Introductory Biology

Introductory Biology

MEASTERLING

TULSA COMMUNITY COLLEGE
TULSA

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This text supports students studying biology for majors. As an introductory course, there is broad coverage of topics. Supplemental information regarding metacognition and a presentation project using public-health data are included as ancillary material.

This introductory biology text for majors is supported with an external lab component. The course includes an in-depth study of fundamental biological concepts, including metabolism, homeostasis, heredity, evolution, and ecology at the sub-cellular, cellular and organismal levels. It provides the foundation for other advanced courses in the biological sciences.

Course Outcomes

1. Examine characteristics common to life.
2. Identify the chemical components of life.
3. Describe metabolic processes as these relate to homeostasis.
4. Analyze cell types and cellular reproduction.
5. Relate heredity and evolution to organisms and ecosystems.
6. Apply scientific inquiry to predict outcomes.
7. Classify and compare major groups of organisms.

PART I

MODULE 1

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Module 1

Chapter 1 focuses on the characteristics of life that continue to be debated in science today and provides important parameters for space exploration. Chapter 2 examines the periodic table of elements and the three primary bonds of biology. Chapter 3 covers the molecules of life, providing keystone content for this course. Chapter 4 supports understanding of the cell as the basic unit of life. Microscopes to allow us to see cells. Cell structures are described, and differences between prokaryotic and eukaryotic structures are highlighted. This cover page provides all Module 1 Learning Objectives, a question answered by each chapter and respective chapter summaries.

Module 1 is aligned with the following course objectives.

- Examine characteristics common to life
- Identify the chemical components of life
- Apply scientific inquiry to predict outcomes
- Classify and compare major groups of organisms

Learning Objectives Chapter 1

What determines if something found in space is alive?

1. Recognize the steps of the scientific method
2. Recognize the parameters of scientific outcomes
3. Identify the characteristics common to life

Chapter 1 Summary

Biology is the science of life. All living organisms share several key properties such as order, sensitivity or response to stimuli, reproduction, growth and development, regulation, homeostasis, and energy processing. Living things are highly organized parts of a hierarchy that includes atoms, molecules, organelles, cells, tissues, organs, and organ systems. Organisms, in turn, form a hierarchy of populations, communities, ecosystems, and the biosphere. A diagram called a phylogenetic tree can be used to visualize relationships among organisms. The tree of life has three main branches: Bacteria, Archaea, and Eukarya.

Learning Objectives Chapter 2

What makes up living things?

1. Identify the chemical components of life
2. Recognize elements and the six common to life
3. Recognize atomic structure
4. Recognize three types of bonds in biology

Chapter 2 Summary

Elements in various combinations comprise all matter, including living things. Some of the most abundant elements in living organisms include carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur. These form the four major molecules of life: carbohydrates, lipids, proteins, and nucleic acids. Water has many properties that are critical to maintaining life. Atoms are the smallest units of an element that retain all of the properties of that element and consist of protons, neutrons, and electrons. Electrons can transfer, share, or cause charge disparities between atoms to create bonds, including ionic, covalent, and hydrogen bonds. These bonds form molecules.

Learning Objectives Chapter 3

What molecules are in your food? What do they do?

1. Identify the four major molecules of life
2. Identify corresponding monomers and polymers
3. Identify functions for the four molecules

Chapter 3 Summary

Carbohydrates, lipids, proteins, and nucleic acids are the four biological macromolecules—large molecules necessary for life. These four are built from smaller organic molecules. Macromolecules are made up of single units known as monomers, joined by covalent bonds to form larger polymers. Carbohydrates provide a vital energy source for all cell types and provide structural support to plant cells. Lipids are nonpolar and hydrophobic in nature. Major lipid types include fats and oils, waxes, and phospholipids (famous for forming plasma membranes). Proteins perform a diverse range of functions for the cell. They help in metabolism, provide structural support and act as enzymes, carriers, or hormones. The building blocks of proteins (monomers) are amino acids. Protein shape and function are linked, as any change in shape may lead to protein denaturation and subsequent loss in function. Nucleic acids hold the instructions for building proteins. There are four DNA nucleotides (ACTG) and four RNA nucleotides (AUCG).

NAME	MONOMER	POLYMER	FUNCTION
Carbohydrate	Monosaccharide (glucose most common)	Polysaccharide	Fuel for cells in cellular respiration
Lipid	Glycerol and fatty acid	Triglycerol	Form membranes (compartments)
Protein	Amino acid	Polypeptide	Cellular work of transport, storage and more
Nucleic Acid	Nucleotide: ACTG (U)	DNA and RNA	Hold instructions for building proteins

Learning Objectives Chapter 4

What is inside the cells of your body?

1. Recognize two types of microscopes for observing cell structure

2. Analyze differences in prokaryotic and eukaryotic structures
3. Identify organelle structures

Chapter 4 Summary

A cell is the smallest unit of life. Most cells cannot be seen with the naked eye, and microscopes allow us to visualize cells. Teaching labs use light microscopes, and some research labs use electron microscopes. All prokaryotes have plasma membranes, cytoplasm, ribosomes, and DNA that is not membrane-bound. Like a prokaryotic cell, a eukaryotic cell has a plasma membrane, cytoplasm, and ribosomes, but a eukaryotic cell is typically larger than a prokaryotic cell, has a true nucleus (meaning its DNA is surrounded by a membrane), and has other membrane-bound organelles that allow for compartmentalization of functions. The plasma membrane is a phospholipid bilayer embedded with proteins. Ribosomes provide a location for protein synthesis. Mitochondria are responsible for the majority of ATP produced in the cell. Lysosomes digest macromolecules, recycle worn-out organelles, and destroy pathogens. The RER modifies proteins and synthesizes phospholipids. The SER engages in detoxification and more. Sorting, tagging, packaging, and distribution take place in the Golgi apparatus. The cytoskeleton has three different types of protein elements, microfilaments, intermediate filaments, and microtubules.

When you are ready to prepare for the first exam, this audio study guide might be helpful.

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1. Chapter 1

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Learning Objectives

1. Recognize the steps of the scientific method
2. Recognize the parameters of scientific outcomes
3. Identify the characteristics common to life

The Study of Life

Science is not a set of truths written in stone. It is an approach to discovering truths about the world that applies to problems encountered in everyday life. New ideas, new experiments, new tools, and new ways of gathering data are constantly adding to discovery, so scientific ideas are always subject to change. Science includes many fields of study attempting to comprehend the nature of the universe.

Scientific method is a process for investigating natural phenomena to accurately explain how the natural world works. A hypothesis is a suggested explanation for an observation based on previous research. Theories are established explanations for a phenomenon or observations that are broader in scope than a hypothesis. Theories are also testable and well supported by a tremendous amount of research, like gravitational theory.

Scientific method begins with an **observation**, which leads to one **question** being

generated that can be used to form a testable hypothesis. The **hypothesis** is a falsifiable suggested explanation for a particular phenomenon or set of observations. An **experiment** will be constructed with results that will either support or fail to support the hypothesis. Lab experiments require a control group, which is not exposed to the variable, and a variable group, which is exposed to the variable. Experiments can have only one variable. Two variables would keep anyone from knowing which variable caused the change.

Following the experiment, the results will be **analyzed** and **reported**. The next step is to **share** those results. Scientists share findings to expand and build upon their discoveries. Collaboration with other scientists—when planning, conducting, and analyzing results—are all important for scientific research. Scientists communicate with peers and share results. Most scientists present their results in peer-reviewed papers that are published in scientific journals. Peer-reviewed papers are reviewed by qualified colleagues. These colleagues are often experts in the same research area, who judge whether or not the paper is suitable for publication. Scientists publish their work so other scientists can reproduce their experiments under similar or different conditions to expand on the findings. When additional experimental results are consistent with the paper, the original paper is validated.

A scientific paper consists of several specific sections—abstract (introduction), materials and methods, results, and discussion. Papers usually begin with an **abstract** (a concise summary) and conclude with a reference section. There might be additional sections depending on the type of paper and the journal where it will be published.

The introduction starts with brief, but broad, background information about what is known in the field. A good introduction also gives the rationale of the work mentioning the hypothesis. The introduction should refer to the published scientific work of others and requires citations following the style of the journal. Using the work or ideas of others without proper citation is considered plagiarism.

The **materials and methods** section includes a complete and accurate description of any substances used, and the method and techniques used by researchers to gather data. The description should be thorough enough to allow another researcher to repeat the experiment and obtain similar results. This section will also include information on how measurements were made and what types of calculations and statistical analyses were used to examine raw data.

The **results** section narrates the findings without interpretation. The results are presented by means of tables or graphs, but no duplicate information should be presented. The **discussion** section interprets results, describes how variables may be related, and attempts to explain the

observations. Results are placed in the context of previously published scientific research and require proper citations.

Finally, the **conclusion** summarizes the importance of experimental findings. While the scientific paper almost certainly answered one or more scientific questions that were stated, any good research should lead to more questions. Therefore, a well-done scientific paper leaves doors open for researchers to continue and expand on the findings.

Review articles summarize and comment on findings published as primary literature and typically include extensive reference sections.

Exploring the Properties of Life

Order: Organisms are highly organized structures with one or more cells. Even very simple organisms are complex. Inside each cell, atoms make up molecules that make up organelles. In multicellular organisms, similar cells form tissues. Tissues build organs. Organs work together to form organ systems. Smallest to largest in humans follows this order atoms, molecules, organelles, cells, tissues, organs, and organ systems to form each organism.

Sensitivity or Response to Stimuli: Organisms respond to a variety of stimuli. Plants bend toward a source of light, climb on fences and walls. Even bacteria can move toward or away from chemicals or light.

Reproduction: Single-celled organisms reproduce by first duplicating their DNA and dividing it equally into two new cells. Multicellular organisms often produce specialized reproductive cells that form new individuals. Reproductive cells pass DNA, containing genes, to offspring. Genes ensure offspring belong to the same species and have similar characteristics.

Growth and Development: Organisms grow and develop following specific instructions coded for by their genes, based on the principles of the Central Dogma of Biology. DNA codes for RNA codes for proteins. The genes composed of DNA provide instructions to direct cellular growth and development, ensuring offspring will grow up to exhibit many of the same characteristics as its parents.

Regulation: Even the smallest organisms are complex and require multiple mechanisms to coordinate internal functions, respond to stimuli, and cope with environmental stresses. Two examples of internal functions regulated in an

organism are nutrient transport and blood flow. Organs (groups of tissues working together) perform specific functions, such as carrying oxygen throughout the body, removing wastes, delivering nutrients to every cell, and cooling the body.

Homeostasis: In order to function properly, cells need proper temperature, pH, and an appropriate concentration of diverse molecules. These conditions can change from one moment to the next. Organisms maintain internal conditions almost constantly through homeostasis. For example, an organism needs to regulate body temperature through a process known as thermoregulation. Organisms that live in cold climates, such as the polar bear, have body structures that help them withstand low temperatures and conserve body heat. Structures that aid in this type of insulation include fur, blubber, and fat. In hot climates, organisms have other methods to regulate body heat.

Energy Processing: All organisms use a source of energy for their metabolic activities. Some organisms are producers that capture energy from the sun and convert it into chemical carbohydrate energy. Consumers are organisms that use the chemical energy from producers as food.

Some organisms consist of a single cell, and others are multicellular. Cells are classified as prokaryotic or eukaryotic. Prokaryotes are single-celled or colonial organisms that do not have membrane-bound nuclei. In contrast, the cells of eukaryotes have membrane-bound organelles and a membrane-bound nucleus.

Above the level of organism, there are higher levels of organization. Organisms form populations, communities, ecosystems, and the biosphere. These are in order from smallest to largest.

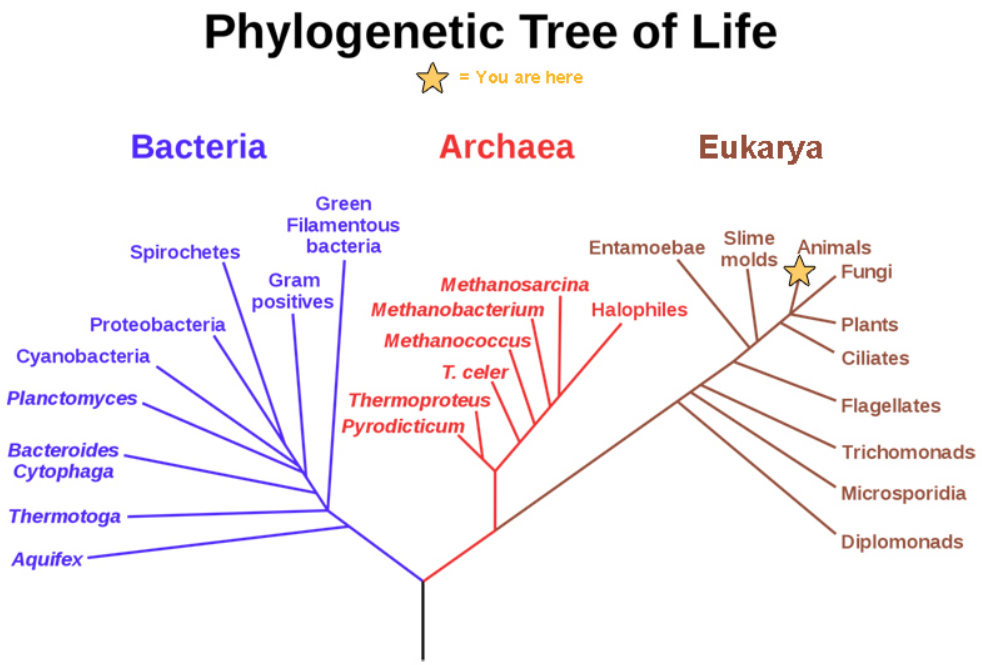

Figure 1.17 This phylogenetic tree was constructed by microbiologist Carl Woese using data obtained from sequencing ribosomal RNA genes. The tree shows the separation of living organisms into three domains: Bacteria, Archaea, and Eukarya. Bacteria and Archaea are prokaryotes, single-celled organisms lacking intracellular organelles. (credit: Eric Gaba; NASA Astrobiology Institute)

Living things can be divided into three domains: Bacteria, Archaea, and Eukarya. Both bacteria and archaea are prokaryotic domains. The eukaryotic domain contains both single-celled organisms and complex organisms. In addition, organisms are either producers or consumers. Producers extract energy from nonliving environmental resources. Consumers extract energy from producers, either directly or indirectly.

Key Takeaways

1. Scientific method involves observation, hypothesis, experimentation and data.
2. Scientific outcomes involve collaboration and peer-review, which are subject to bias.
3. Properties of life include order, sensitivity, reproduction, growth, regulation, homeostasis, and energy processing. The tree of life has three main branches.

Biology-2e. (2018). Houston, RX: website: OpenStax Book title: Biology 2e . Access for free at https://openstax.org/books/biology-2e/pages/1-introduction

2. Chapter 2

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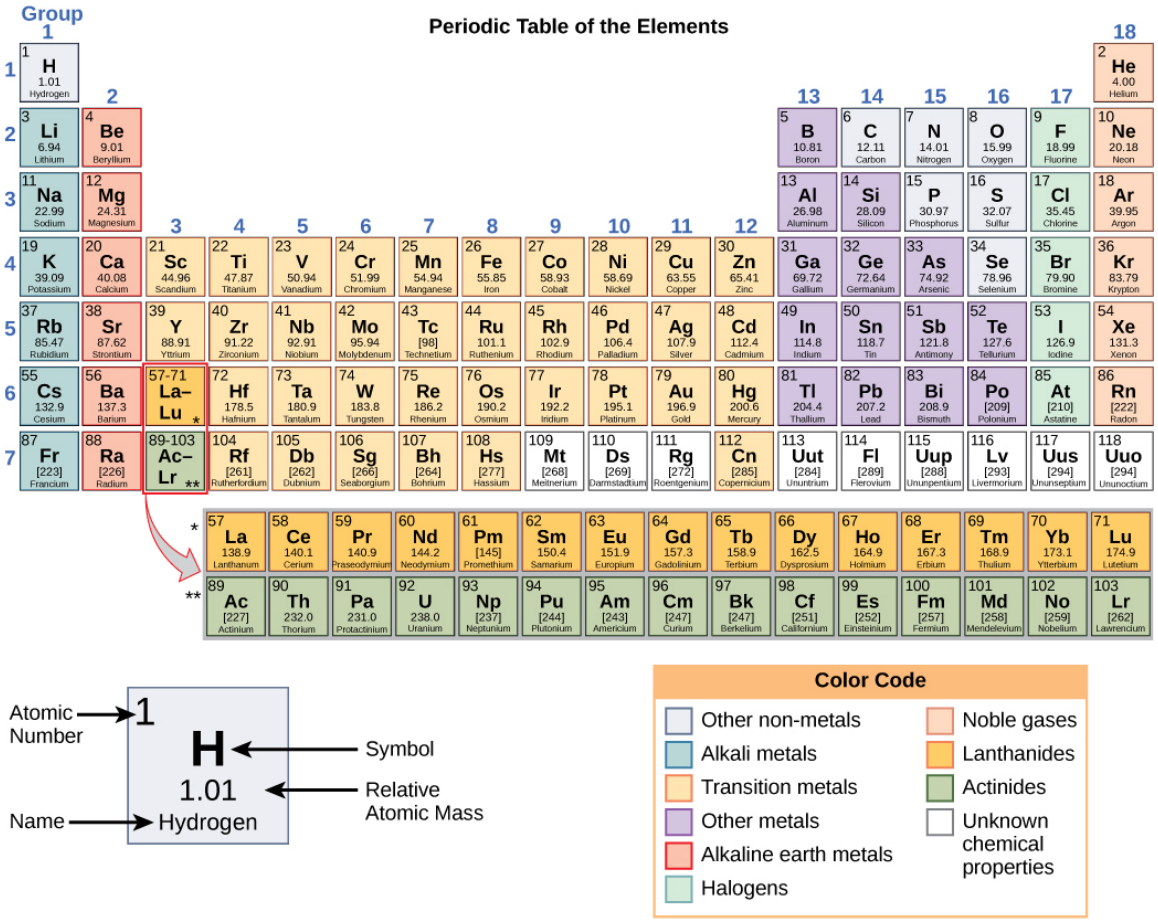
Learning Objectives

1. Identify the chemical components of life
2. Recognize elements and the six common to life
3. Recognize atomic structure
4. Recognize three types of bonds in biology

The Chemical Foundation of Life

At its most fundamental level, life is made up of matter. Matter is any substance that occupies space and has mass. Elements are unique forms of matter with specific chemical and physical properties that cannot be broken down into smaller substances by ordinary chemical reactions. Any pure element would be composed of one type of atom. The elements are shown below in the periodic table. The following are the six most abundant elements in life.

1. Carbon
2. Hydrogen
3. Oxygen
4. Nitrogen
5. Phosphorus
6. Sulfur



The periodic table shows the atomic mass and atomic number of each element. The atomic number appears above the symbol for the element and the approximate atomic mass appears below it.

An atom's nucleus contains positively charged particles called **protons** and neutral, uncharged particles called **neutrons**. Surrounding the atomic nucleus is an area of **electrons** (negatively charged particles) that orbit. Protons and neutrons have approximately the same mass. Although similar in mass, protons and neutrons differ in their electric charge. A proton is positively charged whereas a neutron is uncharged. Therefore, the number of neutrons in an atom contributes significantly to its mass, but not to its charge. Electrons are much smaller in mass than protons, about 1/1800 of a proton. They do not contribute much to an element's overall atomic mass. Atomic mass is based on the number of protons and neutrons alone. Electrons contribute greatly to the atom's charge, as each electron has a negative charge equal to the positive charge of a proton. In uncharged, neutral atoms, the number of electrons orbiting the nucleus is equal to the number of protons inside the nucleus.

The number of protons determines an element's atomic number and is used to distinguish one element from another. Uncharged atoms of each element contain an equal number of protons and electrons. An **ion** is an atom with unequal numbers of protons and electrons resulting in a charge. An **isotope** is an element with an unequal number of neutrons and protons.

Atoms naturally reach the most stable state possible. Many atoms become stable when they satisfy the octet rule, by having eight valence electrons. Electrons fill orbitals in a consistent order. First, the orbitals closest to the nucleus fill, then they continue to fill orbitals of increasing energy further from the nucleus. Electrons of the outermost energy level determine the energetic stability of the atom and its tendency to form chemical bonds with other atoms to form molecules. Under standard conditions, atoms fill the inner shells first, often resulting in a variable number of electrons in the outermost shell. The innermost shell has a maximum of two electrons but the next two electron shells can each have a maximum of eight electrons. This is known as the octet rule, which states, with the exception of the innermost shell, atoms are more stable energetically when they have eight electrons in their valence (outermost) shell. This principle drives atomic bonding. When atoms bond together, molecules are formed. When some elements form chemical bonds, the elements share, donate, or accept electrons so their valence shell contains eight electrons.

Ionic bonds are formed between ions with opposite charges and involve an atom that gains or loses an electron. For instance, positively charged sodium ions and negatively charged chloride ions bond together to make crystals of sodium chloride (table salt). These bonds form a crystalline molecule with zero net charge. Certain salts are referred to as electrolytes (including sodium, potassium, and calcium). These ions are necessary for nerve signals, muscle contraction and water balance.

Covalent bonds are stronger and much more common than ionic bonds in the molecules of living organisms. These bonds are the result of shared electrons. Sharing of electrons can be equally distant from both atoms nucleus (nonpolar covalent) or unequal (polar covalent). Oxygen and hydrogen are held by covalent bonds in water (H_2O).

Hydrogen bonds are the weak bonds, commonly found between individual water molecules. Although, individual hydrogen bonds are weak and break easily, many of them together are strong enough for surface tension and adhesion. In water, each hydrogen has a slightly positive charge because hydrogen's electron is pulled more strongly toward the other element and away from the hydrogen. Because the

hydrogen is slightly positive, it will be attracted to neighboring negative charges. When this happens, a weak interaction occurs between the δ+ of the hydrogen from one molecule and the δ– charge on the more electronegative atoms of another molecule, usually oxygen or nitrogen, or within the same molecule. This type of bond is common and occurs regularly between water molecules. Although individual hydrogen bonds are weak and easily broken, they occur in very large numbers in water and determine its characteristics.

Chemical reactions occur when chemical bonds between atoms are formed or broken. The substances that go into a chemical reaction are called the reactants, and the substances produced at the end of the reaction are known as the products. In a chemical equation, reactants usually appear on the far left followed by a directional arrow that points to the right. Products appear to the right of the arrow. The arrow indicates a reaction occurred.

The polarity of the water (H_2O) molecule and resulting hydrogen bonds make water a unique substance with special properties tied to the processes of life. Water is the universal solvent. The positively charged end of the water molecule attracts negatively charged particles. The negatively charged end of the water molecule attracts positively charged particles. These properties are vital to life as we know it on the surface of the earth.

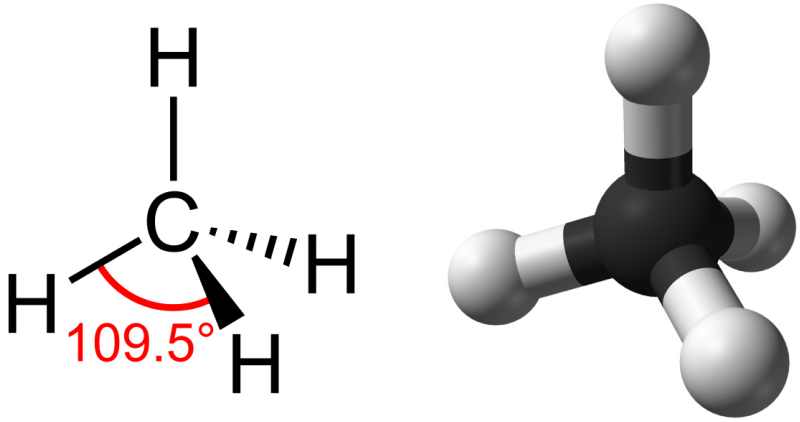
Water has a high heat of vaporization, meaning water can turn into steam requiring a lot of energy to raise its temperature high enough for that to happen. Water has a high heat capacity, so it stores heat well. Water also has a crystalline lattice structure when frozen into ice, meaning the angles of its bonds form a lattice. This phenomena allows ice to be less dense than liquid water, so ice floats in water.

Water is attracted to other water molecules through the property of cohesion. This results in surface tension that allows some insects to cross water. Water molecules also display adhesion by attraction to other surfaces. The water droplets in an empty water bottle cling to the sides because of this property. The properties of adhesion and cohesion are vital to the energy cycle.

Many substances are hydrophilic, or water loving. Others are hydrophobic and repel water. Oil is an example of a hydrophobic molecule.

Water is has a neutral pH of 7. Neutral is at 7, with acids below that (smaller numbers) and bases above it (higher numbers). The pH scale is logarithmic, so the difference between a 3 and a 4 is a change in the concentration of hydrogen ions [H+] times ten. Buffers are chemicals that act to minimize changes in pH.

Individual carbon atoms have an incomplete outermost electron shell. With an atomic number of 6, the first two electrons fill the inner shell, leaving four in the second shell. Therefore, carbon atoms can form up to four covalent bonds with other atoms to satisfy the octet rule. The methane molecule provides one example, as it has the chemical formula CH_4. Each of its four hydrogen atoms forms a single covalent bond with the carbon atom by sharing a pair of electrons. This results in a filled outermost shell. For this reason, methane is described as having tetrahedral geometry. Both of the images here represent methane.



Methane has a tetrahedral geometry with each of the four hydrogen atoms spaced 109.5° apart.

As the backbone of the large molecules of living things, hydrocarbons may exist as linear carbon chains, carbon rings, or combinations of both. Structure determines function. Read more about the chemical properties of life here.

Key Takeaways

1. Matter is composed of atoms.
2. The periodic table of elements arranges by atomic number, and CHONPS are the six most common elements to life
3. Atoms contain protons, neutrons and electrons. Protons (positively charged) and neutrons (uncharged) are in the atomic nucleus, while electrons (negatively charged) orbit them. Because of this, electrons drive bonding.
4. Ionic, covalent and hydrogen bonds are common to life.

