way to accomplish this would be to *increase the concentration* of the reactants; more molecules per unit volume increase the chances that these molecules will bump into each other and react.

Increasing the concentration of reactants is not the only way to speed up a reaction. *Raising pressure* on the reactants is another way. *Heating reactants* is still another way. Heat is a form of energy, and all forms of energy involve speeding up motion of the molecules (called ***thermal agitation***). The more that molecules move around, the greater is the probability that they will bump into each other and react. The application of heat is a standard and frequently used laboratory technique for speeding a reaction. For example, heating a pan of water causes the molecules to speed up, producing steam.




All substances contain energy. When one substance is converted into another substance, a *change of energy content* occurs as the result of bonds breaking and new bonds forming. In some reactions, the products contain *less* energy than the reactants and the extra energy is released by the reaction. This would be written:

$$A + B \rightarrow C + D + \text{energy}$$

Such reactions are said to be ***exergonic reactions*** and the energy released is called *reaction energy*. An example would be a dynamite or bomb explosion. In ***endergonic reactions***, the products contain *more* energy than the reactants. An endergonic reaction requires an external source of energy (like heat). An example would be applying a lighted match to dry weeds. Endergonic reactions are expressed as:

$$A + B + \text{energy} \rightarrow C + D$$

In reactions of living things, exergonic and endergonic reactions are commonly paired

## VOCABULARY

***Endergonic reaction:*** a non-spontaneous chemical reaction in which free energy is absorbed from the surroundings

***Reversible reaction:*** a reaction that may go forward or backward

***Equilibrium point:*** the point at which the rates of the forward and backward reactions are equal. At this point in a *reversible reaction*, there is no net change in the concentrations of the reactants or the products. In an *irreversible reaction*, this point is when all the reactants have been converted to products

***Irreversible reaction:*** a reaction that may go only in the forward direction

***Activation energy:*** the energy needed to get a chemical reaction going

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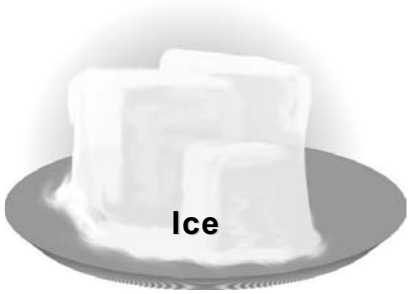
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together so that the energy released by one reaction is used to drive the other reaction.

Let us suppose that the reaction of A with B to form C and D has been going on for a period of time and that high concentrations of C and D are accumulating, while the concentrations of A and B are dwindling. At this point, some chemical reactions are ***reversible reactions***. For example, as the concentrations of the products (C and D) start rising, these will begin to react to form A and B. This is written:

$$A + B \rightleftharpoons C + D$$

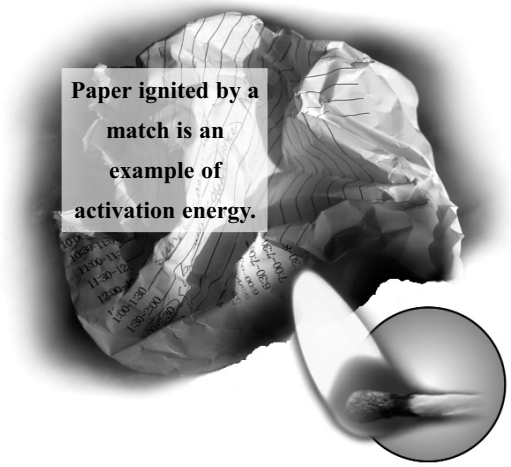
The reaction can go either left to right (forward) or from right to left (backward), depending on conditions around the living things. For example, water can form steam or ice, and both can return to water.




The ***equilibrium point*** of a reaction is the point at which the relative concentrations of reactants and products are such that the rates of the forward and the backward reactions are equal, and there is no net change in the concentrations of reactants and products. If the relative concentrations of reactants and products change, the reaction tends to go in the direction that will restore equilibrium. In an ***irreversible reaction***, the equilibrium point is reached when all the reactants have been converted to products, as in a combination of ingredients that have been irreversibly baked in a cake.


The destruction of this building displays an irreversible reaction.

In summary, concentration, pressure, temperature and energy changes all effect chemical reactions. However, these forces are not all the factors that must be considered by scientists who study various aspects of biology. Many exergonic reactions do not begin spontaneously, even when the conditions of concentration, pressure and temperature are all adequate. They need a "push" to get them going. This push must come from some outside source and is called ***activation energy***.


**Paper ignited by a match is an example of activation energy.**

For example, a sheet of paper will burn easily once it is ignited, but that same paper may exist in direct contact with a plentiful supply of oxygen for years without ever burning. Activation energy, in the form of heat from a match or some other hot object, must be applied to start the reaction of paper with oxygen. (This is also an example of an irreversible reaction! The paper cannot return

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to its original state once it has been ignited.) Activation energy is a very important concept in the study of reactions in living systems, as we will see in a later chapter.

**The next lesson deals with a most unique, but abundant, component of life.**

## LIFE PRINCIPLE



**"The great end of life is not knowledge, but action."**

—Mark Twain (1835-1910)
American writer

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*Water*

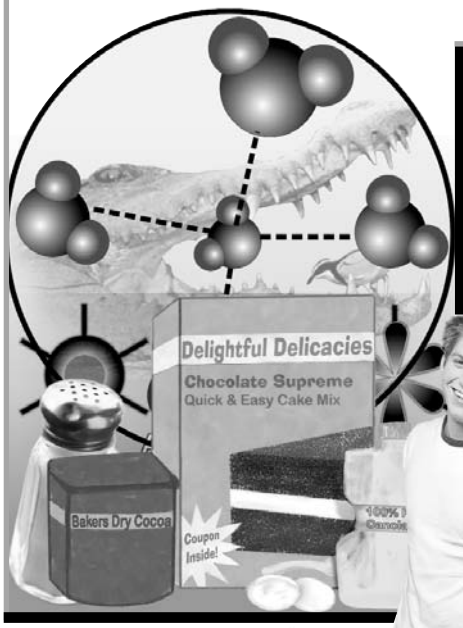
**Lesson 10**

# *Chapter 1*

## *WATER— THE SEA OF LIFE*

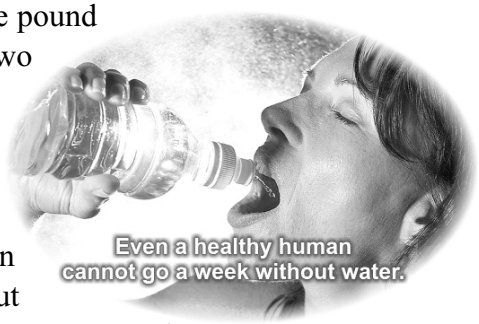
## Section 2

***Lessons 6-10***




We drink it freely and use it carelessly. It falls, flows, permeates, and circulates. It destroys with abundance and devastates with absence. It frequently controls our lives with its moody atmospheric expressions. It is everywhere, comprising 80-90% of all living material. Water is the key ingredient that makes all the cellular mechanics of life possible. While most of us take water for granted and consider it a bland, inert substance, nothing could be further from the truth.

We have a difficult time imagining life without an abundant supply of water. Water is replaced in the human body seventeen times a year and every twelve days in the atmosphere. In today's industrial world, incredible volumes of water are used. Twenty-three hundred (2,300) gallons of water are required to produce one pound of beef, 300 gallons to produce two and one half pounds of bread, twenty-three gallons to wash a load of clothes, and 100, 000 gallons to manufacture an automobile. A healthy human can survive nearly eighty days without food, but less than a week without water. Entire populations have been forced to relocate because of dwindling water supplies.



Even a healthy human cannot go a week without water.

## VOCABULARY

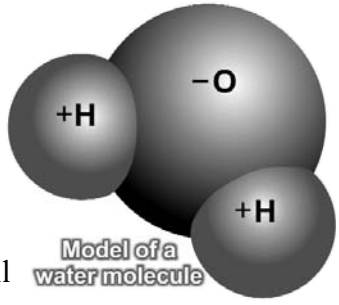
***Polar:*** a chemical bonding in which the valence electrons are shared unequally, causing the molecule to develop a positive end (where the electrons spend less time) and a negative end (where the electrons spend more time)

***Tetrahedral:*** in the shape of a *tetrahedron* which is a geometric solid having four sides, each of which is a triangle (as in a pyramid

***Nonpolar:*** a bond in which valence electrons are shared equally so that the charges are distributed evenly

### STRUCTURE OF WATER

In a molecule of water, an atom of oxygen is covalently bonded to two atoms of hydrogen. The molecule is bent, with an angle of about 105° between the two bonds. Because oxygen is more *electronegative* (having the tendency to pull

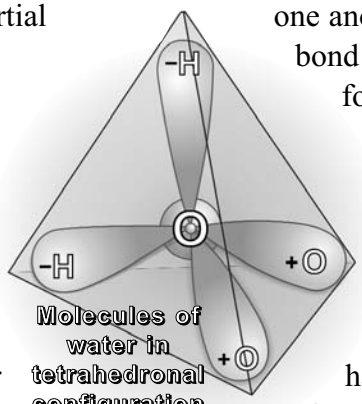



Model of a water molecule

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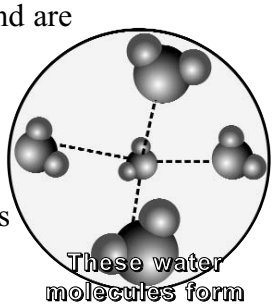
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electrons towards itself) than is hydrogen, the molecule is ***polar***, with a partial *negative* charge ($\delta^-$) on the oxygen atom, and a partial *positive* charge on each hydrogen atom ($\delta^+$). These partial charges are distributed in an almost perfect ***tetrahedral*** configuration, with the oxygen nucleus at the center and the two partially positive hydrogens at two corners. The oxygen's two, partially negative, unshared electron pairs are at the other two corners.



Molecules of water in tetrahedronal configuration

Although water has no net charge, this unequal charge distribution gives the molecule electrical polarity. As a result, water molecules form hydrogen bonds with one another. Each molecule has the ability to bond with four neighboring molecules, forming a well-ordered lattice. These hydrogen bonds have very short life spans (10-11 seconds) and are constantly being broken and reformed. In ice, about 100% of these bonds are formed and have much longer life spans than bonds in liquid. Surprisingly, 80% of these hydrogen bonds still exist in liquid water. The visual difference between the ice and water is due to the high rate of breakdown and formation of bonds in the liquid. (The term "flickering clusters" has been appropriately used to describe this phenomenon of bonding.)


These water molecules form clusters due to the formation of hydrogen bonds.

## VOCABULARY

***Micelles:*** electrically charged particles, formed at the interface of polar and non-polar bonds in substances such as oil and water

***Cohesion:*** the holding together of like substances

***Adhesion:*** the holding of one substance to a different one

***Surface tension:*** a measure of the difficulty of stretching or breaking the surface of a liquid; water has a high surface tension because of hydrogen bonding of surface molecules

***Capillary action:*** the ability of a liquid to move up a piece of porous paper, or to creep through the fine pores in the soil or in a leaf

***Specific heat:*** the amount of heat that must be absorbed or lost for 1 gram of a substance to change its temperature $1^{o}C$

***Thermal conductivity:*** the measurement of the rate of heat as it is conducted through a liquid

### PROPERTIES OF WATER

Water is vital to life because of several extraordinary properties that result from the structure of the molecule, $H_20$.

1 Water is an excellent solvent. Because of its polarity, more substances are soluble in water than in any other known liquid. This feature of water allows great numbers of minerals, vitamins and other essential nutrients to be transported by water within living organisms and also allows unwanted wastes to be expelled.


Water is vital to life

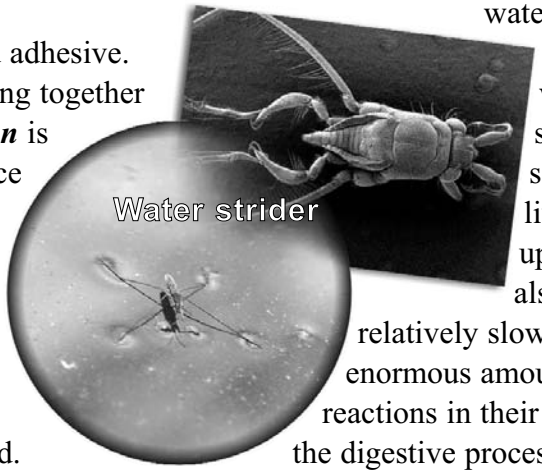
***Non-polar*** substances, such as those composed mainly of carbon and hydrogen

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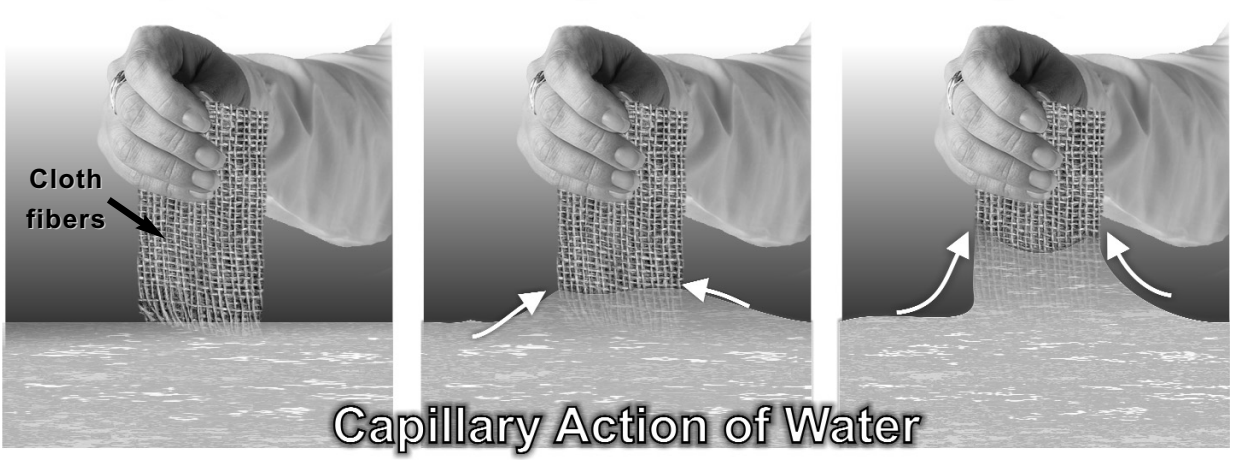
atoms, will not dissolve in water, but instead form interfaces called ***micelles***. An example would be the interaction between oil and water. This does not form a true solution, but simply a dispersion. These micelles are the sites for many chemical reactions in living organisms; thus the inability of water to dissolve non-polar substances is also necessary for life.

2 Water is cohesive and adhesive. ***Cohesion*** is the holding together of like substances; ***adhesion*** is the holding of one substance to a different kind of substance. You can pour water into a glass jar until the water actually rises above the level of the rim. A water-strider can run across the surface of a pond. Both of these observations are a result of the high ***surface tension*** of water, which means that a water surface appears to be covered by a "skin." Surface tension results from the cohesion of water molecules to one another by their hydrogen bonds. Water is more cohesive than any other liquid except mercury. These two characteristics account for its ***capillary action***, which allows water and other liquids to move up a piece of porous paper or cloth, or to creep through the fine pores of the soil or a leaf. Because water is highly polar, it also adheres strongly to any surface that bears an electric charge.




3 Water has a high ***specific heat***. This means a great deal of heat is needed to raise the temperature of water, and much heat must be lost to lower the temperature of water. Compared with the air above it, a body of water warms more slowly in the spring and cools more slowly in the fall. Since living organisms are made up largely of water, they also gain and lose heat relatively slowly. Organisms produce enormous amounts of heat from chemical reactions in their bodies, especially during the digestive process or strenuous physical activity. Were it not for the high capacity of water to absorb heat, the temperature of an organism would rise to the point at which life would be impossible.

Water also has a high ***thermal conductivity*** characteristic, which means that if one part of a body of water is heated, the heat is rapidly conducted throughout the rest of the water. Since all parts of an organism are usually linked to all other parts by water,




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heat produced in one part of an organism is transferred rapidly all over the body. That is why you may feel warm or hot an hour or two after eating—the digestive system produces heat while processing food.

4 Water has a high boiling point. The single hydrogen bond in water is not a very strong bond. In fact, the strength that holds a hydrogen bond together is about one twentieth the strength of the covalent bonds holding the oxygen and hydrogen atoms together. However, the cumulative effect of many hydrogen bonds in water results in very strong intermolecular forces. As a result of these strong forces, a great deal of attraction occurs between water molecules; therefore, a great deal of heat is necessary to overcome this attraction and to change water from a liquid to a gas. Temperatures on Earth seldom reach the boiling point of water ($100^{o}$C or $212^{o}$F), and so living organisms need not contend with the problem of boiling away. This may seem ridiculous to mention, but when you consider the state of other molecules similar to water at the same temperature, you will find most have become gases (such as $NH_3$, HF, $H_2S$).

5 Water is a good evaporative coolant. Water molecules are attracted to each other so strongly that much energy is needed to vaporize a water molecule. Many land-dwelling organisms make use of this property of water to cool their bodies when they overheat. Heat from the body causes water to evaporate, thus cooling the organism.

6 Water has a high freezing point, and a lower density as a solid than as a liquid. These properties have both advantages and disadvantages for living things. Water expands as it is cooled to freezing temperatures. This is because the molecules begin to form a crystal lattice in which the molecules are not packed so closely as they are in liquid water. As a result, ice is less dense than water and therefore floats. In natural bodies of water, the formation of ice on the top of the water creates a "blanket" of insulation that shields the underlying water and its inhabitants from further cooling. That is why fish can survive even when the surface of ponds and lakes freeze.

When organisms freeze, ice crystals form within their bodies. Because water must expand to form crystals, the internal structure of the body is destroyed and subsequent thawing cannot restore its delicate architecture. This is why people subjected to frostbite often lose limbs. Some organisms, however, produce "antifreeze" substances that prevent the formation of ice crystals. Winter wheat and many insect eggs have such a provision. Other organisms, such as tomato plants, are killed when they freeze.