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3. Chapter 3

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Learning Objectives

1. Identify the four major molecules of life
2. Identify corresponding monomers and polymers
3. Identify functions for the four molecules

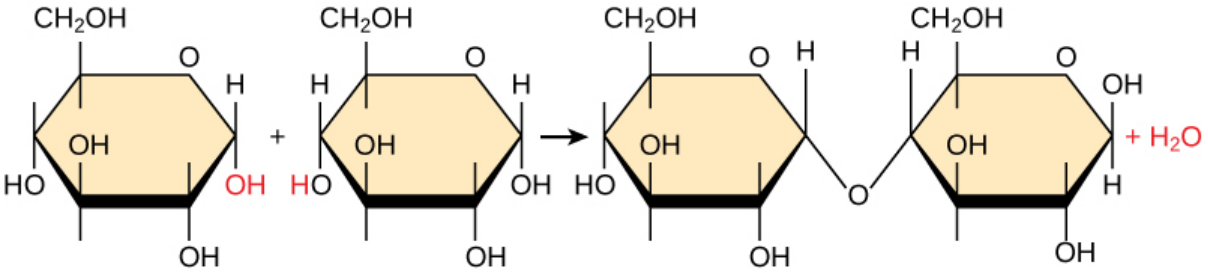
Biological Macromolecules

This chapter covers the four types of macromolecules in biology: carbohydrates, lipids, proteins and nucleic acids. Each contain carbon and hydrogen, so they are organic compounds.

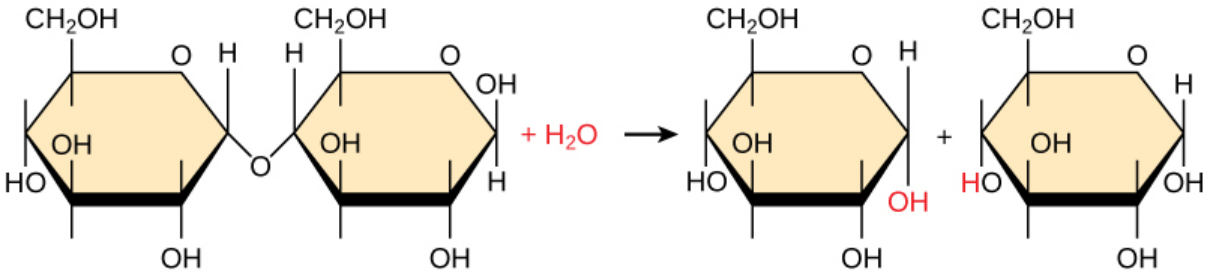
Synthesis of Molecules

Atoms join to build molecules, and monomers join to form polymers. Monomer is a general term for any molecule joining to form a larger molecule. The figure below shows one monomer joined to another by dehydration synthesis. This a chemical reaction. In this reaction, a molecule of water is one of the products shown in red. Because water is removed during the reaction, it is a dehydration synthesis reaction.

The opposite is also true, as shown in the second figure. Polymers break down into monomers in a process called hydrolysis. Water is a reactant in hydrolysis reactions.



In the dehydration synthesis reaction depicted above, two molecules of glucose are linked together to form the disaccharide maltose. In the process, a water molecule is formed.

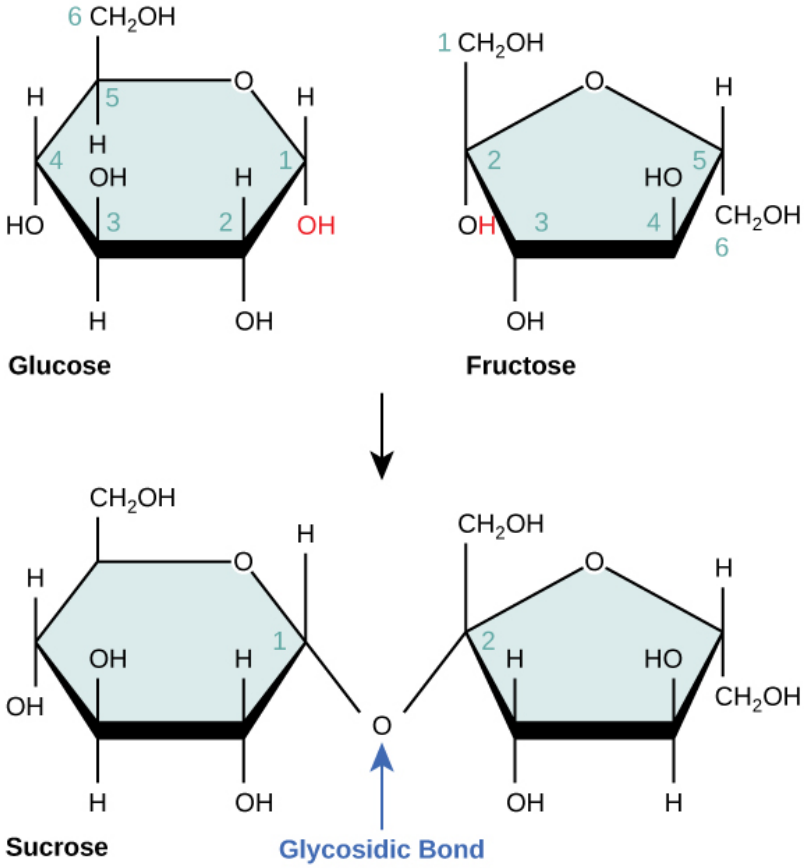


In the hydrolysis reaction shown here, the disaccharide maltose is broken down to form two glucose monomers with the addition of a water molecule. Note that this reaction is the reverse of the synthesis reaction shown above it.

Carbohydrates

Carbohydrates are an essential part of our diet. Monosaccharides join to form disaccharides and polysaccharides. Carbohydrates consist of carbon, hydrogen, and oxygen in a 1:2:1 ratio. Glucose is the most common carbohydrate $C_6H_{12}O_6$ – it clearly demonstrates the ratio. The figure below shows sucrose (a disaccharide) formed by a monomer of glucose and a monomer of fructose joined by dehydration synthesis. Large polysaccharides, like starch and cellulose, may have 100's of monosaccharides in their structure. Cellulose is a vital plant structure and makes up plant cells walls. Humans do not have an enzyme to digest cellulose, so it is considered dietary fiber.

Starch and other polysaccharides store energy. These can be utilized by our cells in cellular respiration reactions that are enzyme driven.



Sucrose is formed when a monomer of glucose and a monomer of fructose are joined in a dehydration reaction to form a glycosidic bond. In the process, a water molecule is lost.

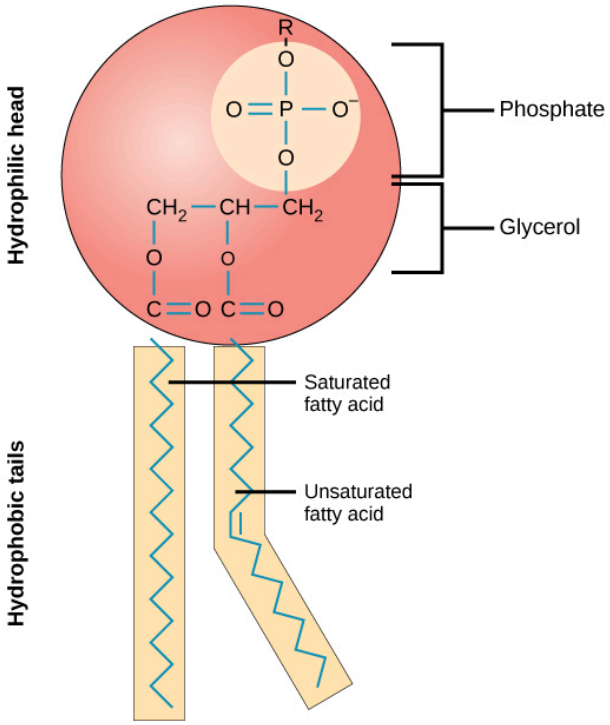
Lipids

Lipids are hydrophobic, so they do not dissolve in water. The phospholipid forms cell membranes. One gram of fat stores more than twice the energy of a gram of carbohydrate. As a result, fatty foods are high in calories. A calorie is the amount of heat required to raise 1g of water by 1 degree Celsius, it is a measure of energy stored in food. Lipids mainly consist of long hydrocarbon chains. Lipids consist of carbon, hydrogen, and oxygen but not in the 1:2:1 carbohydrate ratio. Lipids are categorized as fats, oils, or waxes.

If there are only single bonds between neighboring carbons in the hydrocarbon chain, a fatty acid is said to be saturated. These are solid at room temperature and

typically come from animals. When the hydrocarbon chain has a double bond, the fatty acid is said to be unsaturated, as it now has fewer hydrogens. These are liquid at room temperature, and typically come from plants or fish.

A phospholipid molecule has a phosphate head and two fatty acid tails. The phosphate head is hydrophilic while the hydrocarbon tails are hydrophobic. Phospholipids align tail to tail to form cell membranes.



A phospholipid is a molecule with two fatty acids and a modified phosphate group attached to a glycerol backbone. The phosphate may be modified by the addition of charged or polar chemical groups.

Proteins

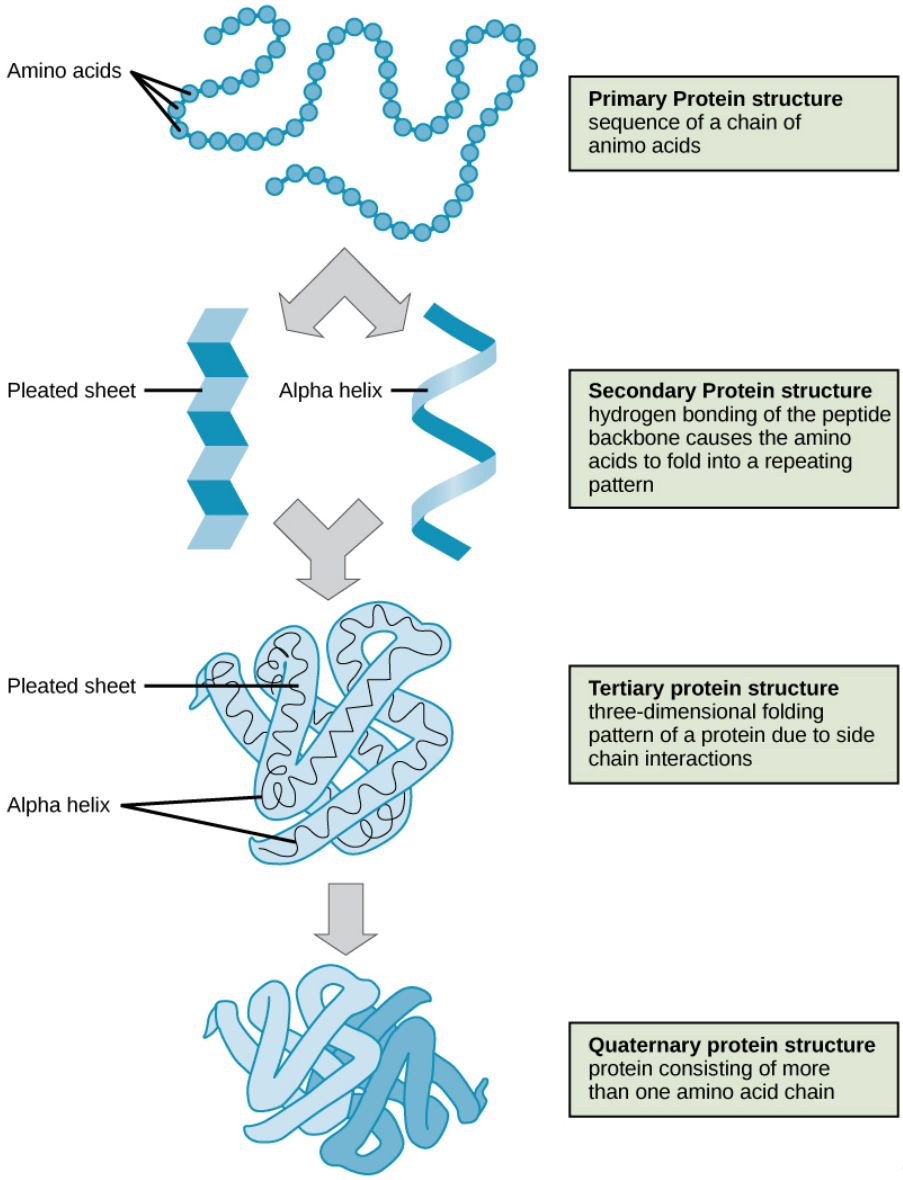
Proteins are one of the most abundant organic molecules in living systems and have the most diverse range of functions of all macromolecules. Proteins may be structural, regulatory, contractile, or protective. Others serve in transport, storage, or function in membranes. There are even classes of protein toxins and thousands of enzymes. Every cell in a living system may contain thousands of proteins, each with a unique function. Their structures, like their functions, vary greatly. They are all polymers composed of amino acids, arranged in a linear sequence.

Enzymes speed up reactions. Enzymes can be used over and over again. Each enzyme is shaped specifically to fit perfectly with another molecule and will only speed up reactions with that molecule.

Amino acids are the monomer of proteins. There are 20 types of amino acids, and their order in a protein determines the protein's shape and its function. All of the 20 amino acids have one part in common and an R group that is not the same. R group chemical structure is what distinguishes one amino acid from another.

The bonds holding one amino acid to another are called peptide bonds. Amino acids join together to form polypeptides through dehydration synthesis. The figure below shows a polypeptide processed and folded into the exact, 3D shape required to function. Structure determines function. As a result, changing a protein's structure can limit its function. Denatured proteins are unfolded and cannot function.

The primary protein structure is the unique sequence of amino acids, forming α-helix and β-pleated sheet secondary structures. The overall three-dimensional structure is the tertiary structure. When two or more polypeptides combine to form the complete protein structure, the configuration is known as the quaternary structure of a protein.



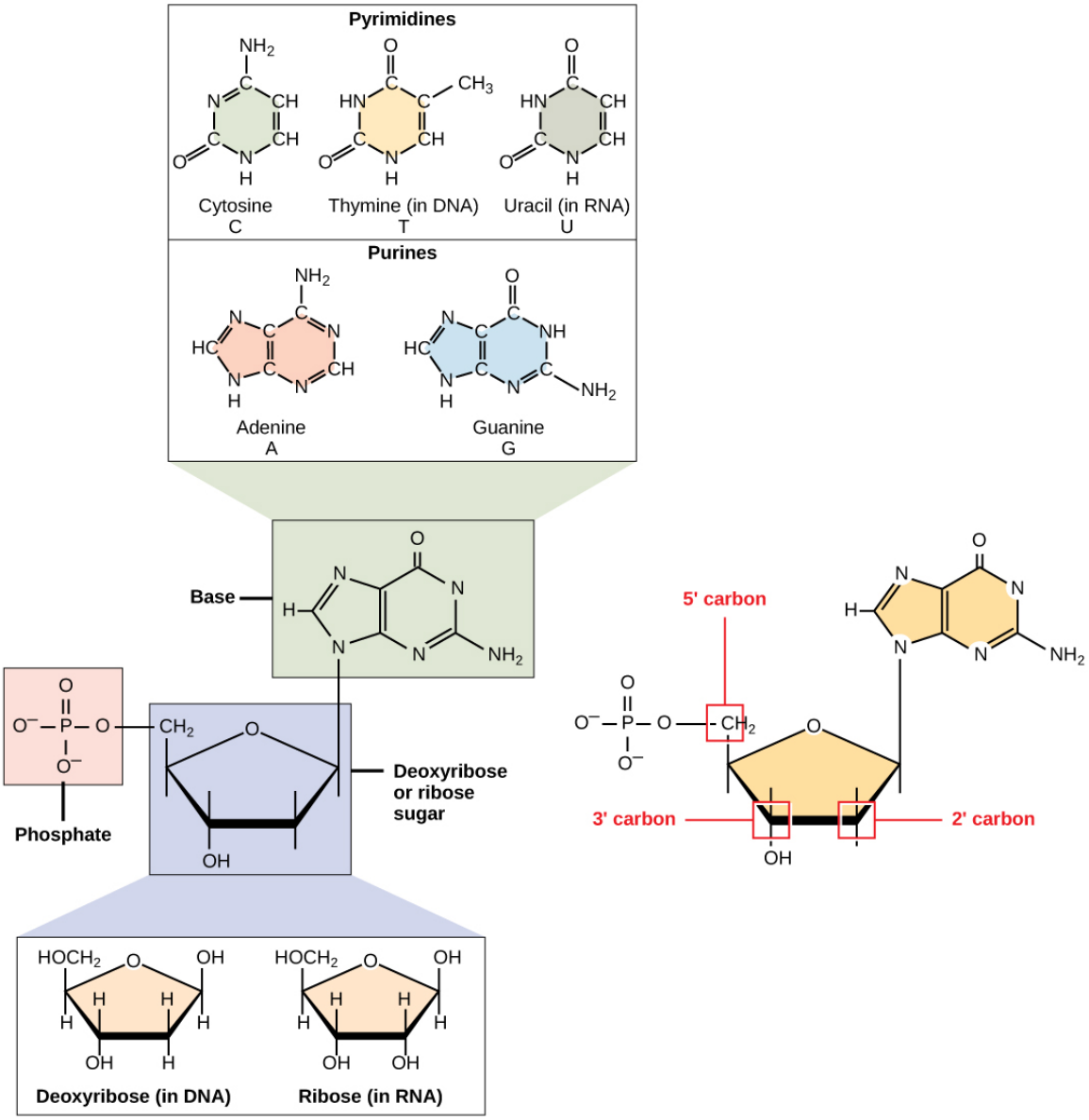
The four levels of protein structure can be observed in these illustrations. (credit: modification of work by National Human Genome Research Institute)

Nucleic Acids

Nucleic acids are DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). DNA is common to all life forms, even those without a nucleus. RNA has several sub-types that help deliver instructions for making proteins, deliver amino acids for making proteins, and activate ribosomes. DNA stores all of the information necessary to build proteins, including cell parts. RNA moves copies of those instructions out of the nucleus and functions to help construct proteins at the ribosome.

The monomer for nucleic acids is the nucleotide, containing a phosphate, a sugar (ribose in RNA, deoxyribose in DNA), and a nitrogenous base. The nucleotides join in a single strand for RNA and in a double helix for DNA.

There are two categories of bases in nucleic acids: the purines (adenine, guanine) and pyrimidines (thymine, cytosine, and uracil). In DNA, A binds to T and G binds to C. In RNA, there is no thymine. RNA contains uracil (U), which binds to adenine (A). You can explore more DNA topics here.



Three components comprise a nucleotide: a nitrogenous base, a pentose

sugar, and one or more phosphate groups.

NAME	MONOMER	POLYMER	FUNCTION
Carbohydrate	Monosaccharide (glucose most common)	Polysaccharide	Fuel for cells in cellular respiration
Lipid	Glycerol and fatty acid	Triglycerol	Form membranes (compartments)
Protein	Amino acid	Polypeptide	Cellular work of transport, storage and more
Nucleic Acid	Nucleotide: ACTG (U)	DNA and RNA	Hold instructions for building proteins

Key Takeaways

1. Carbohydrates, lipids, proteins, and nucleic acids are the molecules of life.
2. Monomers join by dehydration synthesis to form polymers, which can be broken down by hydrolysis.
3. Carbohydrates provide fuel to cells, lipids form membranes (compartments), proteins all sorts of cellular work, and nucleic acids hold the instructions for building proteins.

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4. Chapter 4

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Learning Objectives

1. Recognize two types of microscopes for observing cell structure
2. Analyze differences in prokaryotic and eukaryotic structures
3. Identify organelle structures

Cell Structure

Atoms bond together to make molecules, and macromolecules form organelles. These organelles work together to maintain the environment within the cell. Cells are considered the fundamental units of life. The smallest living things are single-cell bacteria.

Studying Cells

Microscopes are necessary for visualizing cells. Microscopes enlarge the objects being viewed to allow for study of appearance and behavior. Light microscopes are used in teaching labs. Electron microscopes are for more detailed magnification and study. In a scanning electron microscope, a beam of electrons moves back and forth across a cell's surface, creating details of cell surface characteristics. In a transmission electron microscope, the electron beam penetrates the cell and

provides details of a cell's internal structures. As you might imagine, electron microscopes are significantly more bulky and expensive than light microscopes.

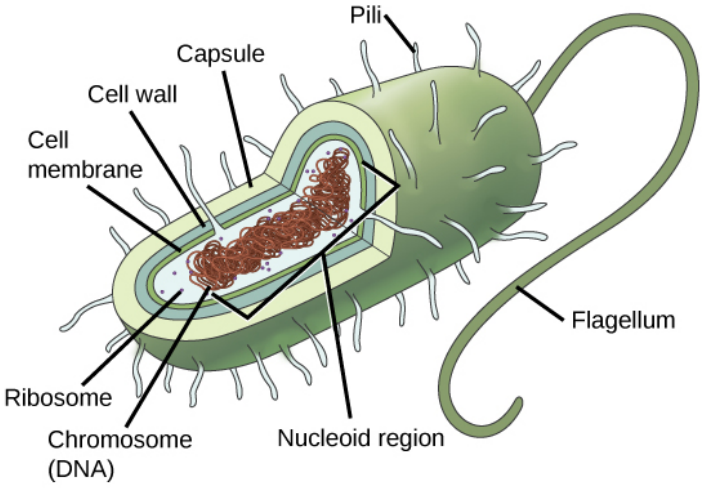
By the late 1830s, botanist Matthias Schleiden and zoologist Theodor Schwann were studying tissues and proposed the unified cell theory, which states that all living things are composed of one or more cells, the cell is the basic unit of life, and new cells arise from existing cells.

All cells share four common components.

1. A plasma membrane separating the cell's interior from the surrounding environment.
2. Cytoplasm, consisting of a jelly-like cytosol, within the cell, in which other cellular components are found.
3. DNA molecules provide the genetic material of the cell.
4. Ribosomes which are proteins providing a location for protein synthesis.

Prokaryotic Cells

Prokaryotic cells do not have membrane-bound DNA, which means there is no nucleus. They contain DNA organized into a single circular chromosome. Prokaryotic cells are typically smaller than eukaryotic cells. Bacteria are prokaryotes and do not contain any membrane-bound organelles.



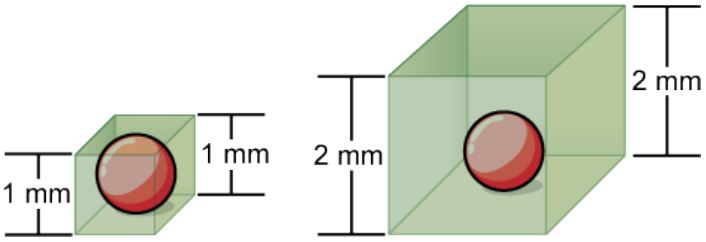
This figure shows the generalized structure of a prokaryotic cell. All prokaryotes have chromosomal DNA localized in a nucleoid, ribosomes, a

cell membrane, and a cell wall. The other structures shown are present in some, but not all, bacteria.

Eukaryotic Cells

Eukaryotic cells have membrane-bound DNA within a nucleus. Eukaryotes have membrane-bound organelles. Plants, protists, fungi and animals are all eukaryotes. All cells (both prokaryotes and eukaryotes) have an external membrane called a plasma membrane surrounding their contents that determines which molecules are permitted to enter and leave the cell. This membrane is considered selectively permeable. The plasma membrane is composed of a phospholipid bilayer embedded with proteins.

The membrane must take in enough nutrients to sustain the cell and must release enough waste to detoxify the cell. For this reason, cells do not get very large. The laws of physics limit the size of cells. When necessary, cells reproduce by dividing into two smaller cells. This gives a better ratio of surface area to volume.



Notice that as a cell increases in size, its surface area-to-volume ratio decreases. When there is insufficient surface area to support a cell's increasing volume, a cell will either divide or die.

All cells are filled with a gel-like cytoplasm containing many molecules necessary for cellular reactions. It is a semi-fluid matrix containing the organelles. All cells contain genetic information. Chromosomes are composed of condensed DNA. In eukaryotes, the chromosomes are held within the nuclear membrane.

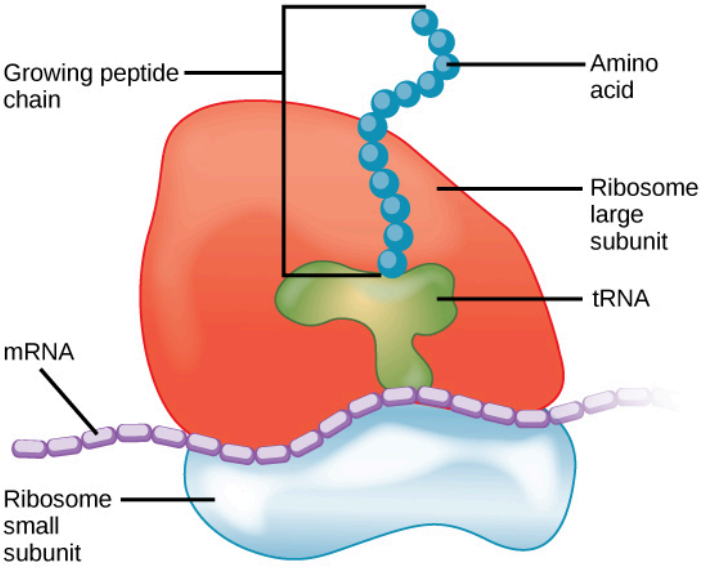
Organelles

It can be difficult to visualize a cell in three dimensions. The video for this chapter contains an animation of cellular activities that allows you to see the organelles in motion. The following PDF is linked to provide a comprehensive visual of the cell with descriptions.

https://www.yourgenome.org/wp-content/uploads/2000/01/downloads/activities/cell-snap/cellsnap-information.pdf

The **nucleus** is the largest of the organelles and is at the centre of the cell. It is the storage site of the cell's DNA. The human genome contains 3 billion bases and provides all the information needed to make a human. It is packaged into chromosomes inside the nucleus.

Within the nucleus, the nucleolus aggregates ribosomal RNA (rRNA) with associated proteins to assemble the ribosomal subunits that are transported through nuclear pores to the cytoplasm. **Ribosomes** are proteins that provide a location for assembly of amino acids into proteins. Some ribosomes are free ribosomes, and float in the cytoplasm. Other ribosomes are attached to the **Rough Endoplasmic Reticulum (RER)**. Whether free or bound, ribosomes are the location where proteins are assembled. Proteins can stay within the cell or be exported through the plasma membrane to other cells.



A large subunit (top) and a small subunit (bottom) comprise ribosomes. During protein synthesis, ribosomes assemble amino acids into proteins.

Eukaryotic cells contain many membranes, including the nuclear membrane, rough ER, smooth ER, Golgi apparatus, lysosomes, and the plasma membrane. **Vesicles** are membrane-bound sacs that function in storage and transport. Vesicle membranes can fuse with either the plasma membrane or other membrane systems within the cell. Vesicles bud in and out of the membrane, due to the properties of phospholipids. The movement of a vesicle by a transport protein is highlighted in the chapter video and is shown on the video preview screen.

Smooth ER does not have any bound ribosomes. It sustains an environment for the generation of lipid molecules, including phospholipids and steroid hormones. This organelle helps break down pharmaceuticals, toxins and stores calcium ions.