Water is truly a unique compound, perfectly designed for life as we know it.

**In the next section, we will cover some basics of biological chemistry—often called biochemistry.**

WATCH VIDEO:
Water and Sound Experiment

## LIFE PRINCIPLE



**"Water is the only drink for a wise man."**

—Henry David Thoreau (1817-1862)
American essayist

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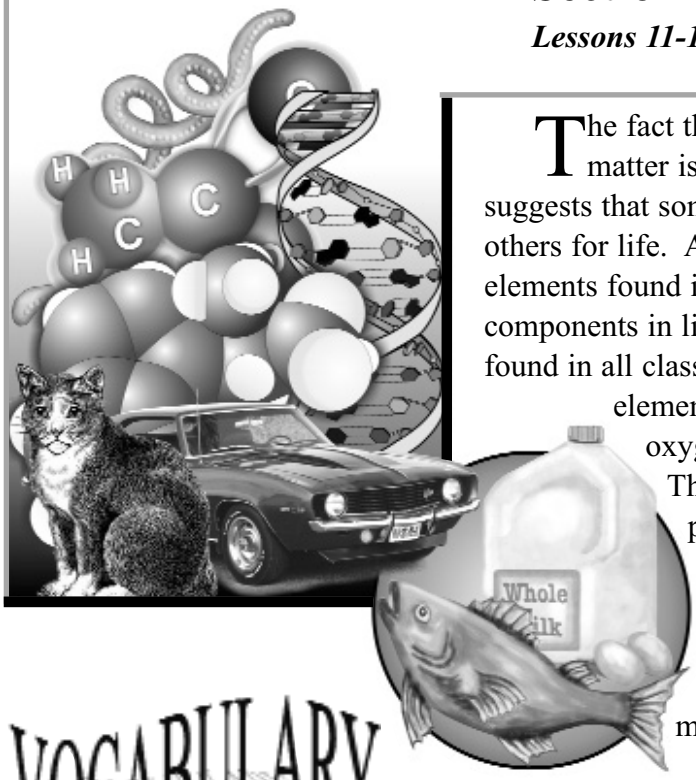

**Lesson 11**

# *Chapter 1*

## BIOLOGICAL CHEMISTRY —THE CHEMISTRY OF LIFE

## Section 3

***Lessons 11-15***




The fact that the elementary composition of living matter is very different from that of the atmosphere suggests that some chemical elements are more "fit" than others for life. As we learned, only 22 of the 100 chemical elements found in the Earth's crust are essential components in living organisms. Of these 22, only 15 are found in all classes of organisms. The four most abundant elements in living organisms are hydrogen (H), oxygen (O), carbon (C) and nitrogen (N). These four elements make up about 99 percent of the mass of most cells. However, the four most abundant elements in the Earth's crust are oxygen (O), silicon (Si), aluminum (Al) and sodium (Na). Obviously, the "fitness" of these first four make them particularly suitable for life.

Biological chemistry, also known as *organic chemistry*, is based on molecules that contain carbon. Carbon compounds occur mainly in living organisms (and their remains) and are, therefore, called ***organic compounds***. Only the simplest carbon compounds, such as carbon dioxide ($CO_2$), are considered ***inorganic compounds***. All substances that do not contain carbon are also classed as *inorganic*.

Carbon is present in an enormous quantity of known chemical compounds. Of all the elements, only hydrogen is more common among compounds. Although carbon can and does bond to a variety of elements, it is most commonly bonded to hydrogen, oxygen, nitrogen or more carbon.

More carbon compounds exist than any other compounds of all other elements. Carbon compounds surround our lives. Our cars, our clothes and our homes are full of carbon. Plastics, foods,




## VOCABULARY

***Organic compounds:*** those compounds that contain carbon and occur mainly in living systems

***Inorganic compounds:*** all substances that do *not* contain carbon. There are some simple carbon compounds such as carbon dioxide ($CO_2$) and carbonate compounds (containing $CO_2$) that are considered inorganic

***Hydrocarbons:*** organic molecules consisting only of carbon and hydrogen

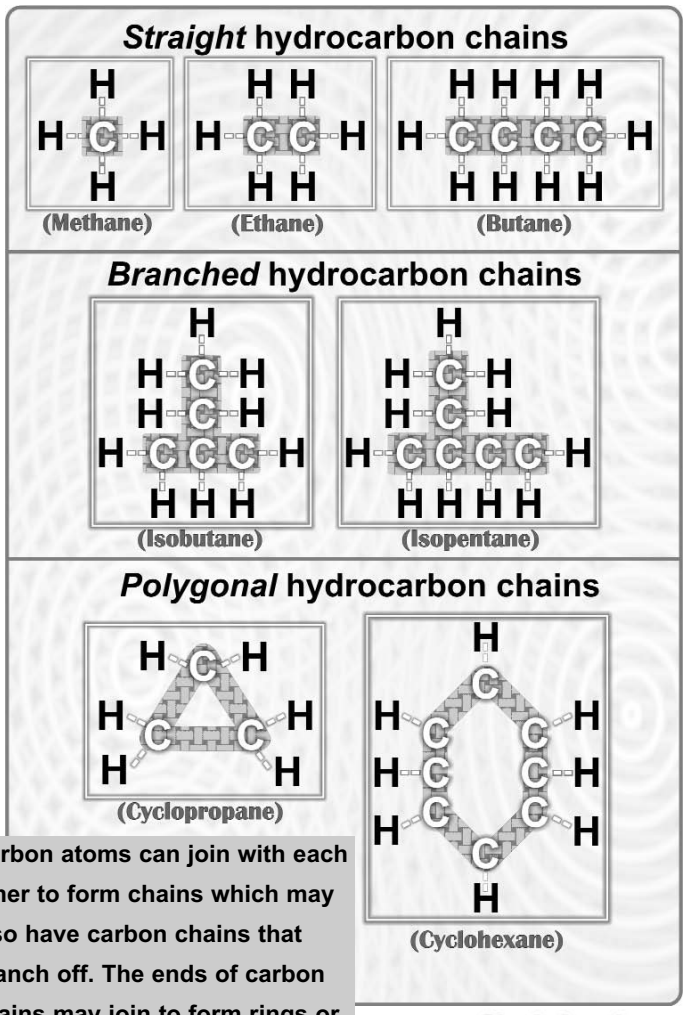
***Monomers:*** simple, small organic molecules

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and synthetic items are based on carbon. Carbon takes many different forms, from a beautiful diamond to the ugly, dirty coal which is so important for production of electrical power.

The properties of carbon atoms make them uniquely suited as the basis of the chemistry of life. Of central importance in organic chemistry are the compounds containing carbon and hydrogen, called ***hydrocarbons***. The number of these compounds is immense. The reason so many exist is because of the readiness of carbon to bind with other carbons. A carbon atom can form four covalent bonds. When it does, the four atoms bonded to carbon are as far from each other as possible, with the carbon nucleus at the center. Carbon atoms can also join with each other to form long chains, which may also have carbon chains that branch off. The ends of carbon chains may join to form ring structures. The carbon-to-carbon bonds may be single, double or triple bonds, adding to the huge variety of hydrocarbons.




**Carbon atoms can join with each other to form chains which may also have carbon chains that branch off. The ends of carbon chains may join to form rings or polygonal structures.**

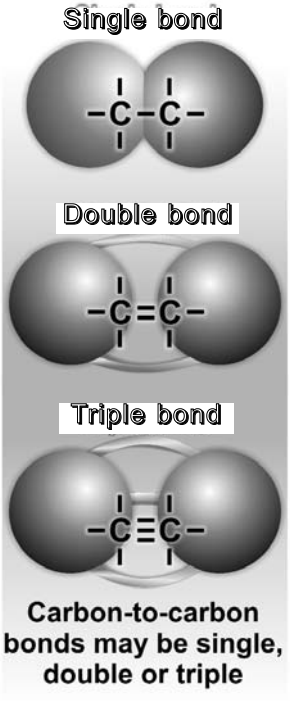
## VOCABULARY

***Polymers or macromolecules:*** large molecules consisting of many identical or similar monomers linked together

***Functional groups:*** specific configurations of atoms that are commonly attached to the carbon skeletons of organic molecules. They offer a way of organizing the compounds into "families" and are usually involved in chemical reactions

***Organic acids:*** compounds that contain carboxyl groups (COOH) and amino acids; they release hydrogen ions in solution

Organisms form various types of small organic molecules called ***monomers***, meaning "single units". These monomers may be linked together to form ***polymers*** (meaning "many units"), also called ***macromolecules*** (macro = big), which may be long, straight or branched chains. You can think of monomers as the individual letters and other characters of the English language. When these characters join together like the polymers, they can




**Carbon-to-carbon bonds may be single, double or triple**

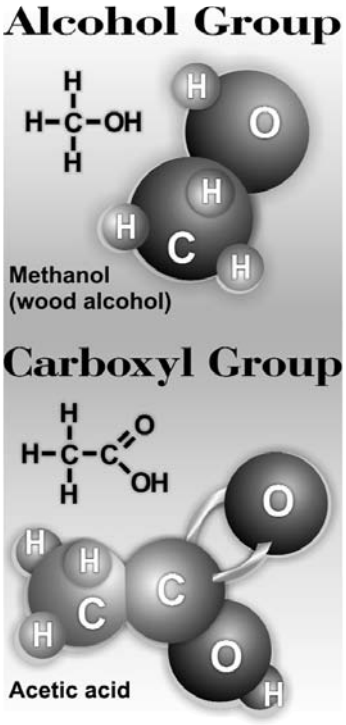
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form a nearly infinite variety of words, sentences or paragraphs. The unique properties of life depend upon the enormous array of different polymers that can be constructed from a relatively small number of biological monomers.