Rough ER has a surface studded with ribosomes, where protein are assembled. Assembled proteins are secreted to the inside of Rough ER to be folded and packaged in vesicles for transport. Most transport vesicles will deliver proteins to Golgi apparatus for further processing.

Golgi apparatus receives, packages, modifies, and sends materials both internally and externally. Secretion cells have extensive Golgi apparatus.

Lysosomes are small membrane sacks of digestive enzymes. The enzymes break down macromolecules into smaller molecules for recycling. Acidic pH of the lysosome contributes to the process.

Peroxisomes are small, round organelles enclosed by single membranes. They carry out oxidation reactions that break down fatty acids and amino acids. They also detoxify many poisons that may enter the body.

Mitochondria have a double membrane and their own DNA. Human mitochondria follow maternal inheritance and are responsible for the capture and release of energy. Cellular respiration is the process of making ATP using the chemical energy in glucose and other nutrients. In mitochondria, this process uses oxygen and produces carbon dioxide as a waste product. In fact, the carbon dioxide and water you exhale with every breath comes from the cellular reactions that produce carbon dioxide as a byproduct. This is a foundational concept in Module 2.

Centrioles are a pair of organelles found in the cell consisting of small protein tube structures known as microtubules. These organelles play an important role in cell division. The centrioles organize fibers called microtubules into spindles which attach to the chromosomes and move them during cell division.

Plant cells contain all of the organelles described above as well as vacuoles and chloroplasts. **Vacuoles** are membrane-bound sacs that function in storage and transport. Vacuoles are somewhat larger than vesicles and contain enzymes to break down macromolecules. Although similar to vesicles, vacuoles do not fuse with the membrane system. **Chloroplasts** are the location for photosynthesis — a series of reactions using carbon dioxide, water, and light energy to produce glucose and oxygen. Like mitochondria, chloroplasts have outer and inner membranes. The ability to complete photosynthesis is the difference between producers and consumers. Plants are producers capable of making their own food (chemical energy). Consumers use the organic compounds generated by producers for their food (chemical energy). Chloroplasts also have their own DNA and contain chlorophyll.

Endosymbiosis is a theory explaining the origins of mitochondria and chlorophyll based on their similarities to bacteria. Bacteria have their own DNA and ribosomes, just like mitochondria and chloroplasts.

Structural Components

The **cytoskeleton** is a network of protein tracks and microtubules. These proteins work to support cellular structure, aid in cell division, transport, and move cells. There are 3 main types of cytoskeleton fibers: microtubules, intermediate filaments, and microfilaments. Microtubules help the cell resist compression, serve as tracks for motor proteins that move vesicles through the cell (also shown on chapter video preview screen at the bottom), and pull replicated chromosomes to opposite ends of a dividing cell. They are also the structural element of centrioles, flagella, and cilia. Microfilaments provide rigidity and shape to the cell and facilitate cellular movements. Intermediate filaments bear tension and anchor the nucleus and other organelles in place.

Cell walls are found in prokaryotes, fungi, some protists and all plants. They are considered extracellular structures, because they are outside the cell membrane. Cell walls protect, support and contain cellulose. ECM (extracellular matrix) is an exterior network providing supports to maintain a cell's shape. Cells attached to other cells form tissues.

Key Takeaways

1. Light and electron microscopes allow us to visualize cells.
2. Prokaryotes do not have a nucleus, but eukaryotes do.
3. Eukaryotes also have a variety of organelles: ribosomes, ER, Golgi, lysosomes, and mitochondria. In addition to these structures, plants also have vacuoles and chloroplasts.

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PART II

MODULE 2

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Module 2

Module 2 is all about membranes and cellular energy. How can cells move molecules across their membranes? How can molecules store and release energy? Do cells communicate with chemical signals? Module 2 will address these questions and much more. This cover page provides all Module 2 Learning Objectives, a question answered by each chapter and chapter summaries.

Module 2 is aligned with the following Course Learning Objectives:

- Identify the chemical components of life
- Describe metabolic processes as these relate to homeostasis
- Apply scientific inquiry to predict outcomes
- Classify and compare major groups of organisms

Learning Objectives Chapter 5

How does the food you eat and the air you breathe enter your cells?

1. Identify major structural components of the cell membrane
2. Identify three types of passive transport
3. Identify the characteristics of active transport

Chapter 5 Summary

The plasma membrane is composed of primarily phospholipids studded with proteins, some which span the membrane. Carbohydrates are attached to some of the proteins and lipids on the membrane's outward-facing surface, forming complexes that function to identify the cell to other cells. Plasma membranes enclose and define the cells' borders. Not static, these membranes are dynamic and constantly in flux. Transport moves molecules across membrane, as substances diffuse from areas of high concentration to areas of low concentration (down the concentration gradient). Moving substances up the gradient requires ATP energy. Active transport requires integral proteins in the cell membrane to move the materials. In a bulk transport process call phagocytosis, other cells can engulf large particles, such as macromolecules, cell parts, or whole cells.

Learning Objectives Chapter 6

How do cells manage energy?

1. Recognize the characteristics of metabolism
2. Apply the first and second laws of thermodynamics to biological processes
3. Examine the role of ATP in metabolism
4. Describe the role of enzymes in metabolism

Chapter 6 Summary

Metabolism refers to the chemical reactions that take place within the cell. Metabolic reactions involve both catabolic reactions (breaking down complex chemicals to release energy) and anabolic reactions (building complex molecules out of simpler ones that require energy). Energy comes in many different forms. Objects in motion do physical work, and kinetic energy is the energy of objects in motion. Objects that are not in motion may have the potential to do work and have potential energy. Molecules can also have potential energy because breaking molecular bonds has the potential to release energy. The laws of thermodynamics are a series of laws that describe the properties and processes of energy transfer. ATP is the primary energy-supplying molecule for living cells. Enzymes are chemical catalysts that lower activation energy. Enzymes are usually proteins consisting of an active site providing a unique chemical environment perfectly suited to convert particular chemical reactants for that enzyme.

Learning Objectives Chapter 7

How does your body convert carbohydrates to energy?

1. Describe reactions vital to cellular respiration
2. Identify cellular location, requirements and products for the three processes of cellular respiration in eukaryotes
3. Describe types of fermentation

Chapter 7 Summary

ATP functions as the energy currency for cells. Energy derived from glucose catabolism is used to convert ADP into ATP. Glycolysis is the first pathway within the cytoplasm used in the breakdown of glucose to extract energy. The six-carbon glucose is converted to two three-carbon pyruvate. It was probably one of the earliest metabolic pathways to evolve and is used by nearly all of the organisms on Earth. Two ATP molecules are invested in the first half and four ATP molecules are produced for a net gain of two ATP. In eukaryotic mitochondria with oxygen present, pyruvate is transformed in to acetyl-CoA. Most often, this molecule enters the Krebs or Citric Acid Cycle (CAC). CAC is a series of redox reactions that move high-energy electrons within the matrix of the mitochondria. Two ATP molecules are produced. The electron transport chain is composed of protein complexes embedded in the inner mitochondrial membrane with electron carriers shuttling electrons. Their action builds up a high concentration of hydrogen ions between the inner and outer membranes of the mitochondria to power ATP synthase (≅32 ATP). In total, aerobic cellular respiration will yield approximately 36 ATP per molecule of glucose. Most organisms will use some form of fermentation (lactic acid and alcohol) to ensure the continuation of glycolysis, when oxygen is not plentiful. The net yield of ATP is much less, but the process is much faster.

Learning Objectives Chapter 8

Where do glucose molecules come from?

1. Describe reactions vital to photosynthesis
2. Identify cellular location, reactants and products for the two stages of photosynthesis
3. Describe the energy cycle

Chapter 8 Summary

By harnessing energy from the sun, photosynthesis provides living things access to enormous amounts of energy. Chlorophyll containing organisms can perform photosynthesis, using carbon dioxide and water to assemble carbohydrate molecules and release oxygen as a byproduct. Plants and algae, have organelles called chloroplasts that contain chlorophyll. The light-dependent reactions, absorb energy from sunlight. A photon strikes chlorophyll to initiate photosynthesis. The thylakoid membrane contains its own electron transport chain, which pumps hydrogen ions into the thylakoid interior. This action builds up a high concentration of hydrogen ions. The hydrogen ions flow through ATP synthase to form molecules of ATP contributed to the Calvin cycle, where CO_2 from the atmosphere is converted in a series of enzyme reactions to a carbohydrate molecule. Photosynthesis forms an energy cycle with the process of cellular respiration, as the products of photosynthesis are the reactants for aerobic cellular respiration. The opposite is also true. Because plants contain both chloroplasts and mitochondria, they rely upon both photosynthesis and respiration for their ability to function in both the light and dark.

Learning Objectives Chapter 9

Can cells communicate with each other?

1. Recognize characteristics of four types of cell signals
2. Identify mechanisms of nerve cell signals

The four categories of signaling in multicellular organisms are autocrine signaling, direct signaling across gap junctions, paracrine signals and endocrine signals. Autocrine signals involve a cell targeting itself. Gap-junction signals are designed for cells to signal adjoining cells. Paracrine signals involve generating signals that travel a short distance. One example is the nerve cell. Nerve cell signals must be degraded by enzymes to terminate the signal. Endocrine signals are capable of signaling distant cells.

When you are ready to review Module 2, you might find this study guide helpful.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://open.ocolearnok.org/introductorybiology/?p=34#audio-34-1

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5. Chapter 5

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://open.ocolearnok.org/introductorybiology/?p=41#oembed-1

Learning Objectives

1. Identify major structural components of the cell membrane
2. Identify three types of passive transport
3. Identify the characteristics of active transport

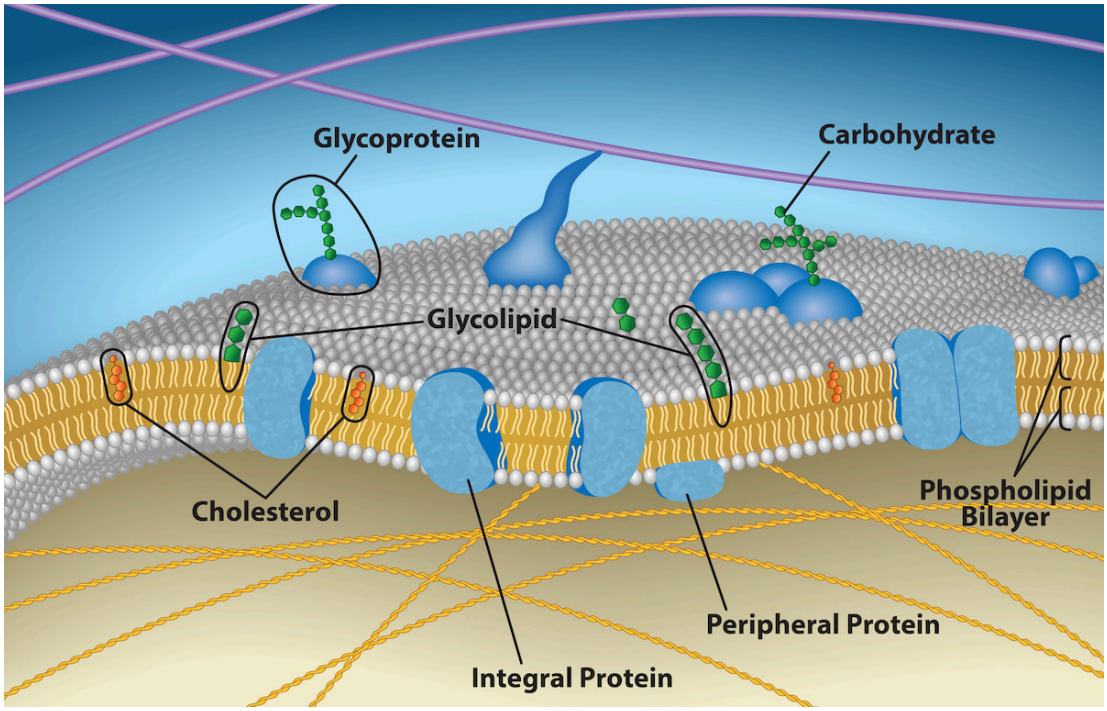
Structure and Function of Plasma Membranes

A cell's plasma membrane defines the cell, outlines its borders, and determines the nature of its interaction with its environment. Cells exclude some substances, take in others, and excrete still others, all in controlled quantities. The plasma membrane must be very flexible. In addition, the plasma membrane's surface carries markers that allow cells to recognize one another, which is vital for tissue and organ formation during early development and later plays a role in the immune response.

Each phospholipid molecule is composed of a hydrophilic head and two hydrophobic tails. The hydrophilic head group consists of a phosphate-containing group attached to a glycerol molecule. The hydrophobic tails, each containing either a saturated or an unsaturated fatty acid, are long hydrocarbon chains.

Among the most sophisticated plasma membrane functions is the ability for complex, integral proteins, receptors to transmit signals. These proteins act both as extracellular input receivers and as intracellular processing activators. These membrane receptors provide external attachment sites for hormones and growth

factors and activate internal response cascades when bound. Occasionally, viruses hijack receptors and use them to gain entry into cells.

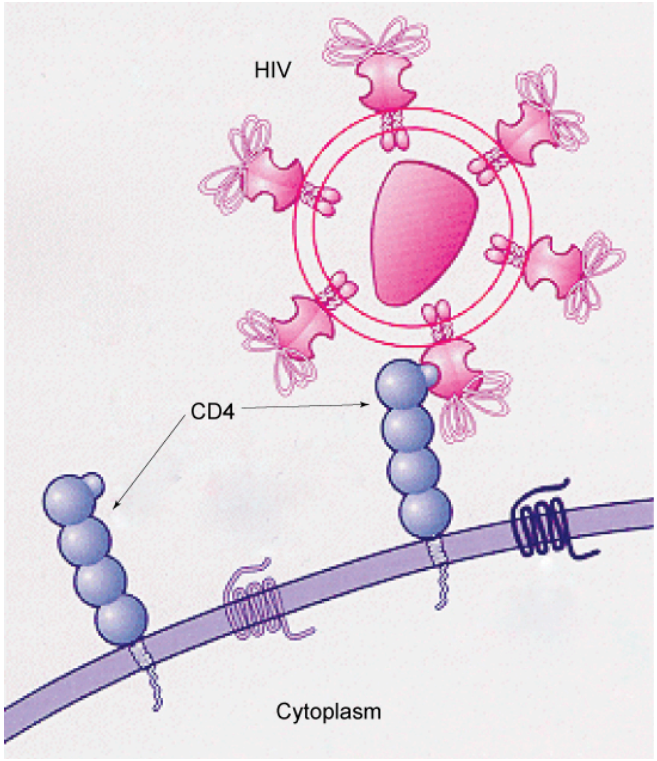


Two layers of phospholipids compose the plasma membrane, which is a phospholipid bilayer. Proteins are indicated as blue structures embedded in the membrane to control the passage of molecules through the phospholipid bilayer. Cell membranes are modeled with a fluid mosaic model. Fluidity of cells is due to the molecular structure of the phospholipid bilayer, cytoskeleton, and extracellular matrix. Structure determines function.

Membrane proteins can be either integral or peripheral. Most integral proteins are transmembrane proteins, spanning the cell membrane from interior to exterior. Transmembrane proteins are sometimes specialized to be transport proteins. These allow facilitated diffusion of polar, charged, and large molecules. Aquaporins are channel proteins that allow water to pass the membrane at a very high rate to maintain homeostasis. Another transmembrane protein allows sodium and

potassium ions to pass. Their specific shape allows particular molecules to pass the membrane.

Component	Location
Phospholipid	Main fabric of the membrane
Cholesterol	Attached between phospholipids and between the two phospholipid layers
Integral proteins (for example, integrins)	Embedded within the phospholipid layer(s) may or may not penetrate through both layers
Peripheral proteins	On the inner or outer surface of the phospholipid bilayer, not embedded within the phospholipids
Carbohydrates (components of glycoproteins and glycolipids)	Generally attached to proteins on the outside membrane layer



Virus binding to the CD4 receptor, a glycoprotein on T-cell surface. (credit: modification of work by NIH, NIAID)

Each individual's immune system uses glycoproteins to recognize foreign cells. Glycoproteins on transplanted organs can trigger rejection immune reactions in recipients. Potential rejection issues must be managed for life following an organ transplant.

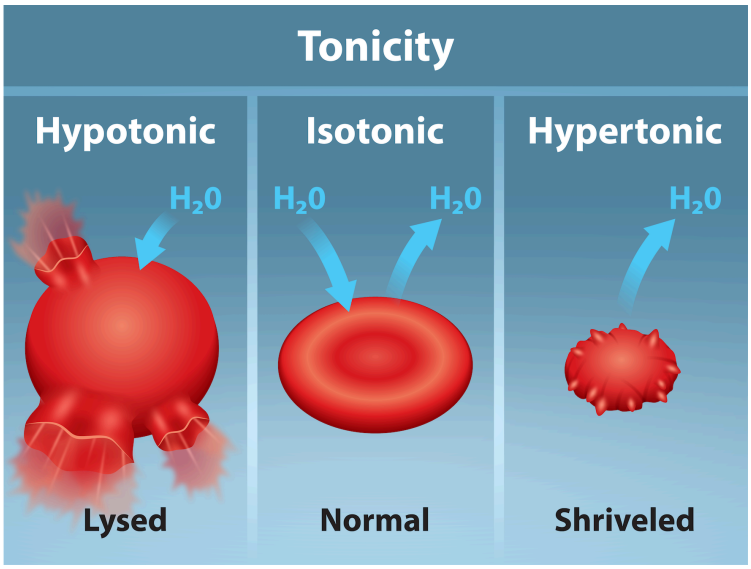
Plasma membranes must allow certain substances to enter and leave a cell, and prevent some harmful materials from entering and some essential materials from leaving. This means membranes are selectively permeable, because some substances pass through but not all.

The most direct forms of membrane transport are passive. Passive transport is a naturally occurring phenomenon and does not require the cell to exert any of its energy to accomplish the movement. In passive transport, substances move from an area of higher concentration to an area of lower concentration. A physical space in which there is a single substance concentration range has a concentration gradient. Diffusion is a passive process of transport. A single substance moves from a high concentration to a low concentration area until the concentration is equal across a space. You are familiar with diffusion of substances through the air. For example, think about someone opening a bottle of ammonia in a room filled with people. The ammonia gas is at its highest concentration in the bottle. Its lowest concentration is at the room's edges. The ammonia vapor will diffuse, or spread away, from the bottle, and gradually, increasingly more people will smell the ammonia as it spreads. Simple diffusion allows non-polar molecules, hydrocarbons, carbon dioxide (CO_2), oxygen gas (O_2), and small, uncharged molecules to pass between lipids.

In facilitated transport, or facilitated diffusion, materials diffuse across the plasma membrane with the help of membrane proteins. A concentration gradient exists that would allow these materials to diffuse into the cell without expending cellular energy. However, these materials are polar molecule ions that the hydrophobic cell membrane portion repels. Facilitated transport proteins allows polar molecules to diffuse into the cell.

Osmosis is the movement of free water molecules through a semipermeable membrane according to the water's concentration gradient across the membrane, which is inversely proportional to the solutes' concentration. While diffusion

transports material across membranes and within cells, osmosis transports *only water* across a membrane and the membrane limits the solutes' diffusion in the water. Aquaporins play a large role in osmosis, most prominently in red blood cells and the membranes of kidney tubules.



Three different scenarios involving red blood cells (RBC) are shown. Left: A RBC placed in a hypotonic solution, where the concentration of solutes in the surrounding fluid is lower than those in the cell, will cause water to rush into the RBC and lead to lysis of the cell. Middle: there is no net water movement into or out of the cell as the concentration of the solutes inside the cell equal or is isotonic to that of the surrounding fluid. Right: a RBC placed in a hypertonic solution, where the concentration of solutes in the surrounding fluid is greater than that in the cell will cause water to rush out of the cell and into the surrounding fluid. This will cause the RBC to shrivel. Credit: Tag, A., Rao, A., Hawkins, A and Fletcher, S. Department of Biology, Texas A&M University.

1. Hypotonic solution has a lower concentration of molecules, while the cell has a higher concentration of molecules. In this condition, water moves into the cell to the point of bursting the cell.

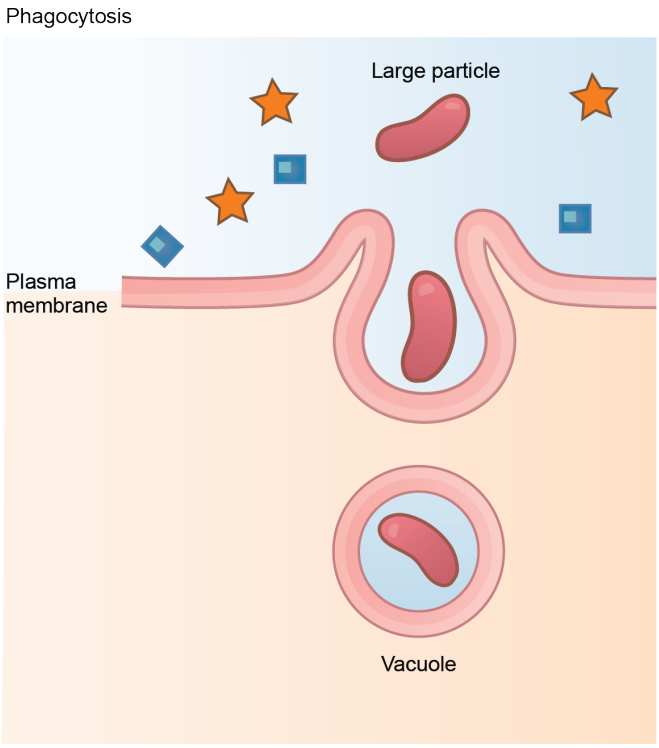
2. Isotonic solution has balanced condition, resulting in no net movement of water into or out of the cell. Some movement of water occurs, but balance is maintained.

3. Hypertonic solution has a higher concentration of molecules, while the cell has a lower concentration of molecules. In this condition, water moves out of cell into solution. The cell shrinks and shrivels.

Active transport mechanisms require energy, usually in the form of adenosine triphosphate (ATP). If a substance must move into the cell from an area of low concentration to an area of high concentration—the cell must use energy to move the substance. Some active transport mechanisms move small-molecular weight materials, such as ions, through the membrane. One great example is the sodium-potassium pump. Other mechanisms transport much larger molecules.
To move substances against a concentration or electrochemical gradient, the cell must use energy. This energy comes from ATP generated through the cell's metabolism. Active transport mechanisms, or pumps, work against electrochemical gradients. Small substances constantly pass through plasma membranes. Active transport maintains concentrations of ions and other substances that living cells require in the face of these passive movements. A cell may spend much of its metabolic energy supply maintaining these processes.

In addition to moving small ions and molecules through the membrane, cells also need to remove and take in larger molecules and particles in bulk transport. Some cells are even capable of engulfing entire unicellular microorganisms. For a cell to take up and release large particles, energy is required. A large particle, however, cannot pass through the membrane, even with energy that the cell supplies. Endocytosis is a type of active transport that moves particles, such as large molecules, parts of cells, and even whole cells, into a cell. There are different endocytosis variations, but all share a common characteristic: the cell's plasma membrane forms a pocket around the target particle. The pocket pinches off, resulting in the particle containing itself in a newly created intracellular vesicle formed from the plasma membrane.

Phagocytosis is the process by which a cell takes in large particles, like other cells or relatively large particles. For example, when microorganisms invade the human body, a type of white blood cell will remove the invaders through this process. The microbes will be surrounded, engulfed and destroyed.



In phagocytosis, the cell membrane surrounds the particle and engulfs it. (credit: modification of work by Mariana Ruiz Villareal)

Key Takeaways

1. Cell membranes are primarily composed of a phospholipid bilayer embedded with a variety of proteins.
2. Passive transport moves molecules from high concentration to low. Simple diffusion involves free movement across the bilayer, facilitated diffusion requires a protein that spans the membrane, and osmosis involves the diffusion of water.
3. Active transport requires both energy and a membrane protein, and it is capable of moving particles from low concentration to high.

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6. Chapter 6

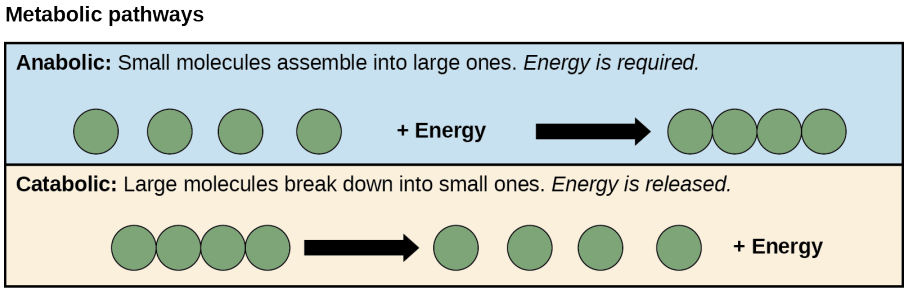
One or more interactive elements has been excluded from this version of the text. You can view them online here: https://open.ocolearnok.org/introductorybiology/?p=43#oembed-1

Learning Objectives

1. Recognize the characteristics of metabolism
2. Apply the first and second laws of thermodynamics to biological processes
3. Examine the role of ATP in metabolism
4. Describe the role of enzymes in metabolism

Metabolism

Cells perform the functions of life through various chemical reactions. Metabolism is a term referring to all of the chemical reactions that take place within each cell. Catabolic reactions involve breaking down polymers into monomers, and anabolic reactions involve building up polymers from their monomers. Catabolic pathways of cellular respiration break glucose down and release energy. Anabolic pathways like photosynthesis build glucose require energy.

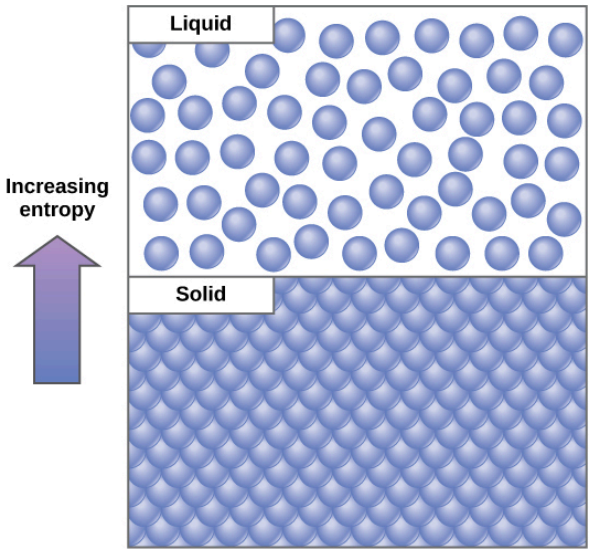


Anabolic pathways require energy to synthesize larger molecules. Catabolic pathways generate energy by breaking down larger molecules. Both pathway types are required for maintaining a cell's energy balance.