### Functional Groups

Organic compounds occur in great variety, but certain ***functional groups*** are found repeatedly and offer a way of organizing the compounds into "families." For instance, if an *alcohol group* (COH) is present in a molecule, the molecule will tend to take part in certain reactions and will behave in certain, defined ways, no matter what the rest of the molecule is like. Compounds that contain *carboxyl groups* (COOH), such as acetic acid and amino acids, are called ***organic acids*** because they release hydrogen ions in solution.




The study of organic chemistry is an enormous field which we cannot even attempt to cover in these few pages. However, in order to understand many of the most important attributes of life, we must be familiar with a few simple facts of organic chemistry. Four classes of organic compounds will be covered in this section: carbohydrates, lipids, proteins and nucleic acids.

**The next lesson will cover the first three classes of organic compounds: carbohydrates—the energy of life, lipids—the oils of life, and proteins—the backbone of life.**

## Life Principle

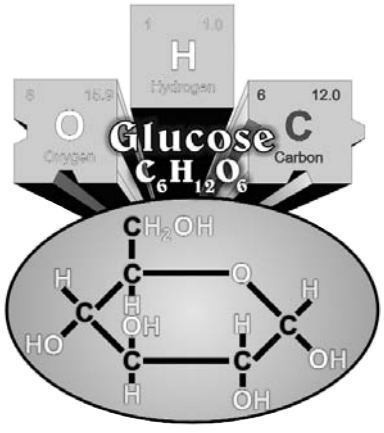


**"Nobody can think straight who does not work. Idleness warps the mind."**

–Henry Ford (1863-1947)
Inventor of Ford automobile and modern assembly line production

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*Compounds*

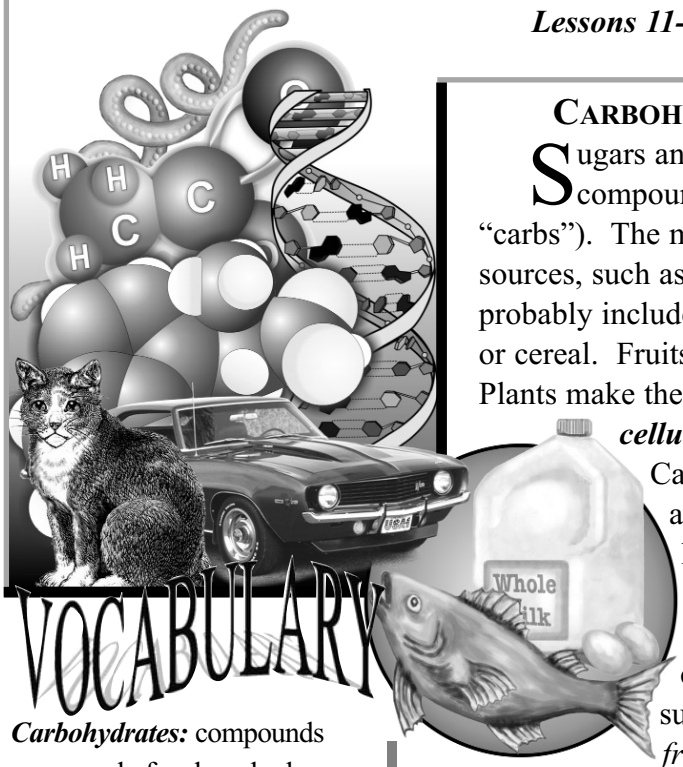
**Lesson 12**

# *Chapter 1*

## *CARBS, LIPIDS AND PROTEINS*

**Section 3**

***Lessons 11-15***




### VOCABULARY

***Carbohydrates:*** compounds composed of carbon, hydrogen and oxygen; includes sugars, starches, and related molecules

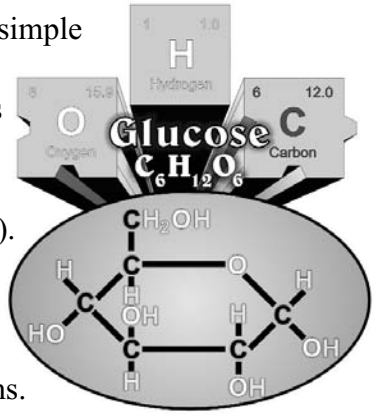
***Cellulose:*** a structural polysaccharide in cell walls, consisting of glucose monomers

***Monosaccharides:*** simplest forms of carbohydrates, also known as *simple sugars:* glucose, fructose, galactose; require no digestion to be utilized by body; provide quick energy

***Disaccharide:*** two single sugars (monosaccharides) linked together chemically, must be digested before entering bloodstream and being used by the body

### CARBOHYDRATES—THE ENERGY OF LIFE

Sugars and starches are members of the class of compounds called ***carbohydrates*** (often called "carbs"). The most familiar carbohydrates are energy sources, such as the sugars and starches. Your last meal probably included some carbohydrates like potatoes, bread or cereal. Fruits and vegetables also contain carbohydrates. Plants make their own carbohydrate substance called ***cellulose***, which is a structural molecule. Carbohydrates are made of carbon, hydrogen and oxygen. They generally contain 2 hydrogen atoms for each oxygen atom, which is the same ratio found in water.

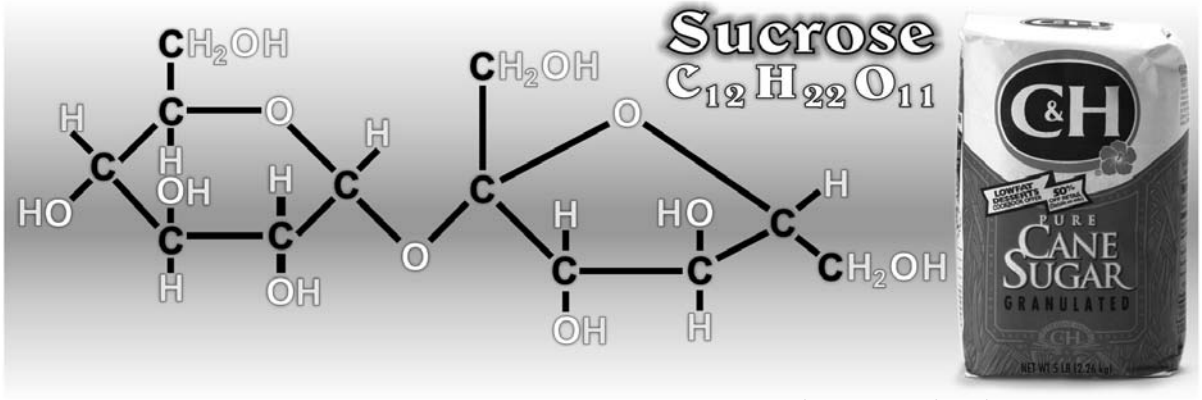



The smallest carbohydrates are the simple sugars, which include *fructose* (found in fruits and honey), *galactose* (found in milk) and *glucose* (found in honey, fruits and the cells of nearly every living organism). Each of these simple sugars has the chemical formula $C_6H_{12}O_6$. However, they are different because each has a slightly different arrangement of its atoms. In other words, each of these sugars has a unique structural formula.

Glucose plays a unique and critical role in the chemistry of life. It is at the core of the chemical pathways in the bodies of plants and animals. Other sugars, like galactose or fructose, are constantly being converted into glucose or synthesized from glucose. When you exert your body by working or exercising, the body cells release glucose into your blood stream to produce the energy you need. Simple sugars are easiest for cells to utilize. The energy released as these sugars are broken down provides cells with energy for numerous activities, including cell movement.

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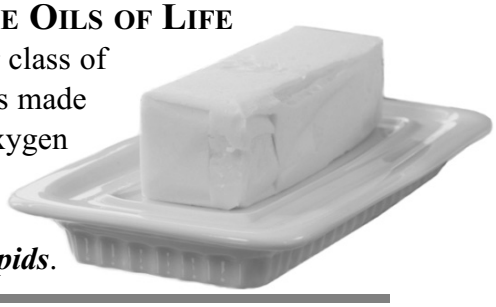

## VOCABULARY

***Polysaccharide:*** a polymer of up to over a thousand monsaccharides
***Starch:*** a polysaccharide used by plants as excess sugar storage
***Glycogen:*** a polysaccharide made and stored in animal liver or muscle tissue as a ready reserve of energy
***Lipids:*** a family of compounds that are insoluble in water, but soluble in nonpolar solvents; lipids are waxy, fatty or oily compounds used to store and release energy.
***Fatty acid:*** a long chain of carbon and hydrogen with a carboxyl (¯COOH) on one end
***Steroids:*** a class of lipids characterized by a carbon skeleton consisting of four rings with various functional groups attached
***Protein:*** a polymer of amino acids used for building cells, catalyzing reactions and other purposes
***Amino acids:*** organic molecules possessing both carboxyl and amino groups; are the building blocks of proteins
***Hormone:*** a chemical messenger secreted in one part of the body that affects other parts of the body

Organisms use simple sugars individually, and also assemble sugars into polymers which contain multiple sugar molecules. A simple sugar is called a ***monosaccharide***, meaning "single sugar." Honey and fructose are monosaccharides. Two simple sugars chemically joined together form a ***disaccharide***. Ordinary table sugar (*sucrose*) and milk sugar (*lactose*) are examples of disaccharides.

A ***polysaccharide*** consists of a large number of monosaccharides joined together. You can think of polysaccharides as warehouses for simple sugars. Grains (such as wheat, rice and oats) and grain products (such as breads, cereals and pastas) are examples of polysaccharides. Plants store excess sugar in the form of polysaccharides, called ***starch*** or *cellulose*. You are probably familiar with starch in the white part of a potato. Cellulose can also be seen as the stringy part of celery. Animals store excess sugar by making a slightly different polysaccharide, called ***glycogen***.

### LIPIDS—THE OILS OF LIFE



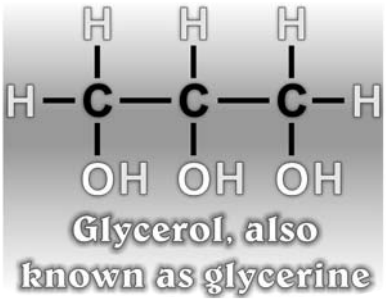
Another class of macromolecules made from carbon, oxygen and hydrogen atoms is known as the ***lipids***.

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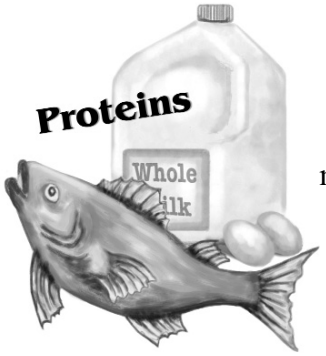
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Generally, lipids are fatty compounds and are a more efficient way of storing energy than are carbohydrates. Like carbohydrates, lipids can be used to store and release energy, but lipids have other uses as well.

Many lipids are formed by combining smaller compounds such as ***fatty acids*** and glycerol. Fatty acids are long chains of carbon and hydrogen acids that have an acidic carboxyl group (-COOH) attached to the end. *Glycerol* is a three-carbon alcohol that contains three hydroxyl groups (-OH). As a rule, molecules with large amounts of hydrogen bonded to carbon release more energy than those that contain a larger amount of oxygen.



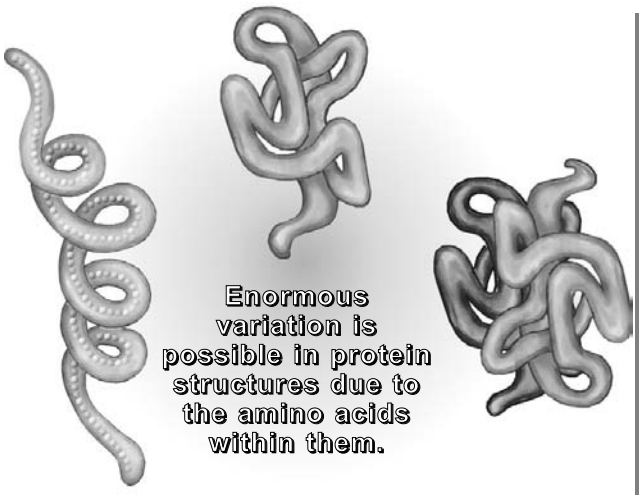

***Steroids*** are large lipids with a basic structure consisting of four carbon rings joined to one another. Various other groups are joined to these rings in different steroids. (Cortisone and cholesterol are examples of important steroids as well as hormones and many vitamins.)




## PROTEINS—THE BACKBONE OF LIFE

Meat, fish, eggs and milk are good sources of ***protein***. Proteins perform a variety of functions and are, by far, the most complex and abundant organic components of the cell. The number of proteins whose structure is known is still very small.

Proteins are composed of ***amino acids***. An amino acid has a carboxyl group (-COOH) and an amino group ($-NH_4$)

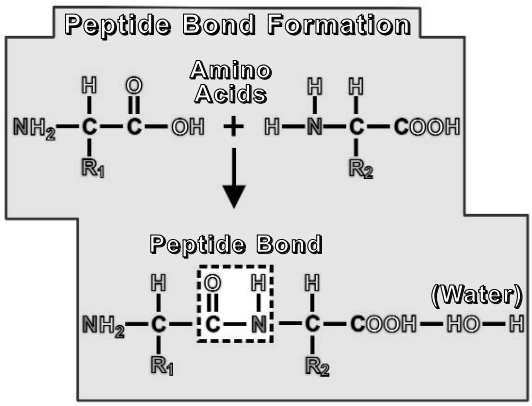



attached to the same carbon atom. A number of different functional groups, or side chains, are also attached. The different side chains determine the differences among the twenty amino acids that commonly occur in proteins. The number of amino acids in a single protein molecule may vary from about 50 to 50,000 or more. Proteins may differ in the total number of amino acid units they contain, especially in the relative quantities of the different amino acids, and in the specific sequence in which the amino acids are bonded. Therefore, from 20 amino acids, enormous variation is possible. This is similar to 26 letters of the English alphabet combining to form hundreds or thousands of words. Studies of amino acids help us to understand how proteins can be specifically designed for a species, and in many cases, for every individual organism.

Two amino acids can be joined together in a reaction between the amino group ($-NH_2$) of one amino acid and the carboxyl group (-COOH) of the other amino acid. The bond that forms from this reaction is called a *peptide bond*. Proteins are initially formed in a line, one peptide bond after another. Such a chain of amino acids is often called a *polypeptide*. A complete protein contains one or more polypeptides

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and may contain a few other chemical groups. Proteins may also form complex, three-dimensional structures by bending, twisting and kinking.

Proteins perform many important functions in living organisms. Hair and fingernails are composed of structural proteins. Many types of proteins are also found in body fluids. *Hemoglobin* is a protein that carries oxygen in the blood.

Proteins are also components of nearly all biological membranes, and they play important roles in regulating the passage of substances through membranes. Other proteins are responsible for the ability of muscles to contract, and for the detection of chemical substances that we can smell or taste. *Insulin* is a protein ***hormone*** that acts as a chemical messenger among different parts of the body. However, the most important proteins in living systems are the *enzymes*.

**In the next lesson, we will examine enzymes—the catalysts of life.**

# LIFE PRINCIPLE



**"Genius is one percent inspiration and ninety-nine percent perspiration."**

—Thomas Edison (1847-1931)
American inventor, entrepreneur and industrialist

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Reactions

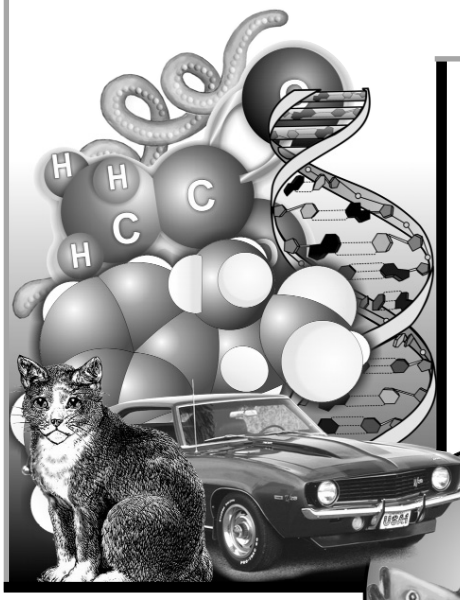
**Lesson 13**

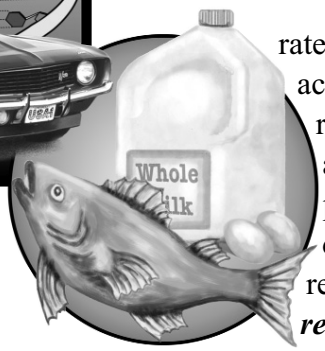
# *Chapter 1*

## Section 3

***Lessons 11-15***

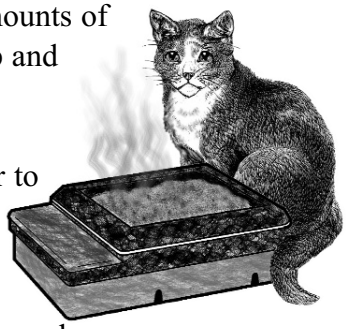
## *ENZYMES— THE CATALYSTS OF LIFE*




As we studied in the lesson on chemical reactions, *activation energy* is the energy required to get a reaction started. In the laboratory, applying heat generally does this. In life, activation energy must also be supplied for reactions to take place within the bodies of living things. Thousands of reactions that require high activation energy in a test tube take place at relatively low temperatures every instant within a living organism.