Energy comes in many different forms. Objects in motion display kinetic energy. Objects that are not in motion with the potential to do work display potential energy. Kinetic energy is the energy of motion. Potential energy is stored energy. Chemical energy is a type of potential energy stored in chemical bonds. Chemical reactions either absorb or release energy.

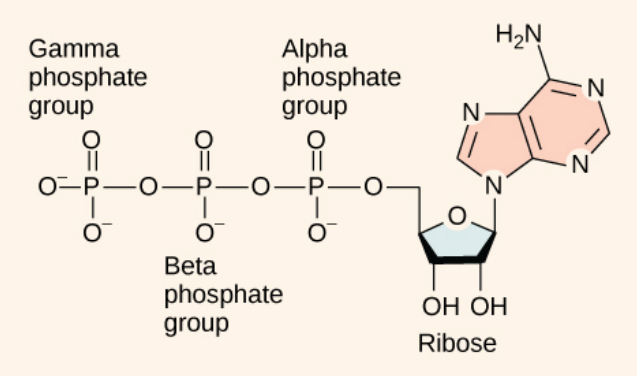
The term system refers to matter and its environment involved in energy transfers. Everything outside of the system is the surroundings. Single cells are biological systems. The laws of thermodynamics are a series of laws that describe the properties and processes of energy transfer. The first law states that the total amount of energy in the universe is constant. This means that energy cannot be created or destroyed, only transferred or transformed. The second law of thermodynamics states that entropy is increasing. Every energy transfer involves some loss of energy in an unusable form, such as heat energy, resulting in a more disordered system. In other words, no energy transfer is completely efficient, and all transfers trend toward disorder. The laws are stated below.

1. Energy cannot be created or destroyed.
2. Entropy is increasing.



Entropy is a measure of randomness or disorder in a system. Gases have higher entropy than liquids, and liquids have higher entropy than solids.

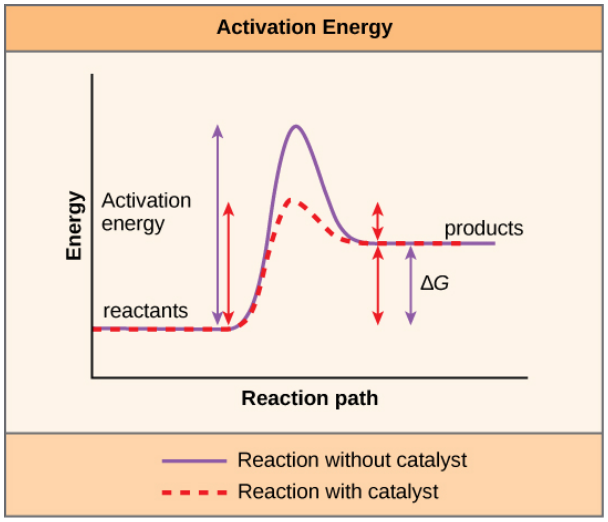
ATP is the primary energy-supplying molecule for living cells. ATP is comprised of a nucleotide, a five-carbon sugar, and three phosphate groups. ATP is the cells' primary energy currency like money is the currency people exchange for things they need. ATP powers the majority of energy-requiring cellular reactions. ATP is adenosine triphosphate, because it contains three phosphates. ADP is a diphosphate, containing two phosphates. Like most chemical reactions, ATP to ADP hydrolysis is reversible. The reverse reaction regenerates ATP from ADP + P_i. Cells rely on ATP regeneration just as people rely on regenerating spent money through some sort of income. Since removal of a phosphate from ATP releases energy, ATP regeneration must require an input of free energy. Most energy transformations in organisms occur in oxidation-reduction reactions involving the transfer of electrons.



ATP is the cell's primary energy currency. It has an adenosine backbone with three phosphate groups attached.

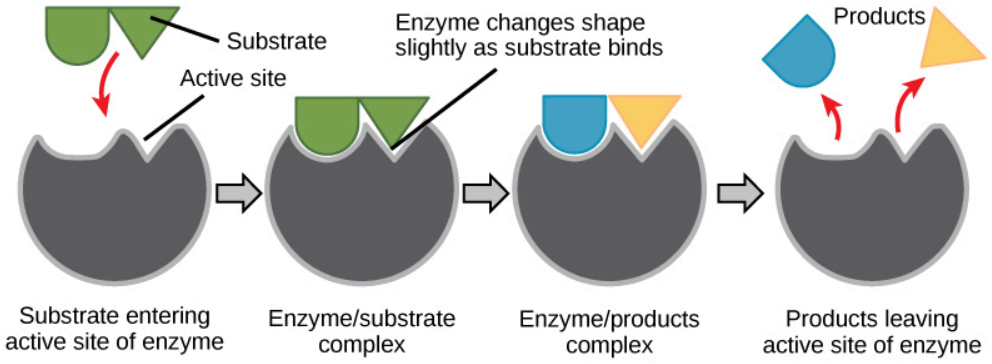
Enzymes are chemical catalysts that accelerate chemical reactions by lowering their activation energy, which increases the rate of reaction. Enzymes are usually proteins consisting of one or more polypeptide chains. Enzymes have an active site providing a unique chemical environment perfectly suited to convert particular chemical reactants for that enzyme called substrates, into unstable intermediates called transition states. Enzymes and substrates bind with an induced fit, which means enzymes undergo slight conformational changes based on the location of their electrons.

Enzymes are usually proteins. They work to lower activation energy. Enzymes are very specific. Protein enzymes are made of long chains of amino acids, held together by peptide bonds in a particular structure that determines their function.



Enzymes lower the reaction's activation energy but do not change the reaction's free energy.

Each enzyme has a specific shape allowing it to accept only one type of substrate. The figure below shows a substrate fitting the active site of the enzyme. Because enzymes are proteins, their structure is impacted by pH, temperature and other conditions. Optimal conditions result in greater enzyme activity. A protein that is not folded correctly is termed denatured and cannot function properly. Some enzymes need cofactors or coenzymes to function. Homeostasis requires regulation of enzymes. Inhibitors turn enzymes off either temporarily or permanently. Competitive inhibitors fit in the active site. Allosteric inhibitors alter the shape of the active site to prevent binding, sometimes called non-competitive inhibitors. To see moving images demonstrating enzyme reactions, look for enzyme gifs like this one (https://www.mrdubuque.com/home/biodub-my-gifs-to-you-enzyme-reactions).



According to the induced-fit model, both enzyme and substrate undergo dynamic conformational changes upon binding. The enzyme contorts the substrate into its transition state, thereby increasing the reaction's rate.

When a chemical pathway is repeated, end products start to build up. Some enzymes get turned off (inhibited) by the end product of the reaction. When there is a buildup of this end product, the enzyme is allosterically inhibited until there is a need for the process to begin again because the supply of the end product has been used.

Enzymes are not randomly located in the cell, but they are localized where needed. Enzymes are required for glucose catabolism and ATP generation within mitochondria. Several enzymes needed for protein synthesis surround ribosomes. Alpha-amylase is one enzyme vital to starch metabolism, you can read more about it here.

Key Takeaways

1. Metabolism is vital to homeostasis. Anabolic reactions build molecules and catabolic reactions break molecules down.
2. The laws of thermodynamics govern the fundamental reactions of photosynthesis and cellular respiration.
3. ATP carries potential energy in its high-energy phosphate bonds. It is the primary currency of the cell.

4. Enzymes are usually proteins. They lower activation energy for reactions.

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7. Chapter 7

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Learning Objectives

1. Describe reactions vital to cellular respiration
2. Identify cellular location, requirements and products for the three processes of cellular respiration in eukaryotes
3. Describe conditions of fermentation

Cellular Respiration

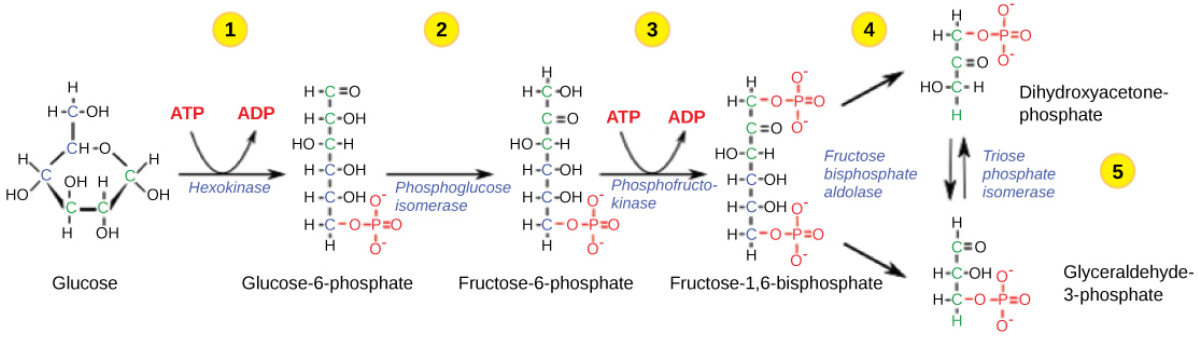
ATP functions as the energy currency for cells. It allows the cell to store energy briefly and transport it within the cell to support endergonic chemical reactions. ATP has the structure of an RNA nucleotide with three phosphates attached. ATP is used for energy by detaching a phosphate group or two, resulting in ADP (two phosphates) or AMP (one phosphate). Energy derived from glucose catabolism is used to convert ADP to ATP. When ATP is used in a reaction, the third phosphate is temporarily attached to a substrate in a process called phosphorylation. The two processes of ATP regeneration that are used in conjunction with glucose catabolism are substrate-level phosphorylation and oxidative phosphorylation through the process of chemiosmosis.

Aerobic Cellular Respiration of glucose occurs in the presence of oxygen and includes three main processes in eukaryotes.

1. Glycolysis
2. Citric Acid Cycle (CAC) — sometimes referred to as Krebs
3. Electron Transport Chain (ETC)

Glycolysis is the first pathway used in the breakdown of glucose to extract energy. It was probably one of the earliest metabolic pathways to evolve and is used by nearly all of the organisms on Earth. Glycolysis consists of two parts. The first part prepares the six-carbon ring of glucose for cleavage into two three-carbon sugars. ATP is invested in the process during this half to energize the separation. The second half of glycolysis extracts ATP and high-energy electrons from hydrogen atoms and attaches them to NAD^+. Two ATP molecules are invested in the first half and four ATP molecules are formed by substrate phosphorylation during the second half. This produces a net gain of two ATP and two NADH molecules for the cell.

Glycolysis occurs in the cytoplasm of prokaryotes and eukaryotes for glucose ($C_6H_{12}O_6$) metabolism. Glucose contains six carbons and is converted to two, three-carbon molecules of pyruvate, in a ten-step process driven by enzymes. The process requires 2 ATP and yields 4 ATP, for a net gain of 2 ATP.

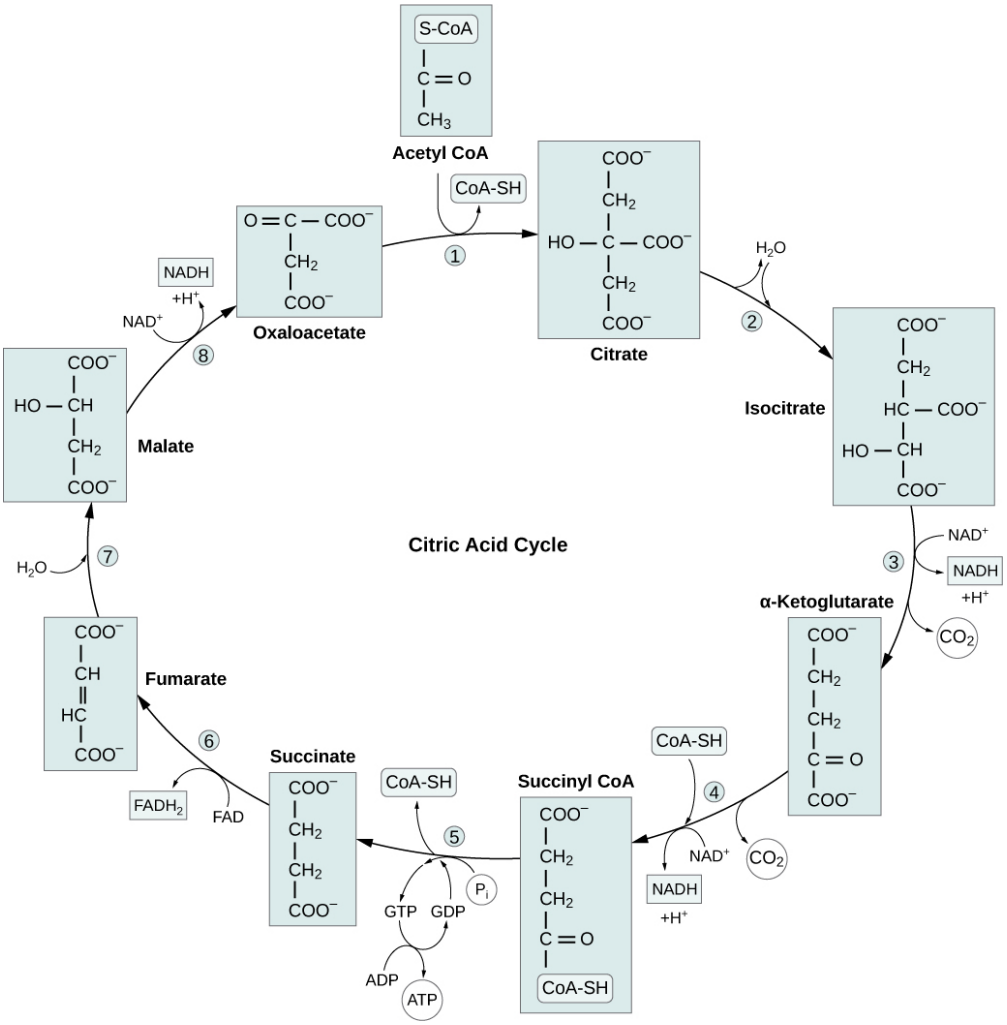


This image shows the first half of glycolysis, which requires two ATP molecules. The phosphorylation of glucose is followed by the split into two three-carbon molecules.

There is one substep between glycolysis and CAC. Within the mitochondria, pyruvate is converted to acetyl-CoA in a three-step process to prepare for citric acid cycle. In the presence of oxygen, acetyl CoA can enter several pathways, but most often, the acetyl group is delivered to the citric acid cycle for further catabolism.

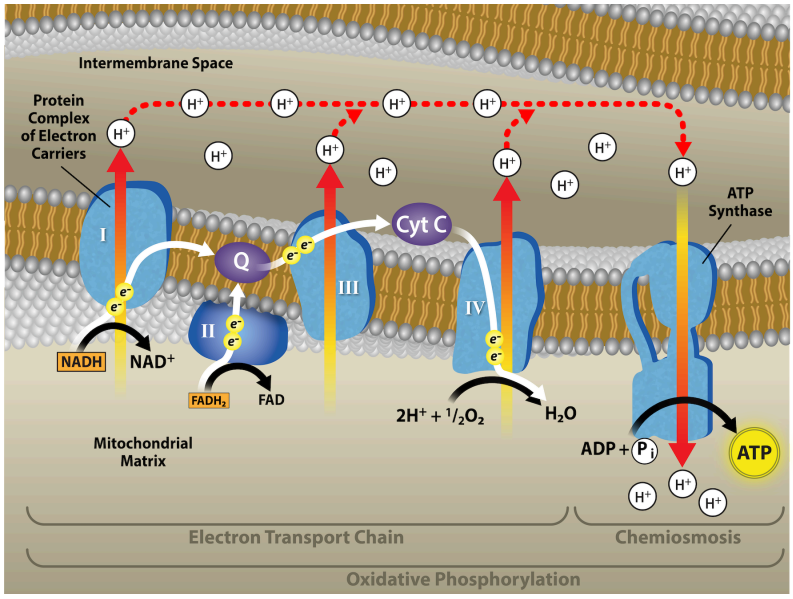
During the conversion of pyruvate, a molecule of carbon dioxide and two high-energy electrons are removed. The carbon dioxide accounts for two of the six carbons from the original glucose molecule. The electrons are picked up by NAD^+, and the NADH carries the electrons to a later pathway for ATP production. At this point, the glucose molecule that originally entered cellular respiration has been completely oxidized.

The citric acid cycle is a series of enzyme-driven reactions removing high-energy electrons and carbon dioxide. The electrons, temporarily stored in molecules of NADH and $FADH_2$, are used to generate ATP in a subsequent pathway. Citric acid cycle (aka Krebs) converts Acetyl CoA to citric acid. Products replenish an ongoing cycle. Molecules of CO_2 are released, hydrogens are carried by NAD+ and FAD to Electron Transport Chain (ETC), and one molecule of ATP is produced from each Acetyl group entering the cycle for a total of two per glucose.



In the citric acid cycle, acetyl CoA is converted through a series of steps. Because the final product of the citric acid cycle is also the first reactant, the cycle runs continuously in the presence of sufficient reactants. Credit: Rao, A., Ryan, K., Tag, A., and Fletcher, S. Department of Biology, Texas A&M University.

The electron transport chain is the portion of aerobic respiration using free oxygen as the final electron acceptor of electrons removed from intermediate compounds in glucose catabolism. The electron transport chain is composed of four large, multiprotein complexes embedded in the inner mitochondrial membrane and two small diffusible electron carriers shuttling electrons between them. Electrons are passed through a series of redox reactions, with a small amount of free energy used at three points to transport hydrogen ions across a membrane. This process contributes to the gradient used in chemiosmosis. The electrons passing through the electron transport chain gradually lose energy. High-energy electrons donated to the chain by either NADH or $FADH_2$ complete the chain, as low-energy electrons reduce oxygen molecules and form water. Hydrogen ions [H+] are protons pumped by active transport through proteins into the intermembrane space. The primary passage for [H+] is through ATP synthase, a protein enzyme embedded in the membrane. Proton pumps [H+] power ATP production and leave ETC to form water, when oxygen is available. Since this process only occurs in the presence of oxygen, it is called aerobic respiration. Oxygen is the final electron acceptor. One glucose molecules will metabolize to yield approximately 36 ATP per molecule of glucose. A number of intermediate compounds of the citric acid cycle can be diverted into the anabolism of other biochemical molecules, such as nonessential amino acids, sugars, and lipids. These same molecules can serve as energy sources for the glucose pathways.

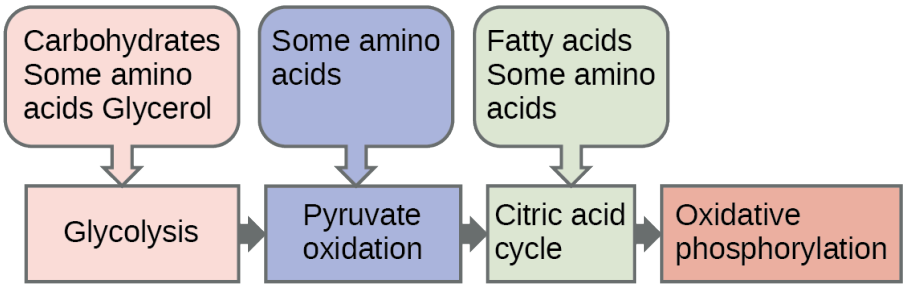


The electron transport chain is a series of electron transporters embedded in the inner mitochondrial membrane shuttling electrons from NADH and $FADH_2$ to molecular oxygen. In the process, protons are pumped from the mitochondrial matrix to the intermembrane space, and oxygen is reduced to form water. In oxidative phosphorylation, the pH gradient formed by the electron transport chain is used by ATP synthase to form ATP. Credit: Rao, A., Ryan, K., Fletcher, S. and Tag, A. Department of Biology, Texas A&M University.

In aerobic respiration, the final electron acceptor is an oxygen molecule. The fermentation method used by animals and certain bacteria is lactic acid fermentation. This type of fermentation is used routinely in skeletal muscle with insufficient oxygen supply for aerobic respiration. This would be muscles used to the point of fatigue. Another familiar fermentation process is alcohol fermentation, which produces ethanol. The fermentation of pyruvic acid by yeast produces the ethanol found in alcoholic beverages. Other fermentation methods take place in bacteria and many prokaryotes are facultatively anaerobic. This means that they can switch between aerobic respiration and fermentation, depending on the availability of free oxygen.

Glucose is not the only macromolecule to be catabolized, but it is the most efficient.

Proteins, other carbohydrates and fats can all enter the process at different points. Each contribute to ATP production less efficiently than glucose.



Glycogen from the liver and muscles, as well as other carbohydrates, hydrolyzed into glucose-1-phosphate, together with fats and proteins, can feed into the catabolic pathways for carbohydrates.

Cellular respiration is controlled by a variety of means. The entry of glucose into a cell is controlled by the transport proteins that aid glucose passage through the cell membrane. Most respiration control is accomplished through control of specific enzymes in the pathways. This type of negative feedback mechanism turns enzymes off. Other pathway intermediates affect certain enzymes in the systems.

Key Takeaways

1. Cellular respiration involves several pathways.
2. Glycolysis occurs in the cytoplasm and yields two, three-carbon pyruvate molecules.
3. Eukaryotes convert pyruvate to enter CAC and ETC within the mitochondria when oxygen is available.
4. Fermentation can occur when oxygen is not available.

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8. Chapter 8

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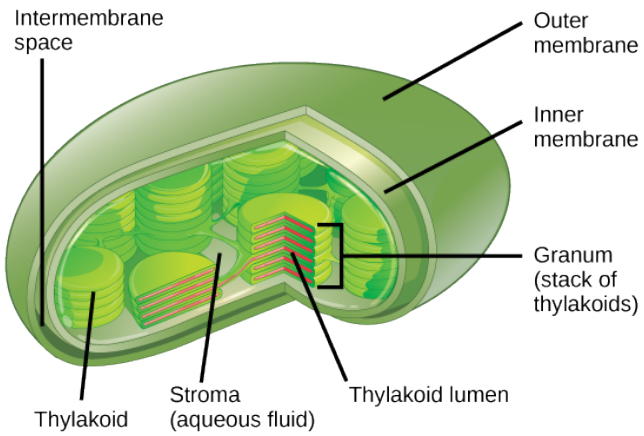
Learning Objectives

1. Describe reactions vital to photosynthesis
2. Identify cellular location, reactants and products for the two stages of photosynthesis
3. Describe the energy cycle

Photosynthesis

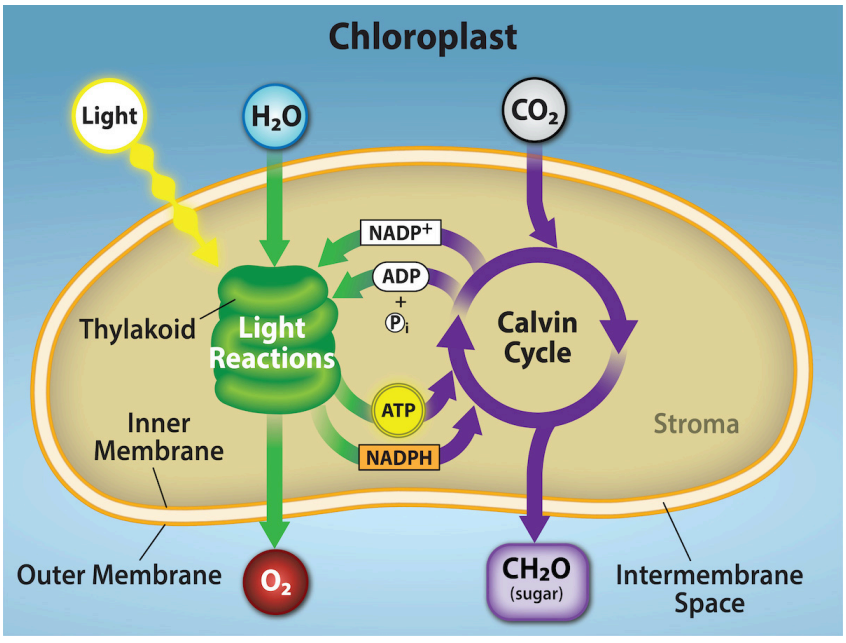
The process of photosynthesis transformed life on Earth. By harnessing energy from the sun, photosynthesis allowed living things access to enormous amounts of energy. Because of photosynthesis, living things had sufficient energy to build new structures and achieve biodiversity. All organisms capable of photosynthesis are considered producers, as they are capable of generating carbohydrates from carbon dioxide. Producers support life on earth for consumers, either directly or indirectly.

Only certain organisms can perform photosynthesis and require chlorophyll, a specialized pigment to absorb certain wavelengths of the visible spectrum. Photosynthesis uses carbon dioxide and water to assemble carbohydrate molecules and releases oxygen as a byproduct. Eukaryotes, like plants and algae, have chlorophyll-containing organelles called chloroplasts to provide a location for photosynthetic reactions. The chlorophyll is embedded in the thylakoid seen in the image below. In prokaryotes like cyanobacteria, there are no chloroplasts, so the process is less localized.



Photosynthesis takes place in chloroplasts, which have an outer membrane and an inner membrane. Stacks of chlorophyll-embedded thylakoids called grana form a third membrane layer.