A ***catalyst*** is a substance that *increases* the rate of a chemical reaction by *reducing* activation energy, the energy required to get a reaction going. In living things, the catalysts are called ***enzymes***. An enzyme is not permanently changed by the reaction, nor does it alter the equilibrium point of the reaction—the relative amounts of ***reactants*** that are used up and of products that are formed.



As an example of the action of an enzyme, let us consider a reaction familiar to anyone who owns a cat. When urea from the cat's urine turns into carbon dioxide and ammonia, a characteristic odor is produced signaling that the litter box is in need of cleaning. An enzyme called *urease*, produced by bacteria that fall out of the air and grow in the cat's box, catalyzes this reaction. At room temperature and at pH 8, a molecule of urease can catalyze the ***hydrolysis*** of about 30,000 molecules of urea in one second. In the absence of the urease enzyme, the reaction would require several million years to complete! In the presence of urease, the reaction happens at more than hundreds of thousands of times its natural rate. Some enzymes work more quickly than urease, others work more slowly.

Enzymes are very specific in that each catalyzes only one, or a very few reactions. Each enzyme is uniquely

## VOCABULARY

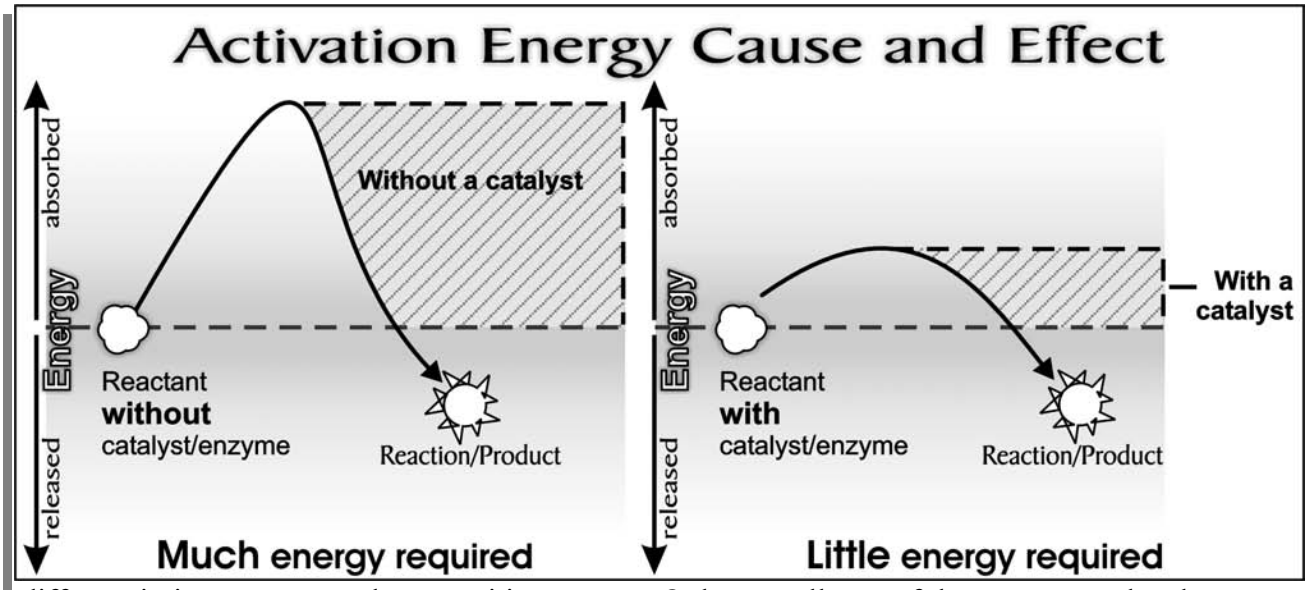
***Catalyst:*** a substance that increases the rate of chemical reactions by lowering activation energy; catalysts are not altered by the reactions, nor do catalysts alter the equilibrium points of reactions

***Enzymes:*** a class of proteins serving as catalysts in living systems

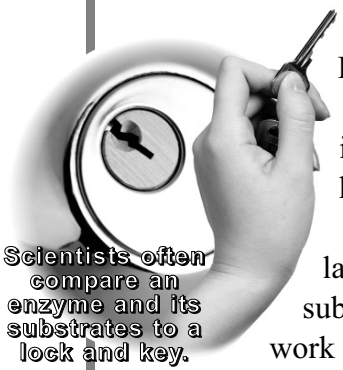
***Reactant:*** an element or compound that enters into a chemical reaction

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different in its structure and composition. Each enzyme catalyzes only those reactions that involve ***substrates*** that can perfectly "fit" the surface of the protein. In fact, scientists often compare an enzyme and its substrates to a lock and key.


Scientists often compare an enzyme and its substrates to a lock and key.

Enzymes are very large molecules while the substrates upon which they work are usually very small. Only a small part of the enzyme molecule can be in contact with the substrate when the two are joined. This small portion of the enzyme is called the ***active site*** which "fits" on a substrate to form an enzyme-substrate complex. Both enzyme and substrate change shape slightly when they combine. This is known as ***induced fit***. However, the enzyme is not permanently changed by participation in a reaction and it emerges exactly as it started, ready to catalyze another reaction.

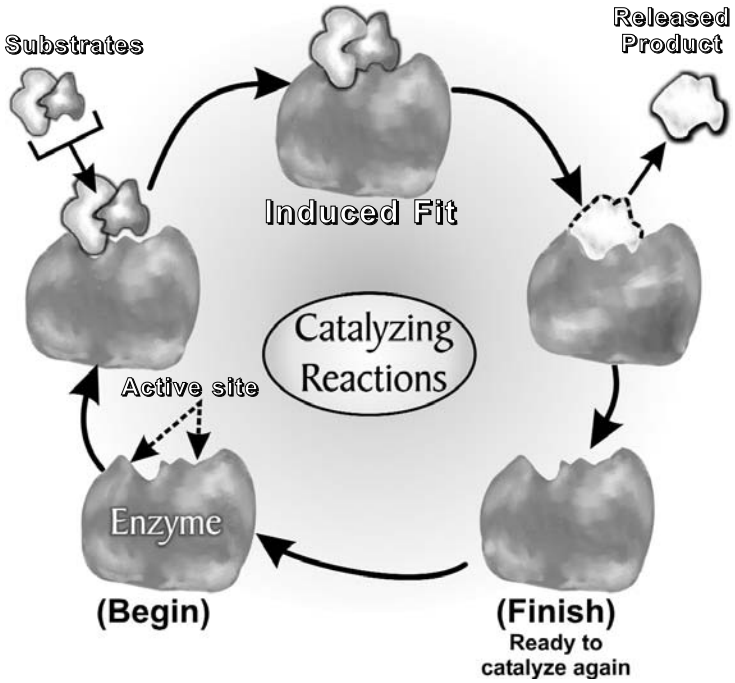
## VOCABULARY

***Hydrolysis:*** decomposition or breaking down of a compound into other compounds by taking up water

***Substrate:*** the substance on which an enzyme works

***Active site:*** that specific portion of an enzyme that attaches to the substrate by means of weak chemical bonds

***Induced fit:*** the change in shape of the active site of an enzyme so that it binds more snugly to the substrate




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Most proteins work best when they are in a medium of approximately neutral pH. However, some organisms live in acidic or basic environments. For example, digestive enzymes of the human stomach work best at an extremely acidic pH of about 1.5-2.0.

Temperature affects the rate of enzyme reactions. Temperatures above about 60ºC disrupt their structure permanently so that they lose all ability to function. For example, heating food preserves it by destroying all the enzyme activity of organisms that cause decay. At the opposite extreme, chemical reactions proceed slowly at low temperatures because molecules move so slowly that few collisions occur between enzyme and substrate molecules. As an application, refrigeration preserves food by slowing the action of enzymes that cause decay.




Some enzymes are designed to work in extremely hot or cold environments. Some blue-green algae live on the surfaces of glacial ice and are adapted to temperatures near freezing (0ºC). Other blue-green algae inhabit the hot springs of Yellowstone which may be at temperatures of 80º to 85ºC (or 176º to 185ºF).

Enzymes regulate chemical pathways, catalyze the synthesis and breakdown of important compounds, help a cell to store and release energy, and transfer information from one part of a cell to another. As you will discover in your study of biology, enzymes are involved in digestion, respiration, reproduction, vision, movement, thought, and even in the making of other enzymes. The world of living things would not survive without enzymes.

**The next lesson will cover the code, or blueprint, of life: nucleic acids.**

## LIFE PRINCIPLE



**"Things which you receive 'free' cost someone something."**

—Ronald Johnson, PhD.
Educator and author

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DNA

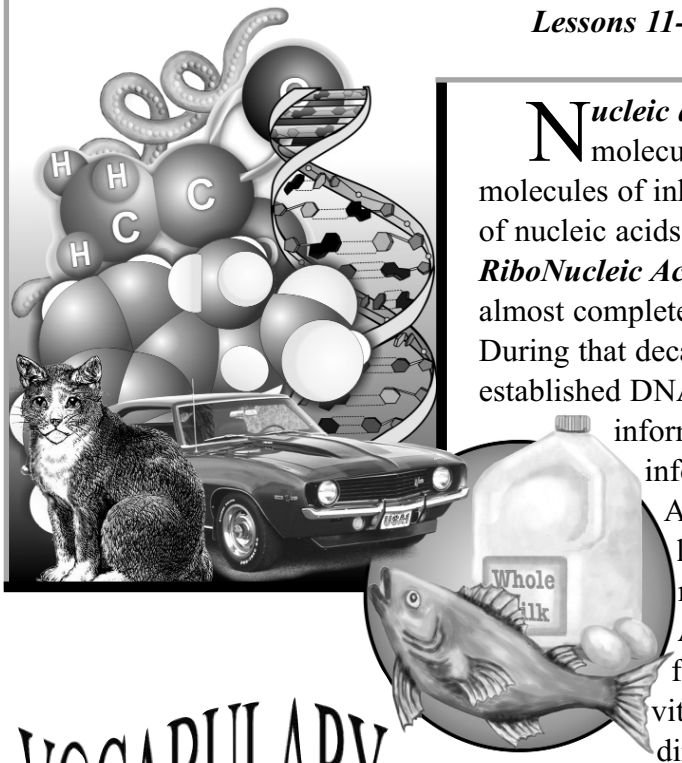
Lesson 14

# Chapter 1

## Section 3

*Lessons 11-15*

## NUCLEIC ACIDS—THE BLUEPRINT OF LIFE




***Nucleic acids*** are the information-carrying molecules of the cell and are known as the molecules of inheritance or ***genetics***. There are two kinds of nucleic acids: ***DeoxyriboNucleic Acid (DNA)*** and ***RiboNucleic Acid (RNA)***. The study of genetics was almost completely ignored until the 1940s and 1950s. During that decade, chemists discovered and factually established DNA as the material that stores coded information for making proteins and passing information from one generation to the next. A DNA molecule contains a group of atoms linked together to form a double ***helix*** that resembles a beautiful, spiral staircase. Amazingly, a single cell contains about a 5 foot chain of DNA material. RNA has a vital role in the synthesis of proteins as directed by the DNA.

Nucleic acid monomers are called *nucleotides*. Each nucleotide is composed of 3 distinct units:

**(1)** a phosphate group
**(2)** a 5-carbon sugar
**(3)** a ring-shaped nitrogenous base

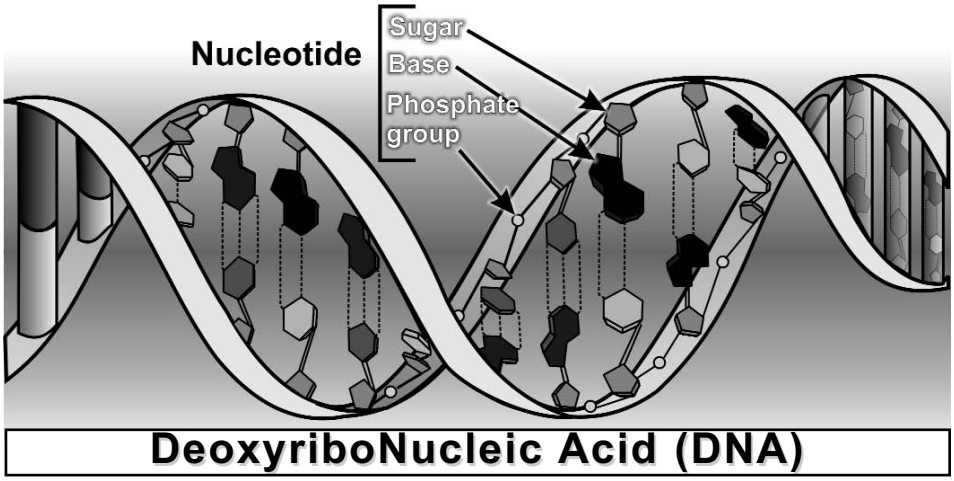
The sugar may be either *ribose*, which is found in the nucleotides that make up RNA (ribonucleic acid) or *deoxyribose*, found in the

## VOCABULARY

***Nucleic acids:*** the information-carrying molecules of the cell; known as the *code of life*, *thread of life* or *blueprint of life*; of two kinds: DNA and RNA

***Genetics:*** the study of heredity and variations in organisms in terms of composition and characteristics passed from one generation to the next

***DeoxyriboNucleic Acid (DNA):*** the genetic material of all cells; consists of two, long, thin polymeric chains twisted about each other in the form of a double helix

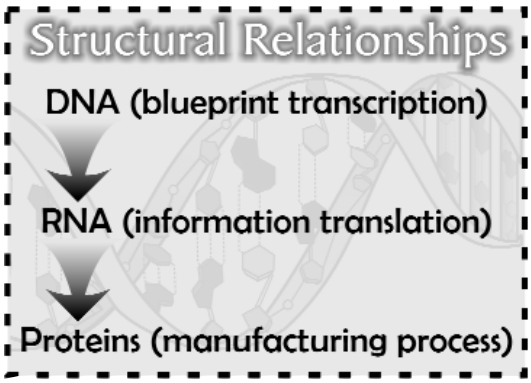



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nucleotides of DNA (deoxyribonucleic acid).

A number of nucleotides have other important functions in living things. For example, ***ATP (adenosine triphosphate)*** plays a critical role in cell function as an immediate source of energy. ***AMP (adenosine monophosphate)*** is an important intermediary in the function of some hormones.




## VOCABULARY

***RiboNucleic Acid (RNA):*** a principal type of nucleic acid that carries out the instructions coded in DNA

***Helix:*** any object having a coiled or spiral form such as a metal spring or DNA molecule

***ATP (Adenosine TriPhosphate):*** energy storage in nucleic acids of cells, can release large amounts of energy in muscle tissue

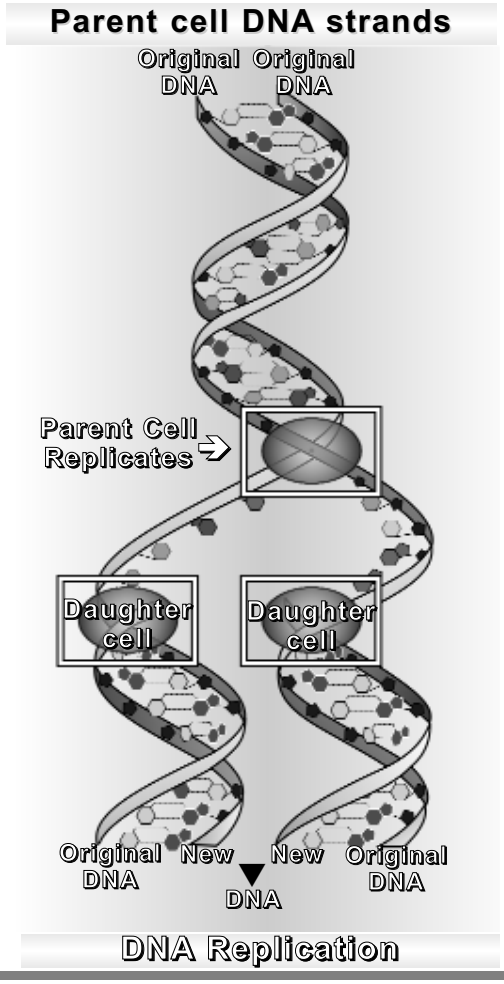
***AMP (Adenosine MonoPhosphate):*** regulates many cellular and enzymatic processes

***Blueprint:*** a comprehensive, master plan for a project; a detailed plan of action

***Hemoglobin opathy:*** a condition resulting from one amino acid being out of sequence in the hemoglobin molecule

***Sickle cell anemia:*** a disease whereby red blood cells are deformed, fragile and easily ruptured, leaving victim with less red blood cells; can lead to kidney or heart failure

DNA has been called "the thread of life" and has taken the central place in understanding the cell. It is a highly stable molecule consisting of four different kinds of units. The order of these units spells out a message, written in code, telling the machinery of the cell how to arrange amino acids in proteins. The DNA acts as the ***blueprint*** for the activities in the cell, and the RNA assists the DNA by carrying the genetic messages bit by bit from the DNA to the cell's protein manufacturing site. When a cell divides, the DNA message is transcribed exactly into two DNA copies of the original molecule. One copy of each message goes to each of the daughter cells during cell division. The process results in each new cell having an exact copy of the DNA of the parent cell.




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In the human body, DNA "programs" all characteristics such as hair, skin, eyes and height. DNA determines the arrangement of your 206 bones, over 600 muscles, some 10,000 auditory nerve fibers, nearly 2 million optic nerve fibers, 100 billion nerve cells, 8,000 miles of blood vessels and much more! The capacity of your DNA to store information vastly exceeds that of today's most sophisticated computer. In fact, the information needed to specify the design of all the species of organisms which have ever lived could be held in a teaspoon with room to spare.