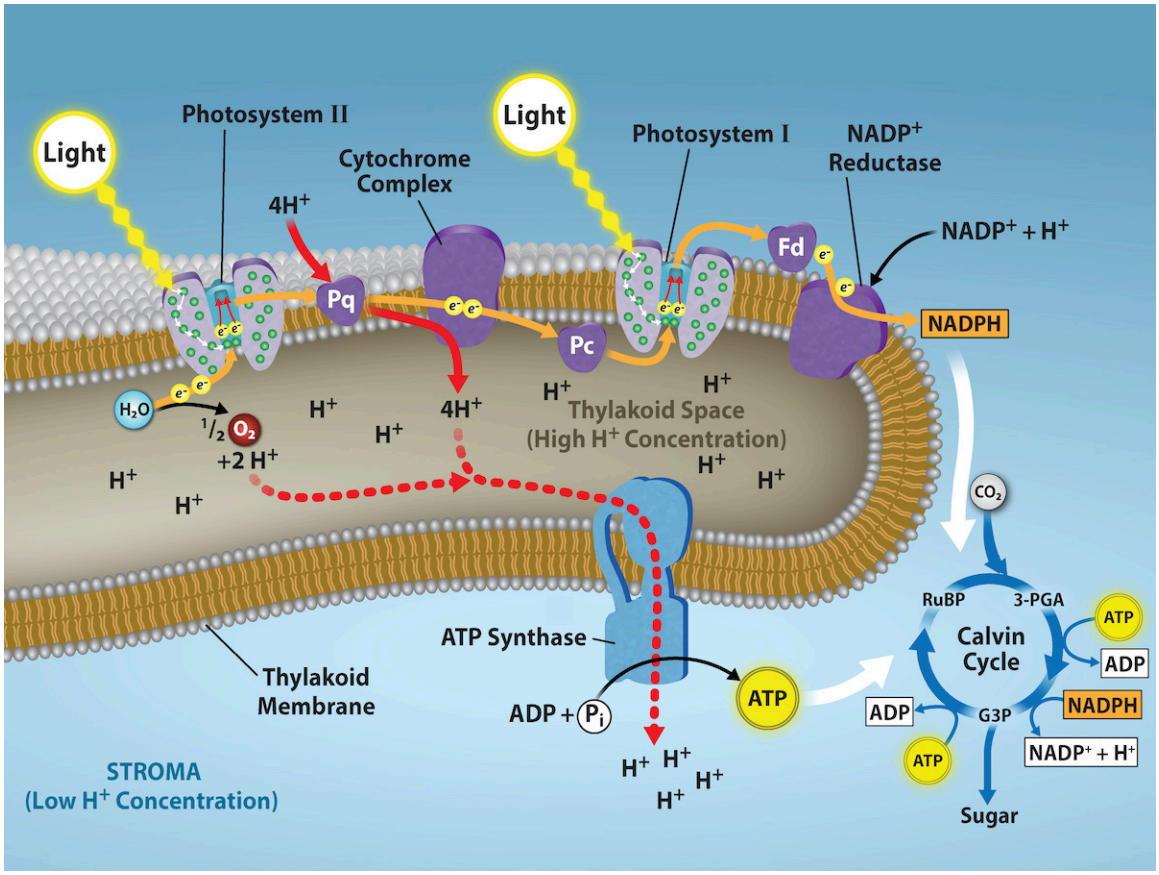
Photosynthesis takes place in two sequential stages: the light-dependent reactions and the Calvin cycle. In the light-dependent reactions, energy from sunlight is absorbed by chlorophyll and that energy is converted into stored chemical energy. In the Calvin cycle reactions, that stored chemical energy drives the assembly of sugar molecules from carbon dioxide.



Photosynthesis takes place in two stages: light-dependent reactions and the Calvin cycle. Light reactions take place in the thylakoid membrane, using light energy to make ATP and NADPH. The Calvin cycle, which takes place in the stroma, uses energy derived from these compounds to make G3P from CO_2. Credit: Rao, A., Ryan, K., Fletcher, S., Hawkins, A. and Tag, A. Texas A&M University.

The pigments of the first part of photosynthesis, the light-dependent reactions, absorb energy from sunlight. A photon strikes the pigments to initiate photosynthesis. The energy travels to the electron transport chain, which pumps hydrogen ions into the thylakoid interior. This action builds up a high concentration of hydrogen ions. The hydrogen ions flow through ATP synthase to form molecules of ATP, which are used for the formation of sugar molecules in Calvin cycle.

Light reactions convert light energy to chemical energy. This happens in the chloroplast across the thylakoid membrane. Water is split to provide hydrogen needed for carbohydrate construction. Hydrogens trickle through ATP synthase to join ADP + P_i generating ATP. Oxygen atoms from water splitting form pairs (O_2) which diffuse as a byproduct into the air. ATP generated will be contributed to the Calvin cycle. NADP+ delivers hydrogen to the Calvin cycle.



Light reactions harness energy from the sun to produce chemical bonds, ATP, and NADPH. These energy-carrying molecules are made in the stroma where carbon fixation takes place. Credit: Rao, A., Ryan, K., Tag, A., Fletcher, S. and Hawkins, A. Department of Biology, Texas A&M University.

Using energy carriers formed in the first steps of photosynthesis, Calvin cycle converts CO_2 to carbohydrates in a series of enzyme-driven reactions. An enzyme, RuBisCO, catalyzes a reaction with CO_2 and another organic compound, RuBP. After three cycles, a three-carbon molecule of G3P leaves the cycle to become part of a carbohydrate molecule. The remaining G3P molecules stay in the cycle to be regenerated into RuBP, which then reacts with more CO_2. Photosynthesis forms an energy cycle with the process of cellular respiration. Because plants contain both chloroplasts and mitochondria, they rely upon both photosynthesis and respiration for their ability to function in both the light and dark, and to be able to interconvert essential metabolites.

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Stomata are tiny openings, or leaf pores, that open and close to allow for gas exchange. They are found on the surface of leaves. Carbon dioxide will diffuse into leaf tissue and oxygen out. Some plants have evolved alternate methods of photosynthesis called C3 and C4 photosynthesis and carassulacean acid metabolism (CAM). These alternate methods allow the plants to survive in dry, hot climates. CAM plants keep stomata open at night. Chloroplasts can have symbiotic relationships with other organisms.

The energy cycle supports life on the surface of the earth, by the relationship of photosynthesis and cellular respiration. Photosynthesis absorbs light energy to build carbohydrates, and aerobic cellular respiration releases energy by using oxygen to metabolize carbohydrates in the cytoplasm and mitochondria. Both processes use electron transport chains to capture the energy necessary to drive other reactions. These two powerhouse processes, photosynthesis and cellular respiration, function in biological harmony to allow organisms to access the sun's energy.

Key Takeaways

1. Photosynthesis includes light-dependent reactions and the Calvin cycle.
2. The reactants of photosynthesis are carbon dioxide and water. The products are glucose and oxygen. Light is required for the reactions to begin.
3. Light-dependent reactions occur across the thylakoid membrane of the chloroplast, producing ATP. Calvin cycle uses CO2 to produce sugars in the stroma and requires ATP.
4. Photosynthesis consumes carbon dioxide and produces oxygen, while cellular respiration in the presence of oxygen does the opposite.

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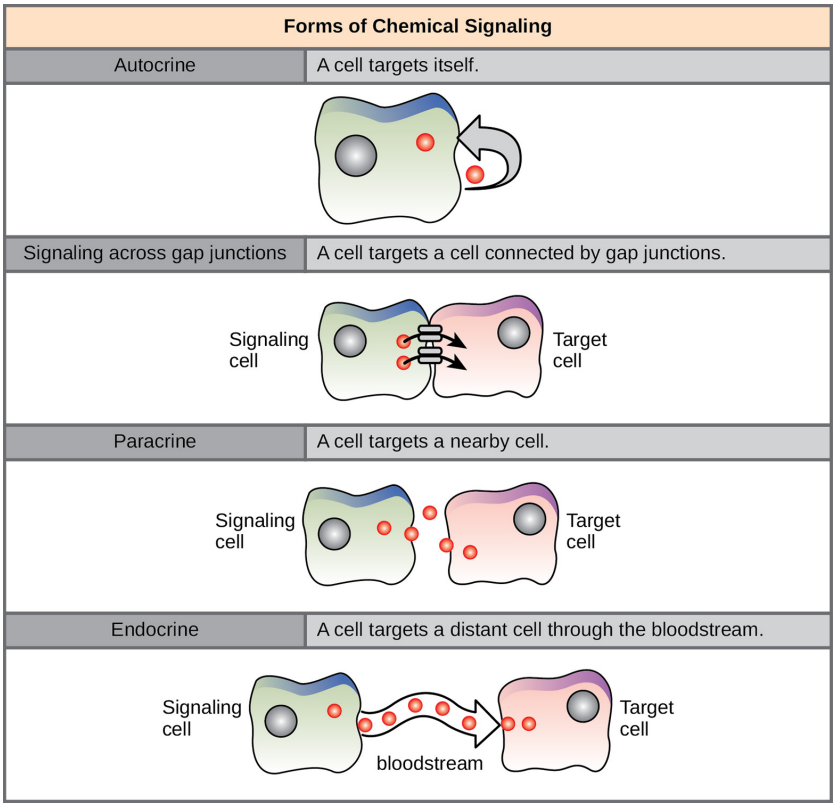
9. Chapter 9

Learning Objectives

1. Recognize characteristics of four types of cell signals
2. Identify mechanisms of nerve cell signals

Chapter 9



In chemical signaling, a cell may target itself (autocrine signaling), a cell

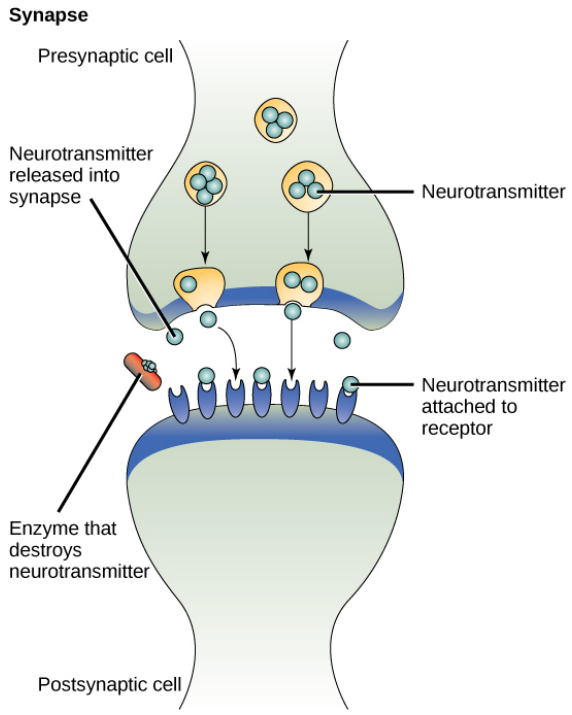
connected by gap junctions, a nearby cell (paracrine signaling), or a distant cell (endocrine signaling). Paracrine signaling acts on nearby cells, endocrine signaling uses the circulatory system to transport ligands, and autocrine signaling acts on the signaling cell. Signaling via gap junctions involves signaling molecules moving directly between adjacent cells.

Cells communicate by both inter- and intracellular signaling. Signaling cells secrete ligands that bind to target cells and initiate a chain of events within the target cell. The four categories of signaling in multicellular organisms are autocrine signaling, direct signaling across gap junctions, paracrine signaling, endocrine signaling. Autocrine signals are received by the same cell that sent the signal or other nearby cells of the same kind. Gap junctions allow small molecules, including signaling molecules, to flow between neighboring cells. Paracrine signaling takes place over short distances. Endocrine signals are carried long distances through the bloodstream by hormones.

Internal receptors are found in the cell cytoplasm. Here, they bind molecules that cross the plasma membrane. These complexes move to the nucleus and interact directly with cellular DNA. Cell-surface receptors transmit a signal from outside the cell to the cytoplasm. Ion channel-linked receptors, when bound, form a pore through the plasma membrane through which certain ions can pass. Enzyme-linked receptors transmit a signal from outside the cell to a membrane-bound enzyme. Binding causes activation of the enzyme. Small hydrophobic molecules (like steroids) are able to penetrate the plasma membrane and bind to internal receptors.

Cell signals control metabolism.

1. Autocrine signals involve a cell signaling itself. These signals are very common in embryonic development, during viral infections, inflammation and pain cascades in humans.
2. Gap junctions are water-filled channels that allow calcium ions [Ca_2+] to pass between cells. The passage is too small for proteins and DNA. This signal is useful for quick and easy transport.
3. Paracrine signals provide a quick response across a distance for nerve cells. This signal can involve enzymes, as shown below.



The distance between the presynaptic cell and the postsynaptic cell—called the synaptic gap—is very small and allows for rapid diffusion of the neurotransmitter. Enzymes in the synapatic gap degrade some types of neurotransmitters to terminate the signal.

4. Endocrine signals function for distant cells. This includes hormones used by our thyroid and pituitary for a slower but longer lasting signal.

Key Takeaways

1. Autocrine signals involve a cell targeting itself. Gap-junction signals are designed for cells to signal adjoining cells. Paracrine signals involve generating signals that travel a short distance, so a great example is the nerve cell. Endocrine signals are capable of signaling distant cells.
2. Nerve cell signals must be degraded by enzymes to terminate the signal.

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PART III

MODULE 3

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Module 3

This module includes details about how proteins are built and follows the role of DNA in cell division and inheritance. A human begins life as a diploid zygote. In our species, billions of cell divisions subsequently must occur in a controlled manner in order to produce a complex, multicellular human containing trillions of cells. Once a human is fully grown, cell reproduction is still necessary to repair and regenerate tissues. Cell division is closely regulated, and the occasional failure of regulation can have life-threatening consequences. This cover page provides all Module 3 Learning Objectives, a question answered by each chapter and respective chapter summaries.

Module 3 is aligned with the following course objectives

- Examine the characteristics common to life
- Analyze cell types and cellular reproduction
- Relate heredity and evolution to organisms and ecosystems
- Apply scientific inquiry to predict outcomes
- Classify and compare major groups of organisms

Learning Objectives Chapter 10

How do your abrasions heal after a wound?

1. Recognize the role of cellular division and associated vocabulary
2. Identify four phases of mitotic division
3. Examine the characteristics of cancer cells

Chapter 10 Summary

Eukaryotes have multiple, linear chromosomes composed of DNA wrapped around histones. The 46 chromosomes of human somatic cells are composed of 22 pairs of autosomes and a pair of sex chromosomes. This is the 2*n* or diploid state. Human gametes have 23 chromosomes, or one complete set of chromosomes, containing either X or Y. This is the *n* or haploid state. An organism's traits are determined by the genes inherited from each parent. The cell cycle is an orderly sequence of events, including a long preparatory period, called interphase. Interphase is divided into G_1, S, and G_2 phases and chromosomes are replicated during S phase. The phases of mitosis (prophase, metaphase, anaphase and telophase) are followed by cytokinesis. Each step of the cell cycle is monitored by internal controls called checkpoints. Cancer is the result of unchecked cell division caused by a breakdown of the mechanisms that regulate the cell cycle.

Learning Objectives Chapter 11

Why are you different than your siblings?

1. Recognize the role of meiosis, particularly in humans
2. Recognize the role of crossover, random alignment and random fertilization in variability
3. Identify potential sources of error in meiosis

Chapter 11 Summary

Sexual reproduction requires that organisms produce cells that can fuse during fertilization to produce offspring. In most animals, meiosis is used to produce haploid gametes of egg and sperm. The fusion of an egg and sperm produces a diploid zygote. As with mitosis, DNA replication occurs prior to meiosis during the S-phase of the cell cycle. Meiosis has two rounds of nuclear division resulting in four different nuclei with half the number of chromosomes as the parent cell. The first division separates homologous chromosomes, and the second separates chromatids into individual chromosomes. Meiosis generates variation in the

daughter nuclei during crossover in prophase I as well as during the random alignment of metaphase I. Cells produced by meiosis are genetically unique, and random fertilization is a result of gamete fusion. In a human karyotype, there are 22 autosomes and the XY sex chromosomes, which are not autosomes. Chromosome number disorders include duplicating or losing entire chromosomes. They are caused by nondisjunction, which occurs when homologous chromosome pairs or sister chromatids fail to separate during meiosis.

Learning Objectives Chapter 12

Where did your chromosomes come from? Where are they going?

1. Recognize the role of genes and genetics for inheritance patterns
2. Apply principles of inheritance in a monohybrid cross with application of genotype and phenotype percentages
3. Identify three patterns of inheritance in human disease

Chapter 12 Summary

Mendel selected a simple biological system and conducted methodical, quantitative analyses using large sample sizes. Because of Mendel's work, the fundamental principles of heredity were revealed. Working with garden pea plants, Mendel found that crosses between parents that differed by one trait produced first generation (F_1) offspring that all expressed the traits of one parent. Observable traits are referred to as dominant, and non-expressed traits are described as recessive. When homozygous individuals that differ for a certain trait are crossed, all of the offspring will be heterozygotes for that trait. If the traits are inherited as dominant and recessive, the F_1 offspring will all exhibit the same phenotype as the parent homozygous for the dominant trait. Alleles do not always behave in dominant and recessive patterns. Genes are the basic functional units of heredity with the capability to be replicated, expressed, or mutated. Genetic disorders can follow autosomal dominant, autosomal recessive or sex-linked patterns of inheritance.

Learning Objectives Chapter 14

What is your DNA doing right now?

1. Recognize DNA structure and mechanisms
2. Identify four major replication enzymes and their function
3. Recognize the Central Dogma components, location and steps
4. Describe the significance of DNA mutations

Chapter 14 Summary

The genetic code refers to the DNA alphabet (ATCG), the RNA alphabet (AUCG), and the polypeptide alphabet (20 amino acids). DNA replication occurs during S-phase of interphase and involves helicase, DNA polymerase, ligase and telomerase. The central dogma describes the flow of genetic information in the cell from genes to mRNA to proteins. Genes form the template for mRNA by the process of transcription. mRNA is used to synthesize proteins by the process of translation. Transcription occurs in the nucleus of eukaryotes, and translation occurs at the ribosome. Almost every species on the planet uses the same genetic code. The players in translation include the mRNA template, ribosomes, tRNAs, and various enzymatic factors. The formation of peptide bonds occurs between sequential amino acids matched to the mRNA template by their tRNAs according to the genetic code. DNA polymerase can make mistakes while adding nucleotides. It edits the DNA by proofreading every newly added base. Most mistakes are corrected during replication, but there are additional repair systems. If mistakes are not corrected, they may result in a mutation. This is a permanent change in the DNA sequence. Mutations can be of many types, such as substitution, deletion, insertion, and frameshift. Mutations in repair genes may lead to serious consequences such as cancer.

When you are ready to prepare for Exam 3, this audio study guide might be helpful.

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10. Chapter 10

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Learning Objectives

1. Recognize the role of cellular division and associated vocabulary
2. Identify four phases of mitotic division
3. Examine the characteristics of cancer cells

Cell Reproduction

A cell's DNA, packaged as a double-helix DNA molecule, is called its genome. In prokaryotes, the genome is composed of a single, double-stranded DNA molecule in a loop or circle. Prokaryotes, including bacteria and archaea, have a single, circular chromosome located in a central region called the nucleoid.

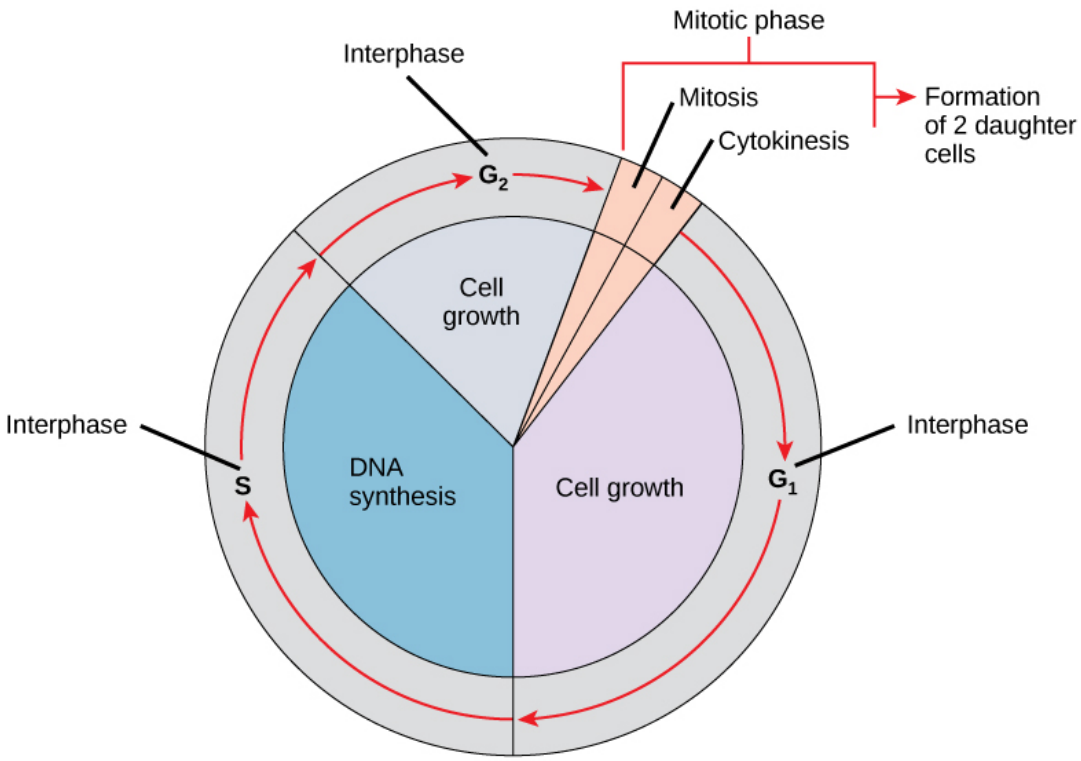
Eukaryotes have multiple, linear chromosomes surrounded by a nuclear membrane. The 46 chromosomes of human somatic (body) cells are composed of 22 autosome pairs and a pair of sex chromosomes, which may or may not be matched. This is the 2*n* or diploid state. Human gametes (egg or sperm) have 23 chromosomes or one complete set of chromosomes. This is the *n* or haploid state. Humans have 23 pairs of chromosomes, for a total of 46 chromosomes, in each somatic cell.

Matched pairs of chromosomes in a diploid organism are called homologous chromosomes, which are the same length and have specific nucleotide segments

called genes. Genes determine specific characteristics by coding for specific proteins. Traits are the variations of those characteristics. Chromosomes are compacted DNA wrapped around histone proteins. Several classes of protein are involved in the organization and packing of the chromosomal DNA into this highly condensed structure. The condensing complex compacts chromosomes, and the resulting condensed structure is necessary for chromosomal segregation during mitosis.

Each copy of a homologous pair of chromosomes originates from a different parent, so the genes are not identical. The variation of individuals is due to the specific combination of genes inherited from both parents. Even a slightly altered sequence of nucleotides within a gene can result in an alternative trait.

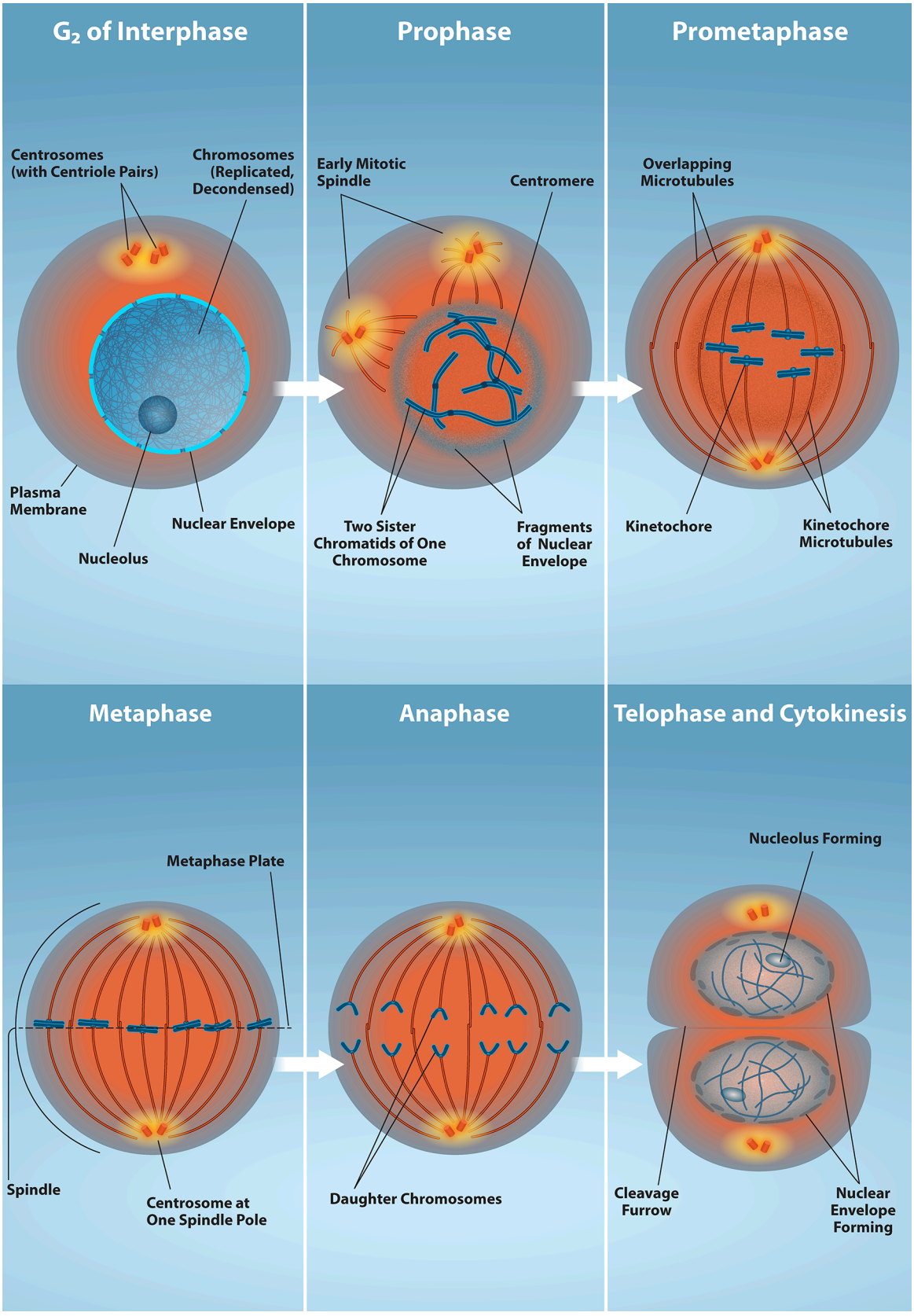
The cell cycle is an ordered series of events producing two new daughter cells. Cells on the path to cell division proceed through a series of precisely timed and carefully regulated stages of growth, DNA replication, and division, producing two identical (clone) cells. During interphase, the cell grows and DNA is replicated. During the mitotic phase, the replicated DNA and cytoplasmic contents are separated, and the cell divides.



The cell cycle in multicellular organisms consists of interphase and the mitotic phase. During interphase, the cell grows and the nuclear DNA is replicated. Interphase is followed by the mitotic phase. During mitosis, the duplicated chromosomes are segregated and distributed into daughter nuclei. Following mitosis, cytoplasm is usually divided by cytokinesis, resulting in two genetically identical daughter cells.

Interphase has 3 parts:

- G_1 Phase (First Gap) cell grows, producing organelles as needed
- S Phase (Synthesis of DNA) DNA replication occurs, centrioles organize
- G_2 Phase (Second Gap) cell grows, producing organelles as needed



Prophase is the first stage in mitosis. The nuclear envelope begins to break

down and chromosomes condense and are now visible. Spindle fibers start to appear and centrosomes begin to move towards opposite poles. During prometaphase, chromosomes continue to condense and are more visible. Kinetochores appear at the centromere and kinetochore microtubules attach. Centrosomes continue to move towards opposite poles. During metaphase, the mitotic spindle is fully developed and centrosomes are at opposite poles. Chromosomes are aligned at the “equatorial plate”, and each sister chromatid rests on one side of the plate, with spindle fibers attached to them. During anaphase, sister chromatids are pulled apart by spindle fibers and are separated from each other. Each chromatid is now a chromosome. During telophase, chromosomes arrive at opposite poles and start to decondense and become less visible. The nuclear envelope reassembles and begins to surround each new set of chromosomes. The mitotic spindle assembly breaks down. During cytokinesis, the division of the cytoplasm begins and the two cells separate. Credit: Rao, A., Hawkins, A.and Fletcher, S. Department of Biology, Texas A&M University.