More fascinating than DNA itself is the question of just how DNA came to exist. DNA is a highly sophisticated engineering wonder. All life, from the most basic bacteria to man, is dependent on DNA. The laws of probability virtually prohibit the accidental synthesis of a single DNA molecule. DNA is so complex in design and function that the probability of instantaneous appearance seems far more plausible than prolonged development over extended periods of time.

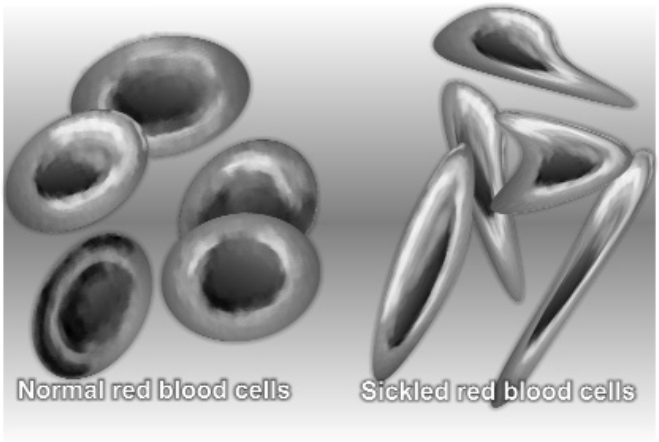
An astounding example would be the molecule *hemoglobin*, perhaps the most important protein in our bodies. Hemoglobin is produced by the directive of a DNA molecule, and is responsible for both the red color of our blood and for the oxygen uptake as we breathe. Even ancient peoples knew and wrote that "the life of the flesh is in the blood." New red blood cells are manufactured in the bone marrow at the amazing rate of over 2,000,000 cells per second.

Scientists have identified only one specific sequence that is hemoglobin. A disease called ***hemoglobin opathy*** occurs if the DNA directs even one amino acid to be out of place in red blood cells, and such an alteration of function is usually lethal to the organism. ***Sickle cell anemia*** is one example of faulty hemoglobin. This mutation results in deformed red blood cells, some having a somewhat "sickle" appearance and resulting in sickle cell anemia.

The number of possible amino acid combinations is approximately $10^{650}$ sequences (that is 10 with 650 zeros after the 10), but only one of them would be hemoglobin. The probability that hemoglobin could have occurred perfectly by chance is considered to be mathematically impossible, considering that the number of atoms in the entire universe is only about $10^{66}$, and that scientists have calculated only about $10^{17}$ seconds in the age of the universe! In physics, scientists consider any possibility more remote than $10^{-50}$ to be absurd.

We will consider the wonders of nucleic acids in much more detail in another chapter.

**In the next lesson, we will examine the fascinating facts of mirror images in living things.**




## LIFE PRINCIPLE

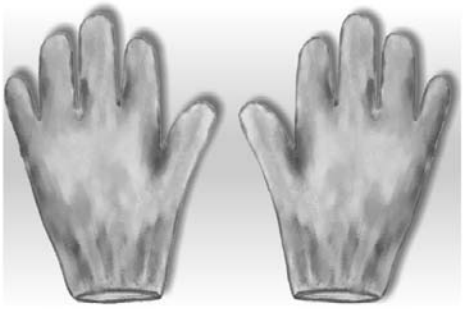


**"Success is how high you bounce once you hit bottom."**

–General George S. Patton, Jr.
(1885-1945)
Distinguished WWII American general

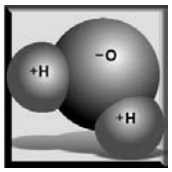
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*Molecules*

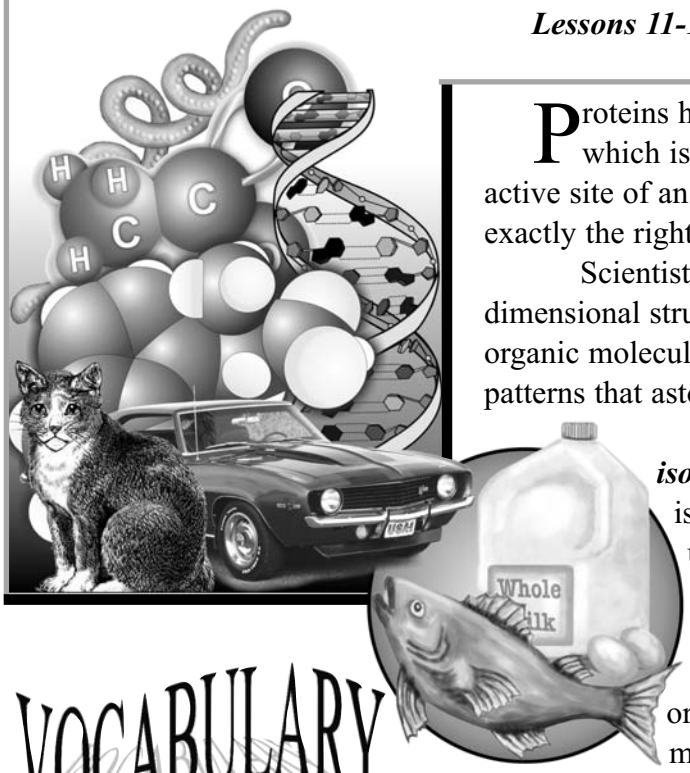
**Lesson 15**

# *Chapter 1*

## Section 3

***Lessons 11-15***

## *MIRROR IMAGES OF LIFE*



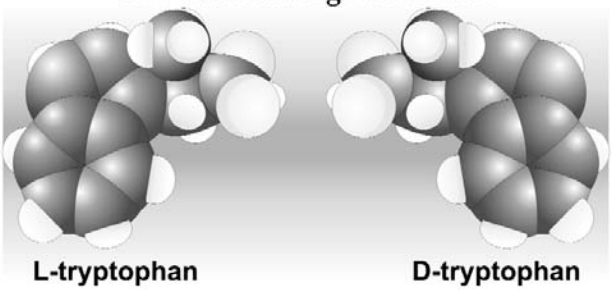

Proteins have a complex, three-dimensional structure which is very important to their function. The active site of an enzyme, for example, needs to have exactly the right shape to bind its substrates.

Scientists who looked closely at the three-dimensional structures of amino acids, sugars and other organic molecules discovered some very interesting patterns that astonished the scientific world.

As scientists first examined the ***optical isomers*** of the amino acid ***tryptophan***, the isomers appeared to be identical. However, under closer examination, scientists noticed that these two optical isomers actually are mirror-images of each other. As scientists continued to examine other complex organic molecules, many were found to have mirror-images.

Think about a pair of mirror-images you use in everyday life, such as a pair of gloves. A pair of gloves consists of a right-handed glove and a left-handed glove; each glove is the mirror image of the other. Despite the fact that a left-handed glove is almost the same as a right-handed one, no matter how you turn or twist the left-handed glove, you cannot make it into a right-handed glove.

Two Mirror-image Molecules




The two types of tryptophan are related to each other in the same way. In fact, chemists describe them as left-handed and right-handed molecules. One type is called *L-tryptophan*. The letter *L* stands for ***levo***, the Latin word for *left-handed*. The



## VOCABULARY

***Optical isomers:*** optical isomers having the same structural formula and the same bonds, but are mirror images of each other

***Tryptophan:*** an essential amino acid formed from protein by certain enzymes; found in milk and many other foods

***Levo:*** Latin for *left-handed*; used to designate the different forms of optical isomers

***Dextra:*** Latin for *right-handed*; used to designate the different forms of optical isomers

***Racemic mixture:*** a solution containing equal amounts of both L and D isomers

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other type is called *D-tryptophan*. The letter *D* stands for ***dextra***, the Latin word for *right-handed*. *L*-trypotphan has the property of producing drowsiness in humans. You may have noticed feeling sleepy after a big Thanksgiving dinner which included a lot of turkey. That is because turkey contains a rich supply of *L*-tryptophan.




Although the two optical isomers (*L* and *D*) may look similar, the properties between the *L* and *D* isomers are almost always very different. For example, in the pain reliever *Ibuprophen*, only the *L*-form is the active pain-reliever; the *D*-form is completely inactive. However, scientists prepare a ***racemic mixture*** of Ibuprophen containing an equal part of each form to sell to drug companies because the human body will covert the *D*-form to the *L*-form so that the entire dose becomes effective.

An example of an optical isomer with a different twist is glucose, the sugar found in the cells of most living organisms. The isomer *D-glucose*, which is a primary source of energy for the body, has a sweet taste. Conversely, *L-glucose* has no taste and is not even metabolized by the body.

With very few exceptions, such as glucose, the amino acids found in living organisms are all of one type—the *L*-type. Like a left-handed glove—one that fits only a left-hand—the enzymes in living cells are designed to fit only the left-handed amino acids. This remarkable consistency is a vital link to reproduction of organisms, generation after generation.

**In the next chapter, we will begin to examine the incredible world and functions of the cell.**

## LIFE PRINCIPLE



**"The greatest homage we can pay to truth is to use it."**

—Ralph Waldo Emerson
(1803-1882)
American poet and essayist

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