Mitosis Summary

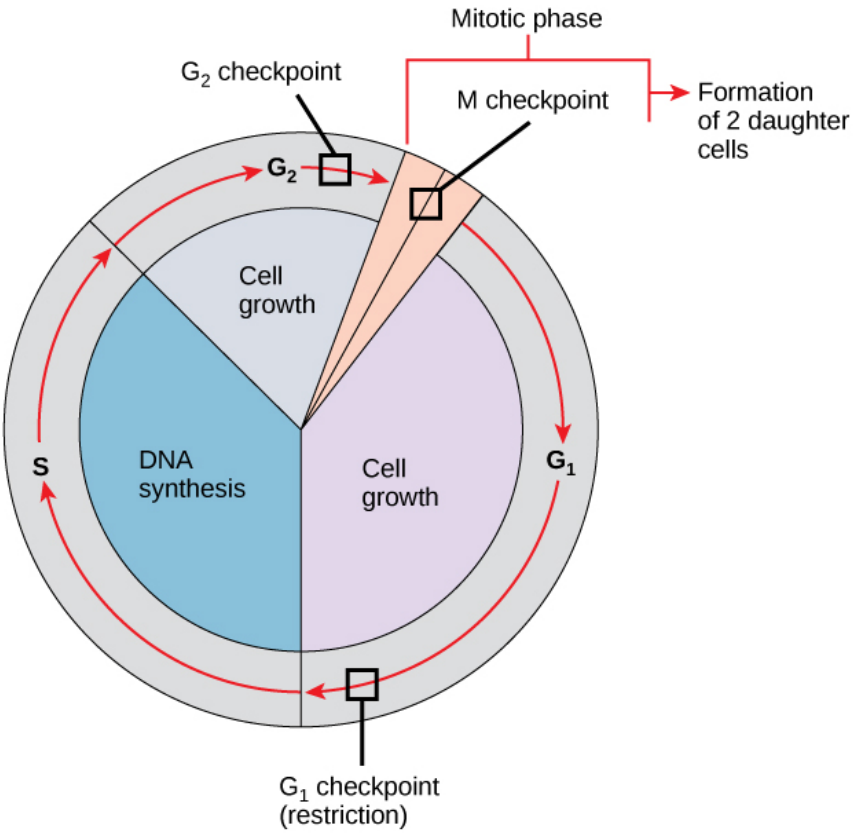
Prophase chromosomes condense, spindle fibers emerge, nuclear membranes break down

Metaphase spindle poles formed, chromosomes lined up at metaphase plate

Anaphase chromosomes pulled toward opposite poles, spindles elongate cell

Telophase chromosomes at poles, nuclear formation begins, spindles break down

Cell cycle is regulated to maintain homeostasis. Cell signals initiate the phases of the cell cycle. Many signals are hormones, like growth hormone. Three checkpoint signals prevent a compromised cell from continuing to divide.



The cell cycle is controlled at three checkpoints. The integrity of the DNA is assessed at the G_1 checkpoint. Proper chromosome duplication is assessed at the G_2 checkpoint. Attachment of each kinetochore to a spindle fiber is assessed at the M checkpoint.

The G_1 Checkpoint determines if conditions are favorable for cell division to proceed. The G_1 checkpoint is a point at which the cell irreversibly commits to cell division. External influences play a large role in the cell passing G_1 checkpoint. In addition, there is a genomic DNA damage check at G_1 checkpoint. A cell not meeting all the requirements will not be allowed to progress to S phase. The cell can halt the cycle or await further signals when conditions improve. If the DNA cannot be repaired, apoptosis (cell death) signals prevent the duplication of damaged chromosomes.

G_2 checkpoint halts mitosis if certain conditions are not met. The most important role of the G_2 checkpoint is to ensure all chromosomes have been replicated and replicated DNA is not damaged. If the checkpoint mechanisms detect DNA

problems, cell cycle is halted. The cell either completes DNA replication or repairs damaged DNA.

M checkpoint occurs near the end of metaphase. The M checkpoint is also known as the spindle checkpoint, because it determines whether all sister chromatids are correctly attached to spindle microtubules.

Cancer includes many different diseases caused by the common mechanism of uncontrolled cell growth. Cancer cells display unchecked cell division caused by a breakdown of the checkpoint mechanisms that regulate the cell cycle. This could be due to an inherited mutation or an accumulation of mutations. The loss of control begins with a change in the DNA sequence of a gene coding for a checkpoint regulatory molecule. Any disruption could allow other mistakes to be passed on to daughter cells. Each successive cell division has potential for accumulated damage.

Genes and the environment can both increase cancer risk. The risk factors include radiation, chemicals, UV light, and errors in replication. When cancer metastasizes its cells can travel in the bloodstream and colonize other areas of the body.

Key Takeaways

1. In humans, cellular division begins with the zygote and generates identical somatic cells. Most of a cell's life is spent in interphase.
2. Prophase: chromosomes condense and nucleus dissolves; metaphase: chromosomes align; anaphase: chromosomes migrate to poles; telophase: two nuclear membranes form
3. Cancer cells are the result of an accumulation of mutations that impact cell division.

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11. Chapter 11

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://open.ocolearnok.org/introductorybiology/?p=179#oembed-1

Learning Objectives

1. Recognize the role of meiosis, particularly in humans
2. Recognize the role of crossover, random alignment and random fertilization in variability
3. Identify potential sources of error in meiosis

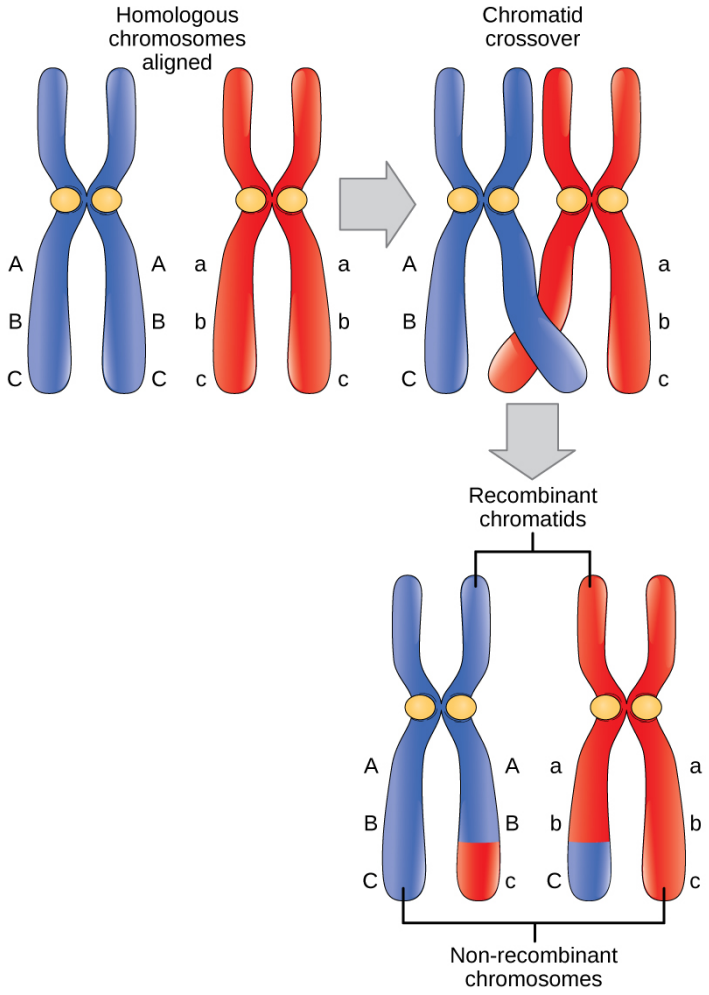
Meiosis and Sexual Reproduction

Sexual reproduction requires that organisms produce cells that can fuse during fertilization to produce offspring. In most organisms, fertilization occurs between two haploid cells, the larger being called “female” or “egg” and the smaller being called “male” or “sperm.” In most animals, meiosis is used to produce haploid eggs and sperm from diploid parent cells so that fusion of an egg and sperm produces a diploid zygote. As with mitosis, DNA replication occurs prior to meiosis during the S-phase of the cell cycle. In meiosis, two rounds of nuclear division result in four nuclei and usually four daughter cells, each with half the number of chromosomes as the parent cell. The first division separates homologous chromosomes, and the second—like mitosis—separates chromatids into individual chromosomes. Meiosis generates variation during crossover in prophase I and random alignment during metaphase I. Cells produced by meiosis are genetically unique.

Most cells in a sexually reproducing organism have two sets of chromosomes, one set inherited from the father and one set inherited from the mother. Cells with two sets of chromosomes are called diploid cells (2n). Humans have 22 pairs

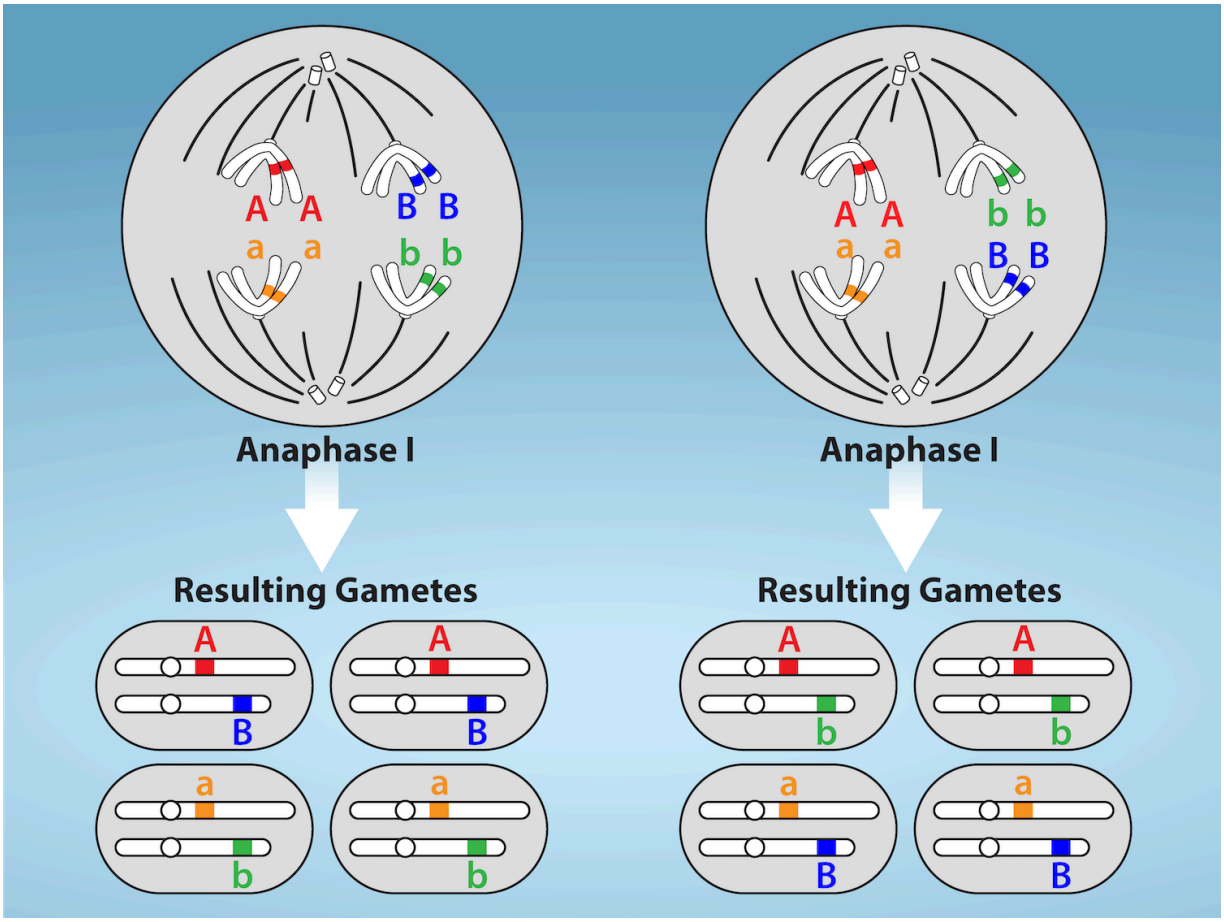
of autosomes or “body chromosomes,” which are all of the non–sex chromosomes. These chromosomes are the same for both sexes. Each autosomal chromosome is paired with an equally sized chromosome. The other pair are sex chromosomes, which are not autosomes. Chromosomes X and Y are not the same size and shape.

Meiosis and mitosis share similar processes but distinct outcomes. In humans, mitosis involves division of a single nucleus to produce two genetically identical daughter cells, while meiosis involves two nuclear divisions to produce four genetically different daughter cells with only one chromosome set. The main differences between these two processes take place during the first division of meiosis, when homologous chromosomes pair, crossover, and exchange segments. The homologous chromosomes separate into different nuclei during meiosis I. The second division of meiosis is similar to a mitosis, except daughter cells do not contain identical genomes due to crossover and chromosome recombination in prophase I. During meiosis, variation in the daughter nuclei is introduced because of crossover in prophase I and random alignment in metaphase I. The cells that are produced by meiosis are genetically unique.



Crossover occurs between nonsister chromatids of homologous chromosomes. The result is an exchange of genetic material between homologous chromosomes.

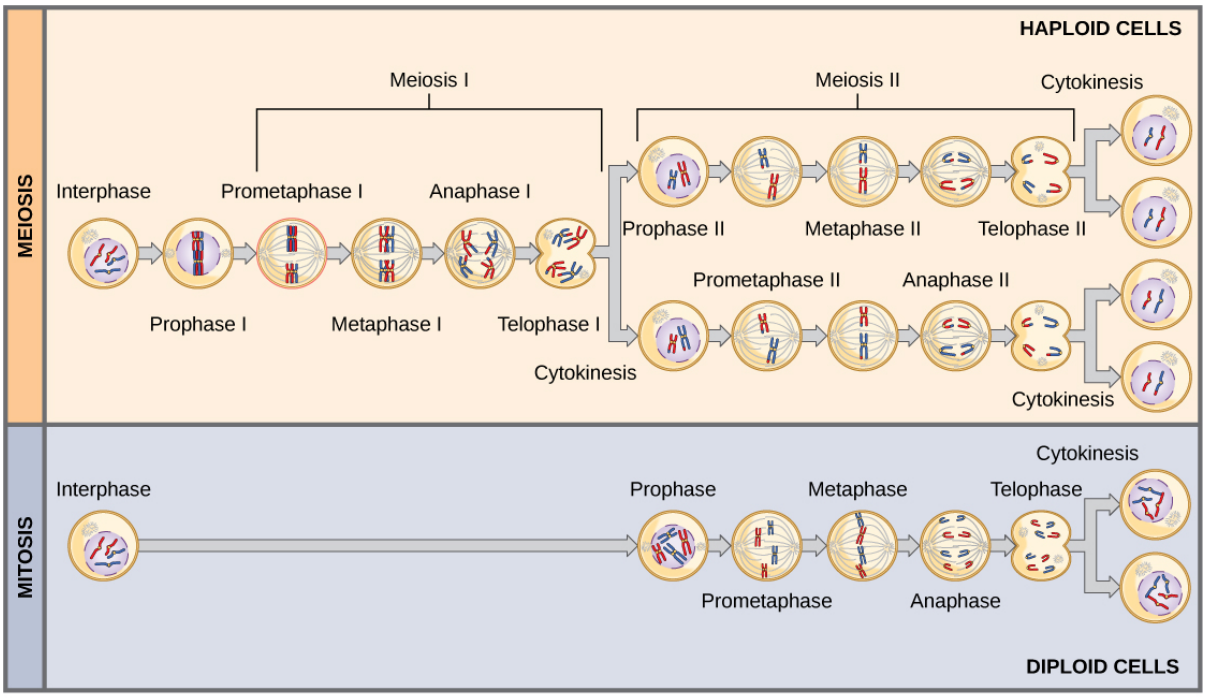
The crossover events are the first source of genetic variation in the nuclei produced by meiosis. Illustrated above, a single crossover event between homologous non-sister chromatids leads to a reciprocal exchange of equivalent DNA between a maternal chromosome and a paternal chromosome. Now, when that sister chromatid is moved into a gamete cell it will carry some DNA from one parent of the individual and some DNA from the other parent. The sister recombinant chromatid has a combination of maternal and paternal genes that did not exist before the crossover. Multiple crossovers in an arm of the chromosome have the same effect, exchanging segments of DNA to create recombinant chromosomes.



Random, independent assortment during metaphase I is demonstrated by considering a cell with a set of two chromosomes (n = 2). There are two possible homologous chromosome arrangements at the equatorial plane in metaphase I, that are then separated during anaphase I. The total possible number of different gametes is 2^n, where n equals the number of chromosomes in a set. In this example, there are four possible genetic combinations for the gametes. With n = 23 in human cells, there are over eight million possible combinations of paternal and maternal chromosomes. Credit: Rao, A.and Fletcher, S. Department of Biology, Texas A&M University.

Sexual reproduction is used by almost all eukaryotes. The variation introduced into the reproductive cells by meiosis appears to be one of the advantages of sexual

reproduction that has made it so successful. Meiosis and fertilization alternate in sexual life cycles. The process of meiosis produces unique reproductive cells called gametes with half the number of chromosomes as the parent cell. Fertilization restores the diploid condition. Sexually reproducing organisms alternate between haploid and diploid stages.



						OUTCOME
PROCESS	DNA synthesis	Synapsis of homologous chromosomes	Crossover	Homologous chromosomes line up at metaphase plate	Sister chromatids line up at metaphase plate	Number and genetic composition of daughter cells
MEIOSIS	Occurs in S phase of interphase	During prophase I	During prophase I	During metaphase I	During metaphase II	Four haploid cells at the end of meiosis II
MITOSIS	Occurs in S phase of interphase	Does not occur in mitosis	Does not occur in mitosis	Does not occur in mitosis	During metaphase	Two diploid cells at the end of mitosis

Meiosis and mitosis are both preceded by one cycle of DNA replication. However, meiosis includes two rounds of nuclear division. The four daughter cells generated from meiosis are haploid and genetically distinct. Two daughter cells generated from mitosis are diploid and identical to the parent cell.

Nearly all eukaryotes undergo sexual reproduction. The variation introduced into reproductive cells by meiosis provides an important advantage for sexual reproduction. The process of meiosis produces unique reproductive cells called gametes, which have half the number of chromosomes as the parent cell. In a fertilization event, two haploid gametes fuse to form a diploid zygote.

Chromosome isolation for microscopic observation is the primary method by which clinicians detect chromosomal abnormalities in humans. A karyotype is the number and appearance of chromosomes, and includes their length, banding pattern, and centromere position. Chromosome number disorders include duplicating or losing entire chromosomes, as well as changes in the number of complete sets of chromosomes. They are caused by nondisjunction, which occurs when homologous chromosome pairs or sister chromatids fail to separate during meiosis. Misalignment, incomplete synapsis or spindle apparatus dysfunction can cause nondisjunction. The risk of nondisjunction increases with the parents' age.

Scientists have identified and characterized several errors in sex chromosome number. Individuals with three X chromosomes, triplo-X, are phenotypically female but express developmental delays and reduced fertility. More complex types of Klinefelter syndrome (XXY) exist in which the individual has as many as five X chromosomes. In all types, every X chromosome except one undergoes inactivation to compensate for the excess genetic dosage. Turner syndrome, characterized as an X0 genotype (one single sex chromosome), corresponds to a phenotypically female individual with short stature, webbed skin in the neck region, hearing impairments, cardiac impairments, and sterility.

Key Takeaways

1. In humans, meiosis generates haploid (n) gametes of egg and sperm.
2. Crossover occurs in prophase I, random alignment in metaphase I and random fertilization – all contribute to variability.
3. Errors in meiosis lead to trisomy and other disorders.

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12. Chapter 12

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Learning Objectives

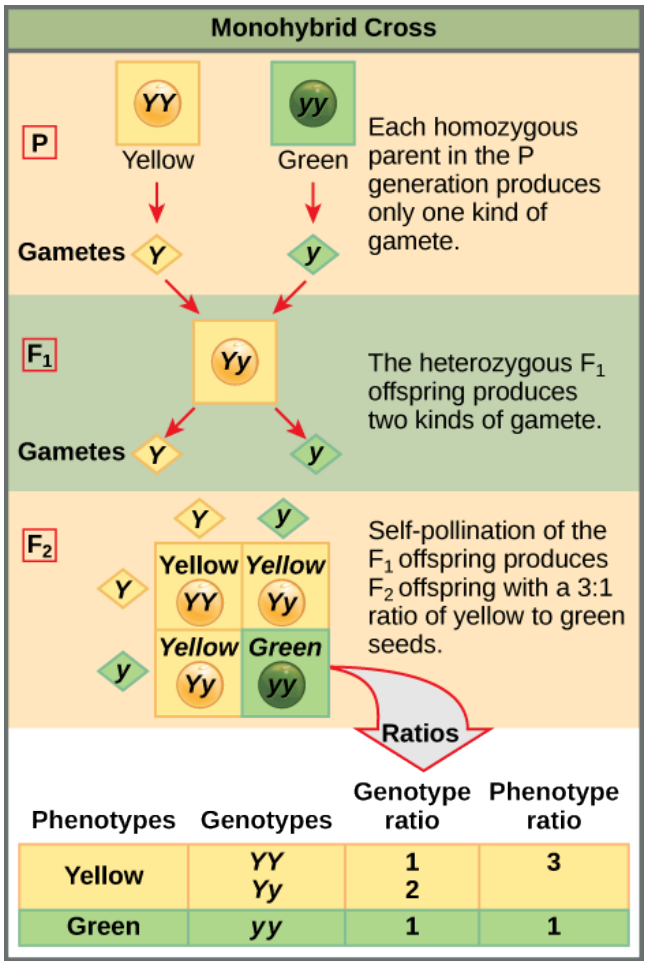
1. Recognize the role of genes and genetics for inheritance patterns
2. Apply principles of inheritance in a monohybrid cross with application of genotype and phenotype percentages
3. Identify three patterns of inheritance in human disease

Mendel's Experiments and Heredity

Johann Gregor Mendel (1822–1884) was a lifelong learner, teacher, scientist and man of faith. Supported by his monastery. in what is now the Czech Republic. In 1865, Mendel presented the results of his experiments with nearly 30,000 pea plants to the local Natural History Society. He demonstrated that traits are transmitted faithfully from parents to offspring independently of other traits and in dominant and recessive patterns.

Mendel's work was accomplished using the garden pea to study inheritance. This species naturally self-fertilizes, preventing pollination from other plants. The result is "true-breeding" pea plants. When fertilization occurs between two true-breeding parents that differ in only one characteristic, the process is called a monohybrid cross, These are plants that always produce offspring that look like the parent. By experimenting with true-breeding pea plants, Mendel avoided the appearance of unexpected traits in offspring that might occur if the plants were not true breeding.

The garden pea also grows to maturity within one season, meaning that several generations could be evaluated over a relatively short time. Finally, large quantities of garden peas could be cultivated simultaneously, allowing Mendel to conclude that his results did not come about simply by chance.



Pea plant with dominant yellow phenotype crossed with recessive green phenotype. This cross produces all heterozygotes with a yellow phenotype. A Punnett square analysis can be used to predict the genotypes of a cross of two heterozygotes.

Working with garden pea plants, Mendel found that crosses between parents differing in one trait produced F_1 offspring expressing traits of one parent. Observable traits are referred to as dominant, and non-expressed traits are described as recessive. When the offspring in Mendel's experiment were self-crossed, the F_2 offspring exhibited the dominant trait (75%) and the recessive trait

(25%) in a 3:1 ratio, confirming the recessive trait had been transmitted faithfully from the original P_0 parent. By examining sample sizes, Mendel showed that his crosses behaved reproducibly according to the laws of probability, and that traits were inherited as independent events.

Gene variants which arise by mutation and exist at the same relative chromosomal locations are called alleles. Two alleles for a given gene in a diploid organism are expressed and interact to produce physical characteristics. The observable traits of an organism are referred to as phenotype. The organism's underlying genetic makeup is referred to as genotype. Mendel's experiments demonstrate the difference between phenotype and genotype. When true-breeding plants in which one parent had yellow pods and one had green pods were cross-fertilized, all F_1 offspring had yellow pods. Offspring were phenotypically identical to the parent with yellow pods. Allele donated by the parent with green pods was not simply lost, because it reappeared in some F_2 offspring. This demonstrates F_1 plants must have different genotypes from the parent with yellow pods.

The plants Mendel used in his experiments were homozygous for traits he was studying. Diploid organisms that are homozygous at a given gene have two identical alleles for that gene on their homologous chromosomes. Mendel's parental pea plants always bred true because both gametes produced carried the same trait.

When plants with contrasting traits were cross-fertilized, all offspring were heterozygous, meaning their genotype had different alleles for the gene being examined.

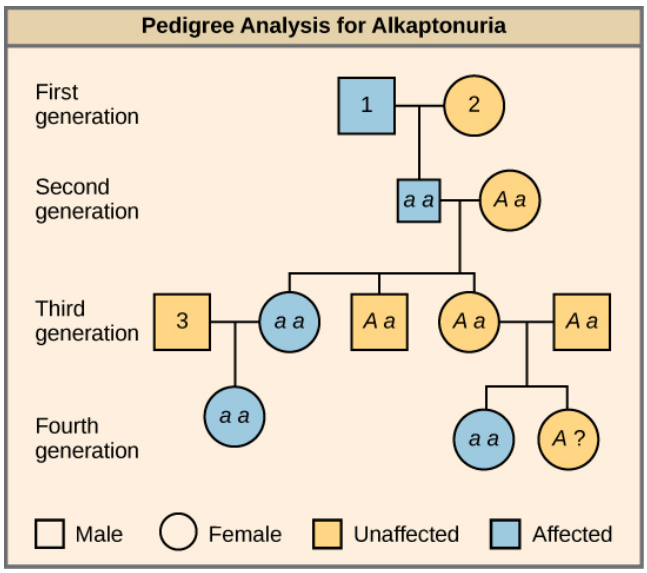
In all seven pea-plant characteristics, one of the two contrasting alleles was dominant, and the other was recessive. We now know this is due to genes on homologous chromosome pairs. For a gene that is expressed in a dominant and recessive pattern, homozygous dominant and heterozygous organisms will appear identical. This means they have different genotypes but the same phenotype. The recessive allele will only be observed in homozygous recessive individuals, so some refer to recessive alleles as masked.

Alleles do not always behave in dominant and recessive patterns. Incomplete dominance describes situations in which the heterozygote exhibits a phenotype that is intermediate between the homozygous phenotypes. Codominance

describes the simultaneous expression of both of the alleles in the heterozygote. Although diploid organisms can only have two alleles for any given gene, it is common for more than two alleles of a gene to exist in a population. In humans, as in many animals and some plants, females have two X chromosomes and males have one X and one Y chromosome. Genes that are present on the X but not the Y chromosome are said to be X-linked, such that males only inherit one allele for the gene, and females inherit two. Finally, some alleles can be lethal. Recessive lethal alleles are only lethal in homozygotes, but dominant lethal alleles are fatal in heterozygotes as well.

Many human diseases are genetically inherited. A healthy person in a family in which some members suffer from a recessive genetic disorder may want to know if he or she has the disease-causing gene and what risk exists of passing the disorder on to his or her offspring. Of course, doing a test cross in humans is unethical and impractical. Instead, geneticists use pedigree analysis to study the inheritance pattern of human genetic diseases. Autosomal dominant disorders are present in both male and female humans and appear in each generation of a pedigree. An example of this in humans is Huntington's disease, in which the nervous system gradually wastes away. People who are heterozygous for the dominant Huntington allele (*Hh*) will inevitably develop the fatal disease. However, the onset of Huntington's disease may not occur until age 40, at which point the afflicted persons may have already passed the allele to 50 percent of their offspring.

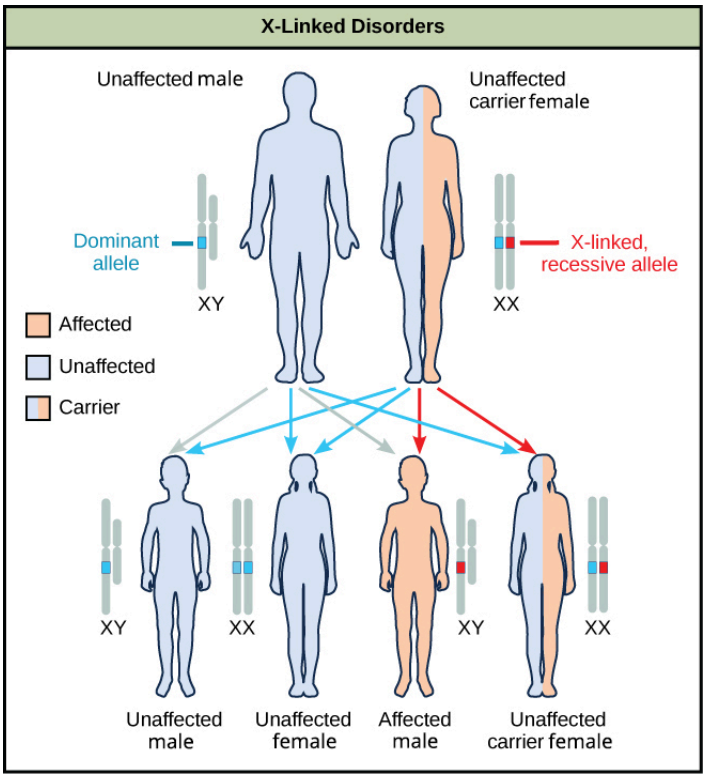
Recessive alleles can be "carried" and not expressed by individuals. Such heterozygous individuals are sometimes referred to as "carriers." Further genetic studies in other plants and animals have shown that much more complexity exists, but that the fundamental principles of Mendelian genetics still hold true. Autosomal recessive disorders will show unaffected carriers and can skip generations in pedigrees.



Alkaptonuria is a recessive genetic disorder in which two amino acids, phenylalanine and tyrosine, are not properly metabolized. Affected individuals may have darkened skin and brown urine, and may suffer joint damage and other complications. In this pedigree, individuals with the disorder are indicated in blue and have the genotype *aa*. Unaffected individuals are indicated in yellow and have the genotype *AA* or *Aa*. Note that it is often possible to determine a person's genotype from the genotype of their offspring. For example, if neither parent has the disorder but their child does, they must be heterozygous. Two individuals on the pedigree have an unaffected phenotype but unknown genotype. Because they do not have the disorder, they must have at least one normal allele, so their genotype gets the "*A*?" designation.

Because human males need to inherit only one recessive mutant X allele to be affected, X-linked disorders are disproportionately observed in males. Females must inherit recessive X-linked alleles from both of their parents in order to express the trait. When they inherit one recessive X-linked mutant allele and one dominant X-linked wild-type allele, they are carriers of the trait and are typically unaffected. Carrier females can manifest mild forms of the trait due to the inactivation of the dominant allele located on one of the X chromosomes. However, female carriers can contribute the trait to their male children, resulting in the male exhibiting the trait, or they can contribute the recessive allele to their female children, resulting in

the children being carriers of the trait. Although some Y-linked recessive disorders exist, typically they are associated with infertility in males and are therefore not transmitted to subsequent generations. X-linked or sex linked disorders affect more males than females, as females can be unaffected carriers.



The male offspring of a person who is a carrier of a recessive X-linked disorder will have a 50 percent chance of being affected. A female will not be affected, but she will have a 50 percent chance of being a carrier like the female parent.

Key Takeaways

1. DNA codes for proteins. Meiosis allows for alleles to be inherited from both parents. Some alleles exert effects when they are present (dominant), while others are not expressed (recessive).
2. Genotype refers to alleles and phenotype refers to appearance. A monohybrid cross allows analysis of heterozygote or homozygote offspring.

3. Pedigrees indicate whether a disease is autosomal dominant, recessive or x-linked.

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13. Chapter 14

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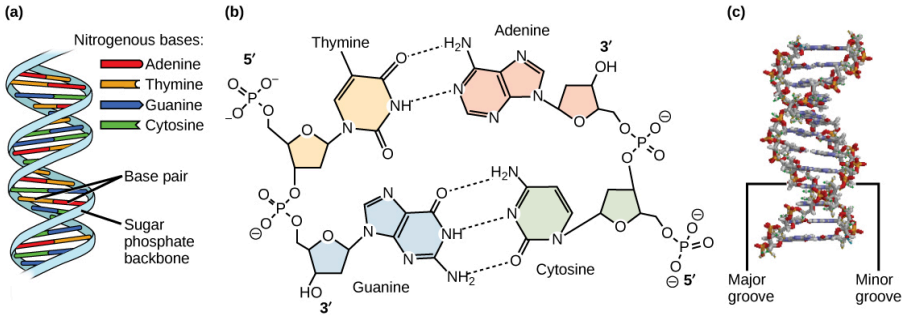
Learning Objectives

1. Recognize DNA structure and mechanisms
2. Identify four major replication enzymes and their function
3. Recognize the Central Dogma components, location and steps
4. Describe the significance of DNA mutations

DNA Structure and Function

The currently accepted model of the double-helix structure of DNA is two complementary strands in a double helix. Deoxyribose sugars and phosphates form the backbone of the structure, and the nitrogenous bases are stacked inside. A pairs with T, and G pairs with C. During cell division, each daughter cell receives a copy of the DNA by a process known as DNA replication.



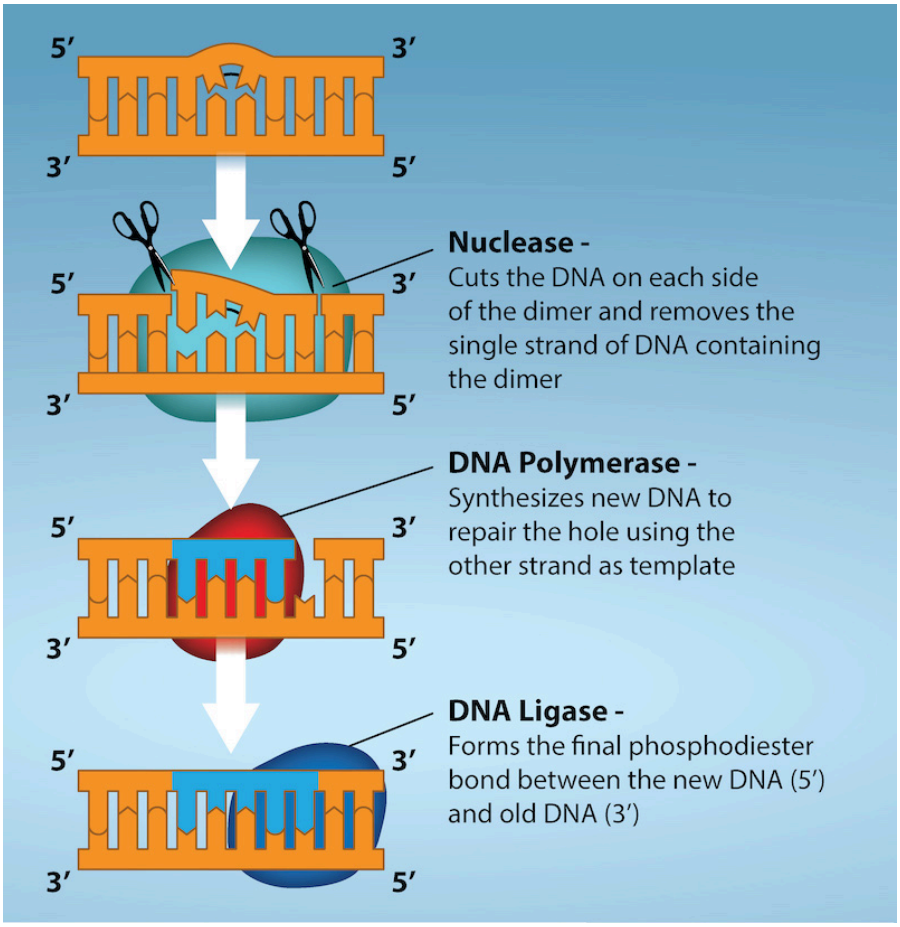
DNA has a double helix structure and phosphodiester bonds and each nucleotide contains a phosphate group, nitrogenous base and a five-carbon sugar.

The model for DNA replication suggests that the two strands of the double helix separate during replication, and each strand serves as a template from which the new complementary strand is copied. The parental DNA strand is conserved, and the daughter DNA is newly synthesized. This semi-conservative method suggests that each of the two parental DNA strands acts as template for new DNA to be synthesized. After replication, each double-stranded DNA includes one parental or “old” strand and one “new” strand.

Replication in eukaryotes occurs in the nucleus and starts at multiple origins of replication. An enzyme called helicase unwinds the DNA by breaking the hydrogen bonds between base pairs. ATP is required for this process. As the DNA opens up, replication forks are formed. A primer is required to initiate synthesis, which is then extended by DNA polymerase as it adds nucleotides one by one to the growing chain. The leading strand is synthesized continuously, whereas the lagging strand is synthesized in short stretches called Okazaki fragments. DNA remains in one continuous strand by DNA ligase linking the DNA fragments. The ends of the chromosomes pose a problem as polymerase is unable to extend them without a primer. Telomerase, an enzyme with an inbuilt RNA template, extends the ends by copying the RNA template and extending one end of the chromosome. DNA polymerase can then extend the DNA using the primer. In this way, the ends of the chromosomes are protected.

DNA polymerase can make mistakes while adding nucleotides. It edits the DNA by proofreading every newly added base. Most mistakes are corrected by proofreading. Those not corrected by proofreading may result in a mutation defined as a permanent change in the DNA sequence. Mutations can be of many types, such as substitution, deletion, insertion, and translocation. If an insertion or deletion results in the alteration of the translational reading frame (a frameshift mutation), the resultant protein is usually nonfunctional. Mutations in repair genes have been known to cause cancer. Many mutated repair genes have been implicated in certain forms of pancreatic cancer, colon cancer, and colorectal cancer. If many mutations accumulate in a somatic cell, they may lead to problems

such as the uncontrolled cell division observed in cancer. Mutations can be induced or may occur spontaneously and have the potential to be helpful or harmful.



Nucleotide excision repairs thymine dimers. When exposed to UV light, thymines lying adjacent to each other can form thymine dimers. In normal cells, they are excised and replaced. Credit: Rao, A., Fletcher, S. and Tag, A. Department of Biology, Texas A&M University.

The Central Dogma states DNA codes for RNA codes for proteins. The genetic code refers to DNA (ATCG), RNA (AUCG) and the 20 amino acids. The Central Dogma describes the flow of genetic information in the cell from DNA containing genes to mRNA to proteins. Genes are used to make mRNA by transcription. Then, mRNA is used to synthesize proteins by translation at the ribosome. Almost every species on the planet uses the same genetic code.

Transcription in eukaryotes involves mRNA and occurs in the nucleus. The players in translation include the mRNA template, ribosomes, tRNAs, and various enzymatic factors. During translation, the mRNA template provides specific information in the form of codons (sets of three bases that each code for a single amino acid). As the ribosome moves along the mRNA, each mRNA codon comes into place to bind with the appropriate tRNA for polypeptide formation. Translation begins at the initiating AUG on the mRNA, specifying the amino acid methionine. The formation of peptide bonds occurs between sequential amino acids specified by the mRNA template according to the genetic code. Charged tRNAs enter the ribosomal A site, and their amino acid bonds with the amino acid at the P site. The entire mRNA is translated in three-nucleotide "steps" at the ribosome. When a stop codon is encountered, a release factor binds and dissociates the components to free the new protein. Folding of the protein occurs during and after translation.

Key Takeaways

1. DNA has two complementary strands composed of ACTG.
2. Helicase unwinds, DNA polymerase adds nucleotides, ligase bonds the strands and telomerase protects the ends of chromosomes.
3. DNA->RNA->protein, the first arrow is transcription (occurs in nucleus) and the second is translation (occurs at ribosome).
4. Mutations can be helpful or harmful and one even nucleotide can cause them. Cancer is an accumulation of mutations.

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PART IV

MODULE 4

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Module 4

Module 4 explores the role of DNA in society, including current and future applications. This includes innovation, technology, understanding of medical implications, public health and personalized medicine. This cover page provides all Module 4 Learning Objectives, a question answered by each chapter and chapter summaries.

Module 4 is aligned with the following Course Learning Objectives:

- Examine characteristics common to life
- Identify the chemical components of life
- Relate heredity and evolution to organisms and ecosystems
- Apply scientific inquiry to predict outcomes
- Classify and compare major groups of organisms

Learning Objectives Chapter 17

How do we use DNA to determine paternity, solve crimes and test embryos?

1. Recognize the requirements for generating transgenic organisms.
2. Recognize the significance of genetically-modified organisms in society.
3. Define 7 components of biotechnology: PCR (polymerase chain reaction), stem cells, cloning, DNA sequencing, DNA probes, PGD (preimplantation genetic diagnosis) and gene therapy.

Chapter 17 Summary

Transgenic organisms, or genetically-modified organisms (GMOs), contain DNA from another species to generate proteins. Vaccines, antibiotics, and hormones are examples of products obtained by recombinant DNA technology. Scientists usually create transgenic plants to improve crop plant characteristics. GMO's provide benefits and raise concerns. Nucleic acids can be isolated from cells for the purposes of further analysis by breaking open the cells and enzymatically destroying all other major macromolecules. Fragmented or whole chromosomes can separate on the basis of size by gel electrophoresis. PCR can amplify short DNA or RNA stretches. Stem cells can generate any cell type. The term "cloning" may refer to cloning small DNA fragments (molecular cloning), cloning cell populations (cellular cloning), or cloning entire organisms (reproductive cloning). DNA sequencing reveals the order of base pairs, DNA probes bind to complementary sequences, and PGD tests IVF embryos before implantation. Medical professionals perform genetic testing to identify disease-causing genes, and use gene therapy to cure an inheritable disease.

Learning Objectives Chapter 18

Where have your chromosomes been?

1. Define evolution, selective pressure and natural selection.
2. Recognize common misconceptions about evolution.
3. Identify factors impacting speciation

Chapter 18 Summary

Evolution is a change in allele frequency in a population. Evolution may be convergent with similar traits evolving in multiple species or divergent with diverse traits evolving in multiple species that

came from a common ancestor. We can observe evidence of evolution by means of DNA code and the fossil record, and also by the existence of homologous and vestigial structures. Natural selection is the result of reproductive success. Individuals cannot evolve, only populations do. Evolution does not involve the origin of life. Evolution involves As, Cs, Ts and Gs – that cannot create, think or feel. Speciation involves a barrier to reproduction and can be based on habitat location or chromosomes.

Learning Objectives Chapter 19

What mutations are in the human population now?

1. Recognize measures of population evolution.
2. Identify four major contributors to population genetics.
3. Recognize the significance of sexual selection.

Chapter 19 Summary

Population genetics describes the evolution of populations and species, from small-scale changes among individuals to large-scale changes over paleontological time periods. To understand how organisms evolve, scientists can track allele frequencies over time within populations. Scientists use genotype (DNA) and phenotype (fossils, anatomy, embryo structure) to establish relationships. Mutations, founder effect, bottleneck, and migration contribute to population genetics. Sexual selection impacts reproductive success and genetic fitness.

When you are ready to prepare for the exam, you might find this audio study guide helpful.

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14. Chapter 17

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Learning Objectives

1. Recognize the requirements for generating transgenic organisms.
2. Recognize the significance of genetically-modified organisms in society.
3. Define 7 components of biotechnology: PCR (polymerase chain reaction), stem cells, cloning, DNA sequencing, DNA probes, PGD (preimplantation genetic diagnosis) and gene therapy.

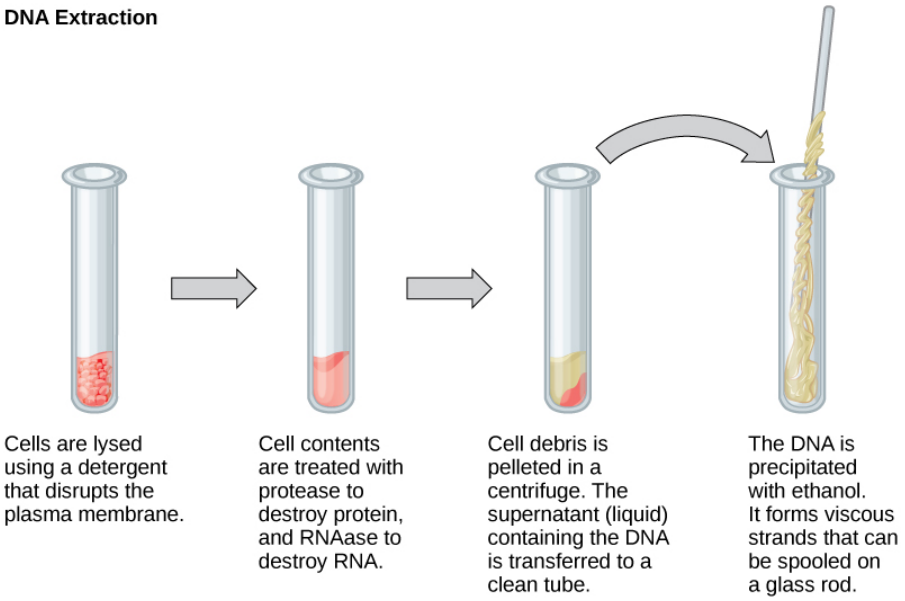
Biotechnology and Genomics

Biotechnology is the use of biological agents for technological advancement. Biotechnology was used for breeding livestock and crops long before the scientific basis of these techniques was understood. Since the discovery of the structure of DNA in 1953, the field of biotechnology has grown rapidly through both academic research and private companies. The primary applications of this technology are in medicine (production of vaccines and antibiotics) and agriculture (genetic modification of crops to increase yields). Biotechnology has many industrial applications, such as fermentation, treatment of oil spills, and production of biofuels.

Genetic engineering is the alteration of an organism's genotype using recombinant DNA technology to modify an organism's DNA to achieve desirable traits. The addition of foreign DNA in the form of recombinant DNA vectors is

the most common method of genetic engineering. The organism receiving recombinant DNA is a genetically modified organism (GMO). If the foreign DNA comes from a different species, the host organism is transgenic. Scientists have genetically modified bacteria, plants, and animals since the early 1970s. In the US, GMOs such as Roundup-ready soybeans and borer-resistant corn are part of many common processed foods.

Nucleic acids can be isolated for further analysis by breaking cells open. Fragmented or whole chromosomes can be separated on the basis of size by gel electrophoresis. Short stretches of DNA or RNA can be amplified by PCR. Use of short tandem repeats and gel electrophoresis can allow differences between individuals to be detected. Embryonic stem cells give rise to all cell types in the body. Stem cells are important tools for biological research, because of their potential to differentiate into other cell types. The term “cloning” may refer to cloning small DNA fragments (molecular cloning), cloning cell populations (cellular cloning), or cloning entire organisms (reproductive cloning).

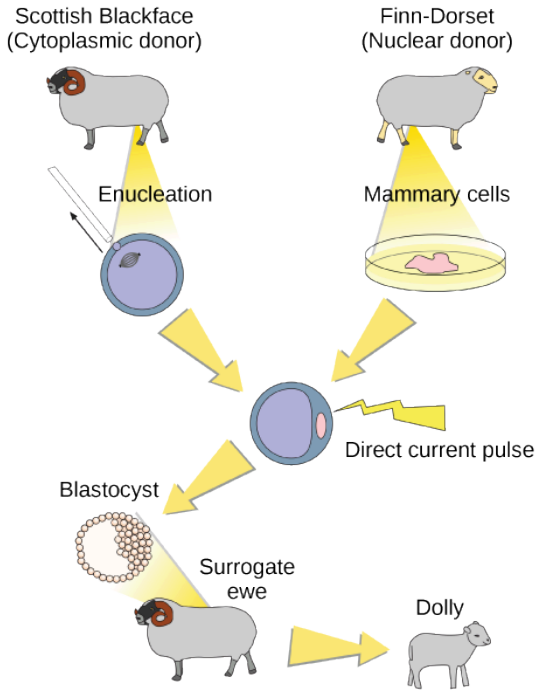


This diagram shows the basic method of DNA extraction.

DNA sequencing uses gel electrophoresis and DNA probes for medical testing. Scientists can probe nucleic acid samples, such as fragmented genomic DNA and RNA extracts, for the presence of certain sequences. Scientists design and label

short DNA fragments, or probes with radioactive or fluorescent dyes to aid detection. Gel electrophoresis separates the nucleic acid fragments according to their size. Preimplantation genetic diagnosis (PGD) uses DNA probes to reduce the odds of having a child with a genetic disease. Genetic testing is performed to identify disease-causing genes. The goal of gene therapy is to cure inheritable diseases.

The first mammal cloned was a sheep born in 1996. Dolly was a product of somatic cell nuclear transfer. This process involves removing the haploid nucleus of an egg cell and replacing it with the diploid nucleus of a donor cell. Vaccines, antibiotics, and hormones are examples of products obtained by recombinant DNA technology. Transgenic plants are usually created to improve characteristics of crop plants.



Dolly the sheep was the first mammal to be cloned. To create Dolly, they removed the nucleus from a donor egg cell. They then introduced the nucleus from a second sheep into the cell, which divided to the blastocyst stage before they implanted it in a surrogate mother. (credit: modification of work by “Squidonius”/Wikimedia Commons)

Genome mapping is similar to solving a big, complicated puzzle with pieces of information coming from laboratories all over the world. Genetic maps provide an outline for the location of genes within a genome, and they estimate the distance between genes and genetic markers on the basis of recombination frequencies during meiosis. Physical maps provide detailed information about the physical distance between the genes. The most detailed information is available through sequence mapping. Information from all mapping and sequencing sources is combined to study an entire genome.

Whole-Genome Sequencing is the latest available resource to treat genetic diseases. Some doctors are using whole-genome sequencing to save lives. Genomics has many industrial applications including biofuel development, agriculture, pharmaceuticals, and pollution control. Although the human genome sequences provide key insights to medical professionals, researchers use whole-genome sequences of model organisms to better understand the genome of the species. Automation and the decreased cost of whole-genome sequencing has led to precision medicine.

Imagination is the only barrier to the applicability of genomics. *Genomics is being used for personalized medicine to predict disease risks at an individual level and to study of drug interactions before clinical trials. Proteomics is the study of the entire set of proteins expressed by a given type of cell under certain environmental conditions. In a multicellular organism, different cell types will have different proteomes, and these will vary with changes in the environment. Unlike a genome, a proteome is dynamic and in constant flux, which makes it both more complicated and more useful than the knowledge of genomes alone. Proteomics has been used to study different types of cancer. Different biomarkers and protein signatures are being used to analyze each type of cancer. The future goal is to have a personalized treatment plan for each individual.*

Key Takeaways

1. Transgenic organisms, or genetically-modified organisms (GMOs), contain DNA from another species to generate proteins.

2. GMO's provide benefits and raise concerns.
3. PCR makes DNA copies fast, stem cells can generate any cell type, cloning generates an organism with identical genetic code, DNA sequencing reveals the order of base pairs, DNA probes bind to complementary sequences, PGD tests IVF embryos before implantation, and gene therapy has the potential to replace faulty genes.

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15. Chapter 18

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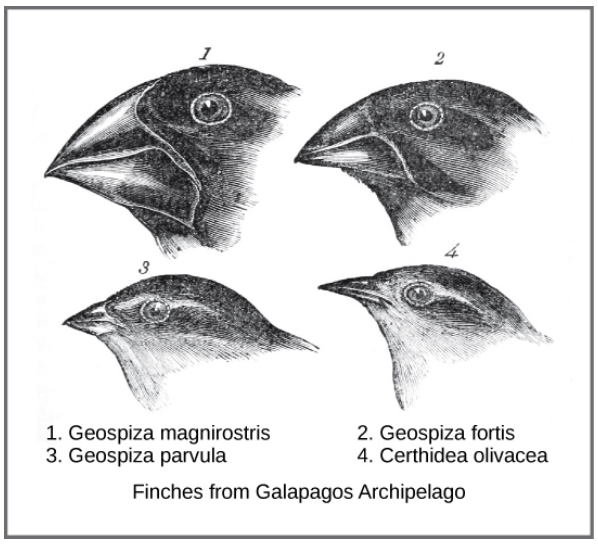
Learning Objectives

1. Define evolution, selective pressure and natural selection.
2. Recognize common misconceptions about evolution.
3. Identify factors impacting speciation.

Evolution and the Origin of Species

Evolution is a change in allele frequency in a population over time. It involves the process of adaptation through mutation allowing more desirable characteristics to appear in the next generation. Evolution occurs in populations not individuals. Darwin wrote *On the Origin of Species by Means of Natural Selection* after studying the Galapagos finches. Over time, characteristics beneficial to survival are retained through selective pressure. For living organisms to adapt and change to environmental pressures, genetic variation must be present. With genetic variation, individuals have differences in form and function that allow some to survive certain conditions better than others. This ability to survive and reproduce is referred to as genetic fitness. Organisms pass favorable adaptations to their offspring. Eventually, environments change, and what was once a desirable, advantageous trait may become an undesirable trait. This exposes populations to variations in selective pressure.



Darwin observed variety in finch beaks. He hypothesized that ancestral beaks had adapted over time for different food sources.

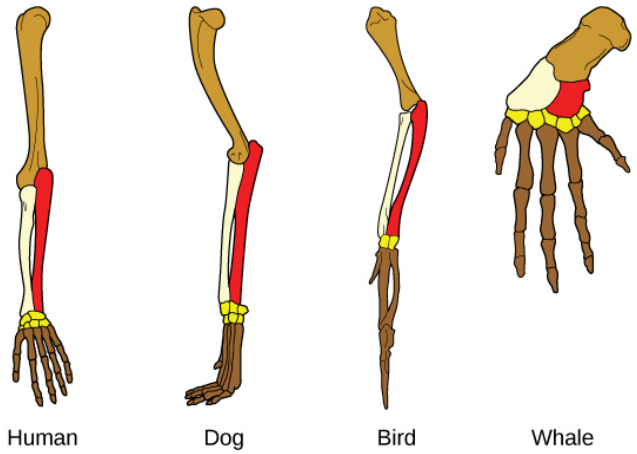
Evolution may be convergent with similar traits evolving in multiple species or divergent with diverse traits evolving in multiple species that came from a common ancestor. Unrelated animals, such as the arctic fox and grouse, living in the arctic region have been selected for seasonal white phenotypes during winter to blend with the snow and ice. These similarities occur not because of common ancestry, but because of selection pressures—the benefits of not being seen by predators. The fox and grouse are both related to populations in other geographic areas with differing coloration.

(a) (b)

The white winter coat of the (a) arctic fox and the (b) grouse plumage are adaptations to their environments. (credit a: modification of work by Keith Morehouse)

Humans can also apply selective pressure by artificial selection, or selective breeding. In artificial selection, a human chooses desired features, then allows only the individuals that best express those qualities to reproduce. This accounts for breeds of dogs, domesticated animals and specific farm crops.

A heritable trait that helps an organism survive and reproduce in its present environment is called an adaptation. The bones in the appendages of a human, dog, bird, and whale all share the same overall construction resulting from their origin in the appendages of a common ancestor. These populations have maintained the same overall appendage layout, despite changes in the shapes and sizes of specific bones in different species.



The similar construction of these appendages indicates that these organisms share a common ancestor.

These are not to be confused with structure that appear similar – like the wings of bats and bees. These structures are referred to as analogous structures, because each function for flight but the structures are not similar. Bats are mammals, and bees are insects. Some structures exist in organisms that have no apparent function at all, and appear to be residual parts from a past common ancestor. These unused structures without function are called vestigial structures. Other examples of

vestigial structures are wings on flightless birds, leaves on some cacti, and hind leg bones in whales.

Evidence of shared ancestors is found in DNA code, the fossil record, and existence of homologous and vestigial structures. Like anatomical structures, DNA reflects descent with modification. Ancestry is reflected in DNA as the genetic material across species, the genetic code, the machinery of DNA replication and protein construction. Fundamental divisions between the three domains are reflected in major structural differences in structures like ribosomes and membrane structures.

Natural selection leads to beak changes in medium-ground finch populations in the Galápagos. This does not mean individual finch beaks are changing. If one measures the average beak size among all individuals in the population at one time and then measures the average beak size in the population several years later, this average value will be different. Although some individuals may survive from the first measurement to the second, they will still have the same beak size. However, there will be many new individuals contributing to average beak size.

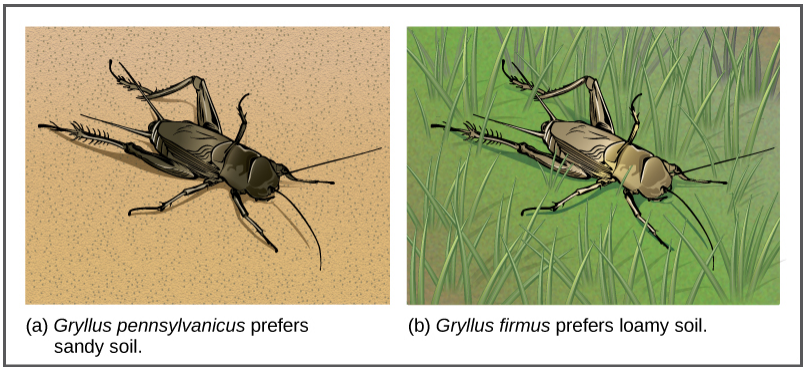
Natural selection depends on the variety of alleles already in a population and does not arise in response to an environmental change. The total set of gene copies for all genes in a population is referred to as its gene pool. For example, applying antibiotics to a population of bacteria will, over time, select a population of bacteria that resist antibiotics. The resistance, caused by a gene, did not arise by mutation because of the application of the antibiotic. The gene for resistance was already present in the gene pool of the bacteria, likely at a low frequency. The antibiotic, which kills the bacterial cells without the resistance gene, strongly selects individuals that are resistant, since these would be the only ones that survived and divided. Experiments demonstrate mutations for antibiotic resistance do not arise as a result of antibiotic. Instead, using antibiotics selects for mutants.

In a larger sense, evolution is not goal directed. Species do not become “better” over time. The changing environment maximizes reproduction in a particular environment at a particular time based on existing adaptations. Evolution has no goal of making faster, bigger, more complex, or even smarter species. A’s, C’s, T’s and G’s do not think or feel. Characteristics in any species are a function of the variation present and the environment, both of which are constantly changing in a

non-directional way. A beneficial trait in one environment at one time may well be fatal at some point in the future. This is true for any species from bacteria to human.

> Only populations evolve, not individuals. Evolution does not explain the origin of life. There is no purpose or goal of an ideal phenotype.

Speciation occurs along two main pathways: geographic separation (allopatric speciation) and through mechanisms that occur within a shared habitat (sympatric speciation). Both pathways isolate a population reproductively in some form. Mechanisms of reproductive isolation act as barriers between closely related species, enabling them to diverge and exist as genetically independent species. Prezygotic barriers block reproduction prior to formation of a zygote, whereas postzygotic barriers block reproduction after fertilization occurs. For a new species to develop, something must cause a breach in the reproductive barriers. Sympatric speciation can occur through errors in meiosis that form gametes with extra chromosomes (polyploidy).



(a) *Gryllus pennsylvanicus* prefers sandy soil.

(b) *Gryllus firmus* prefers loamy soil.

Speciation can occur when two populations occupy different habitats. The habitats need not be far apart. The cricket (a) *Gryllus pennsylvanicus* prefers sandy soil, and the cricket (b) *Gryllus firmus* prefers loamy soil. The two species can live in close proximity, but because of their different soil preferences, they became genetically isolated.

Organisms reproduce with other similar organisms. The fitness of hybrid offspring have led scientists to propose two models for the rate of speciation. One model illustrates how a species can change slowly over time, and the other model demonstrates how change can occur quickly from a parent generation to a new species. Both models continue to follow the patterns of natural selection.

Key Takeaways

1. Evolution is a change in allele frequency in a population, selective pressure can be convergent or divergent, and natural selection is the result of reproductive success.
2. Individuals cannot evolve, only populations do. Evolution does not involve the origin of life. Evolution involves As, Cs, Ts and Gs – that cannot create, think or feel.
3. Speciation involves a barrier to reproduction and can be based on habitat location or chromosomes.

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16. Chapter 19

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Learning Objectives

1. Recognize measures of population evolution.
2. Identify four major contributors to population genetics.
3. Recognize the significance of sexual selection.

The Evolution of Populations

Population genetics begins with understanding evolution and heredity. It describes the changes of populations and species, from small-scale changes among individuals to large-scale changes over paleontological time periods. Scientists can track changes in allele frequencies within populations over time.

The allele frequency within a given population can change depending on environmental factors. Some alleles become more widespread than others during the process of natural selection. Natural selection can alter the population's genetic makeup. If a genetic phenotype allows an individual to better survive or reproduce, more offspring will carry the beneficial alleles, likely display the corresponding phenotype, and have the potential for more offspring of their own that also carry the genotype to perpetuate the cycle. Over time, the allele will spread throughout the population. Some alleles will quickly become fixed in this way, meaning that every individual of the population will carry the allele, while detrimental mutations

may be swiftly eliminated if derived from a dominant allele from the gene pool. The gene pool is the sum of all the alleles in a population.

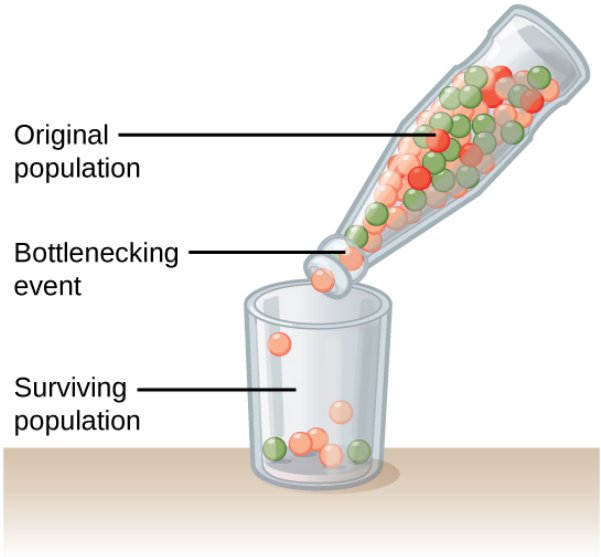
Sometimes, allele frequencies within a population change randomly with no advantage to the population over existing allele frequencies. This phenomenon is called genetic drift. Natural selection and genetic drift usually occur simultaneously in populations and are not isolated events. It is hard to determine which process dominates because it is often nearly impossible to determine the cause of change in allele frequencies at each occurrence. What ultimately interests biologists is not the frequencies of different alleles, but the frequencies of the resulting genotypes.

Both genetic and environmental factors can cause phenotypic variation in a population. Different alleles can confer different phenotypes, and different environments can also cause individuals to look or act differently. Only those differences encoded in an individual's genes can be passed to its offspring and form the basis of natural selection. Genetic drift stems from the chance occurrence that some individuals in the germ line have more offspring than others. When individuals leave or join the population, allele frequencies can change as a result of gene flow. Mutations to an individual's DNA may introduce new variation into a population. Allele frequencies can also be altered when individuals do not randomly mate with others in the group.

Mutations are changes to an organism's DNA and are an important driver of diversity in populations. Species evolve because of the accumulation of mutations that occur over time. The appearance of new mutations is the most common way to introduce novel genotypic and phenotypic variance. Some mutations are unfavorable or harmful and are quickly eliminated from the population by natural selection. Others are beneficial and will spread through the population. Whether or not a mutation is beneficial or harmful is determined by whether it helps an organism survive to sexual maturity and reproduce. Some mutations do not do anything and can linger in the genome. Some can have a dramatic effect on a genotype and resulting phenotype.

Founder effect is an event that initiates an allele frequency change in an isolated part of the population, which is not typical of the original population. Natural selection and founder effects can lead to significant changes in a population.

Genetic drift can also be magnified by natural events, like a natural disaster killing a large portion of the population randomly. The bottleneck effect results in a large portion of the genome suddenly being wiped out. In one fell swoop, the genetic structure of the survivors becomes the genetic structure of the entire population, which may be very different from the pre-disaster population.



A chance event or catastrophe can reduce the genetic variability within a population.

Another important evolutionary force is gene flow due to the migration of individuals or gametes. While some populations are fairly stable, others experience more flux. Many plants, for example, send their pollen far and wide, by wind or by bird, to pollinate other populations of the same species some distance away. Even a population appearing to be stable, like a pride of lions, can experience migration as developing males leave their mothers to seek out a new pride with genetically unrelated females. This variable flow of individuals in and out of the group changes the gene structure of the population and introduces variation to populations in different locations and habitats.

Natural selection acts to increase the frequency of beneficial alleles. Sexual selection results from one sex having more variety in reproductive success than the other. Resulting in males and females under different selective pressures and leading to phenotypic differences between the two.

Because natural selection acts to increase the frequency of beneficial alleles and traits while decreasing the frequency of deleterious qualities, it is adaptive. Natural selection acts at the level of the individual, selecting for those that have a higher overall fitness compared to the rest of the population. If the fit phenotypes are those that are similar, natural selection will result in stabilizing selection, and an overall decrease in the population's variation. Directional selection works to shift a population's variance toward a new, fit phenotype, as environmental conditions change. In contrast, diversifying selection results in increased genetic variance by selecting for two or more distinct phenotypes.

Key Takeaways

1. Scientist use genotype (DNA) and phenotype (fossils, anatomy, embryo structure) to establish relationships.
2. Mutations, founder effect, bottleneck, and migration contribute to population genetics.
3. Sexual selection impacts reproductive success and genetic fitness.

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PART V

MODULE 5

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Module 5

Module 5 involves the way organisms interact within the environment. Chapters 45-46 are covered together. The end of this module is a final exam covering all information in the course. This cover page provides Module 5 Learning Objectives, a question answered by each chapter and chapter summaries.

Module 5 is aligned with the following Course Learning Objectives:

- Relate heredity and evolution to organisms and ecosystems
- Apply scientific inquiry to predict outcomes
- Classify and compare major groups of organisms

Learning Objectives Chapter 44

What is biogeography? How does it influence life?

1. Define the study of ecology and some areas of focus within the field.
2. Recognize the role of biotic and abiotic factors in biogeography.

3. Define primary productivity in ecosystems.

Chapter 44 Summary

Ecology is the study of the way living things interact with their environment. Areas of ecology can focus on organisms, populations, communities and ecosystems. Biotic (living) and abiotic (non-living) factors play a role in biogeography. Biotic populations compete for resources, and abiotic factors of latitude and elevation play a role in resource availability. Primary productivity measures the amount of biomass produced by a biome and includes microbes.

Learning Objectives Chapter 45-46

What are cells doing in the environment?

1. Recognize the dynamic nature of populations and behaviors.
2. Identify the role of macromolecules in protocell formation and the theory of endosymbiosis.
3. Recognize the role of decomposers in ecosystems

Chapter 45-46 Summary

Populations are individuals of a species that live in a particular habitat. Both populations and habitats are dynamic, exposed to change and interrelated. Ecologists measure characteristics of populations, like size, density, dispersion pattern, age structure, and sex ratio. Life tables are useful to calculate life expectancies of individual population members. Populations are dynamic, and so are behaviors. Spontaneous lipid formation and (-) charge of nucleotides could explain developing protocells – that give rise to prokaryotes. Endosymbiosis is the theory that photosynthetic bacteria were engulfed to form chloroplasts and aerobic bacteria to form mitochondria. Bacteria and fungi are decomposers vital to ecosystems. Organisms in an ecosystem acquire energy in a variety of ways, which is transferred between trophic levels as energy flows from the bottom to the top of the food web, with energy being lost at each transfer. This involves producers, consumers and decomposers. Mineral nutrients are cycled through ecosystems and their environment. Of particular importance are water, carbon, nitrogen, phosphorus, and sulfur.

Learning Objectives Chapter 47

How does variety help populations?

1. Define biodiversity and mass extinction.
2. Recognize threats to biodiversity.
3. Identify efforts to preserving biodiversity.

Chapter 47 Summary

Biodiversity exists at multiple levels of organization and is measured in different ways depending on the scientific goals of those taking the measurements. Estimates for the total number of species on Earth vary but are on the order of 10 million. Biodiversity can be measured in species, genetic, chemical and ecosystem diversity. Mass extinction events with existing species losses >50% have been described five times in the fossil record. Threats to biodiversity include habitat loss and over harvesting. Efforts to preserve biodiversity include DNA barcoding, conservation and habitat restoration.

This is the time to prepare for a cumulative final exam covering all five modules.

17. Chapter 44

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Learning Objectives

1. Define the study of ecology and some areas of focus within the field.
2. Recognize the role of biotic and abiotic factors in biogeography.
3. Define primary productivity in ecosystems.

Ecology and the Biosphere

Ecology is the study of interactions between living organisms and their environments. One core goal of ecology is to understand the distribution and abundance of living things in the physical environment. Attainment of this goal requires the integration of scientific disciplines inside and outside of biology, such as biochemistry, physiology, biodiversity, molecular biology, geology, and climatology. Some ecological research also applies aspects of chemistry and physics, and it frequently uses mathematical models.

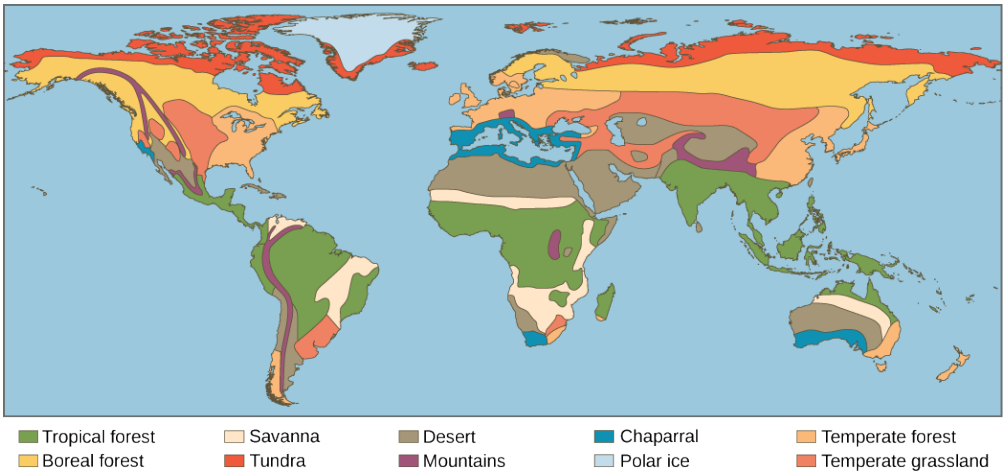
Ecologists ask questions across four levels of biological organization—organismal, population, community, and ecosystem. At the organismal level, ecologists study individual organisms and how they interact with their environments. At the population level, ecologists look at how a population of organisms changes over time. At the community level, ecologists explore the ways in which that population interacts with other species in the community. Ecologists studying an ecosystem examine the living species (the biotic components) of the ecosystem as well as

the nonliving portions (the abiotic components), such as air, water, and soil, of the environment. Study of the ecosystem includes the movement of CHONPS through the system.

Many forces influence communities of living organisms present in different parts of the biosphere (all of the parts of Earth inhabited by life). The biosphere extends into the atmosphere (several kilometers above Earth) and into the depths of the oceans.

Biogeography studies the geographic distribution of living things and abiotic factors affecting their distribution. Abiotic factors such as temperature and rainfall vary based mainly on latitude and elevation. As these abiotic factors change, the composition of plant and animal communities also changes. Endemic species are species that are naturally found only in a specific geographic area. The distribution of living things is influenced by several environmental factors impacted by the latitude or elevation at which an organism is found. Ocean upwelling and spring and fall turnovers are important processes regulating the distribution of nutrients and other abiotic factors important in aquatic ecosystems. Energy sources, temperature, water, inorganic nutrients, and soil are factors limiting the distribution of living things in terrestrial systems. Net primary productivity is a measure of the amount of biomass produced by a biome.

Earth has terrestrial biomes and aquatic biomes. *There are eight major terrestrial biomes: tropical wet forests, savannas, subtropical deserts, chaparral, temperate grasslands, temperate forests, boreal forests, and Arctic tundra. The same biome can occur in different geographic locations with similar climates. Temperature and precipitation are key abiotic factors shaping animal and plant communities in terrestrial biomes. Some biomes, such as temperate grasslands and temperate forests, have distinct seasons, with cold weather and hot weather alternating throughout the year*. In warm, moist biomes, such as the tropical wet forest, net primary productivity is high, as warm temperatures, abundant water, and a year-round growing season fuel plant growth. Other biomes, such as deserts and tundra, have low primary productivity due to extreme temperatures and a shortage of available water.



Each of the world's major biomes is distinguished by characteristic temperatures and amounts of precipitation. Polar ice and mountains are also shown.

Aquatic ecosystems include both saltwater and freshwater biomes. Abiotic factors can be different than those in terrestrial systems. Sunlight is a driving force behind the structure of forests and also is an important factor in bodies of water. Especially those that are very deep, because of the role of photosynthesis in sustaining certain organisms. Density and temperature shape the structure of aquatic systems. Oceans contain different zones based on water depth, distance from shoreline and the amount of light present.

Key Takeaways

1. Ecology studies the way living things interact with their environments. Areas of focus include organismal, population, community and ecosystem.
2. Biotic (living) and abiotic (non-living) factors play a role in biogeography. Biotic populations compete for resources, and abiotic factors of latitude and elevation play a role in resource availability.
3. Primary productivity measures the amount of biomass produced by a biome and includes bacteria.

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18. Chapter 45-46

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Learning Objectives

1. Recognize the dynamic nature of populations and behaviors.
2. Identify the theory of endosymbiosis.
3. Recognize the role of decomposers in ecosystems.

Ecology and Ecosystems

Populations are dynamic entities. Populations consist all species living within a specific area and fluctuate based on a number of factors. Seasonal and yearly changes in the environment, natural disasters like forest fires and volcanic eruptions, and competition for resources between and within species all impact populations.

Each population is composed of individuals of each species living in a particular habitat. Ecologists measure characteristics of populations: size, density, dispersion pattern, age structure, and sex ratio. Life tables are useful to calculate life expectancies of individual population members. Survivorship curves show the number of individuals surviving at each age interval plotted versus time. The world's human population is growing at an exponential rate. Humans have increased carrying capacity through migration, agriculture, medical advances, and communication. The age structure of a population allows us to predict population

growth. Unchecked human population growth could have dire long-term effects on our environment.

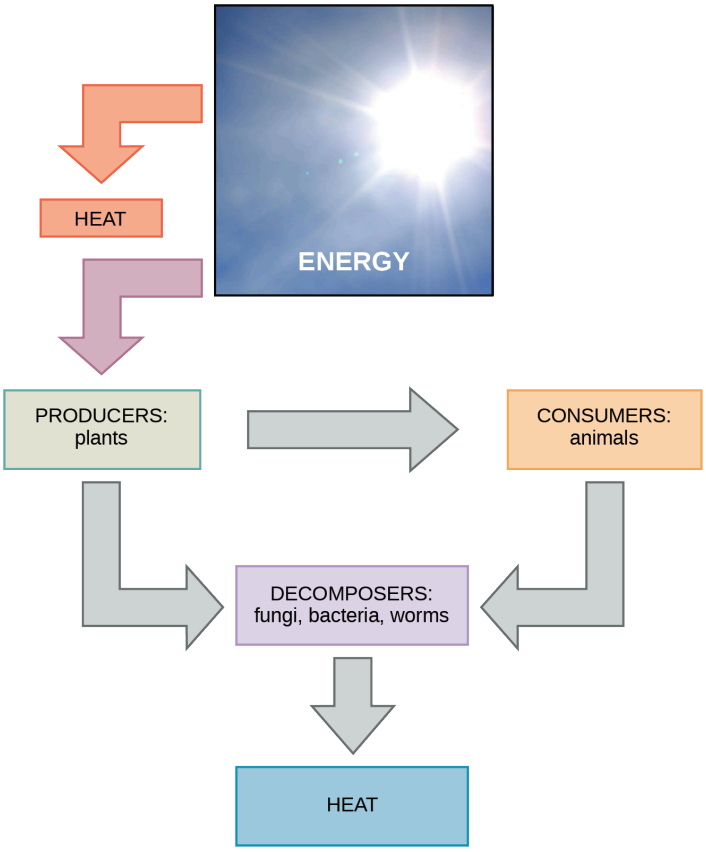
Communities include all the different species living in a given area. The variety of these species is called species richness. Many organisms have developed defenses against predation as a result of interaction with other members of the community. Species may form symbiotic relationships such as commensalism or mutualism. Communities are described by their foundation and keystone species.

Behaviors are responses to stimuli. They can be instinctual behaviors not influenced by the environment or learned behaviors, which are influenced by environmental changes. Instinctual behaviors include mating systems and methods of communication. Learned behaviors include imprinting and habituation, conditioning, and cognitive learning. Although the connection between behavior and genetics is well established, the explanation of human behavior as entirely genetic remains controversial.

The (a) Chinook salmon mates once and dies. The (b) pronghorn antelope mates during specific times of the year during its reproductive life. Primates, such as humans and (c) chimpanzees, may mate on any day, independent of ovulation. (credit a: modification of work by Roger Tabor, USFWS; credit b: modification of work by Mark Gocke, USDA; credit c: modification of work by “Shiny Things”/Flickr)

Spontaneous lipid formation and the negative charge of nucleotides could explain the development of protocells. Scientists have long noticed that bacteria, mitochondria, and chloroplasts are similar in size. Bacteria have DNA and ribosomes, just like mitochondria and chloroplasts. Endosymbiosis proposes host cells and bacteria formed an endosymbiotic relationship when host cells ingested both aerobic and autotrophic bacteria (cyanobacteria) but did not destroy them.

These ingested bacteria became more specialized in their functions, with the aerobic bacteria descending to mitochondria and autotrophic bacteria descending to chloroplasts.



Most life forms on earth obtain their energy from the sun. Plants use photosynthesis to capture sunlight, and consumers eat those plants to obtain energy. Decomposers digest plant and animal matter.

Participants in the carbon cycle are roughly divided among producers, consumers, and decomposers of organic carbon compounds. Primary producers are land plants and photosynthetic bacteria. A related source of carbon compounds is the mixture of organic materials from dead plants and prokaryotes that have resisted decomposition. Consumers use the organic compounds generated by producers and release carbon dioxide to the atmosphere. Other bacteria and fungi, collectively called *decomposers*, carry out the breakdown (decomposition) of plants and animals and their organic compounds. Most carbon dioxide in the atmosphere is derived from the respiration of microbes that decompose dead plants and animals.

Key Takeaways

1. Populations are dynamic, and so are behaviors.
2. Endosymbiosis is the theory that photosynthetic bacteria were engulfed to form chloroplasts and aerobic bacteria to form mitochondria.
3. Bacteria and fungi are decomposers and vital to ecosystems.

Biology-2e. (2018). Houston, RX: website: OpenStax Book title: Biology 2e . Access for free at https://openstax.org/books/biology-2e/pages/1-introduction

19. Chapter 47

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://open.ocolearnok.org/introductorybiology/?p=220#oembed-1

Learning Objectives

1. Define biodiversity and mass extinction.
2. Recognize threats to biodiversity.
3. Identify efforts to preserving biodiversity.

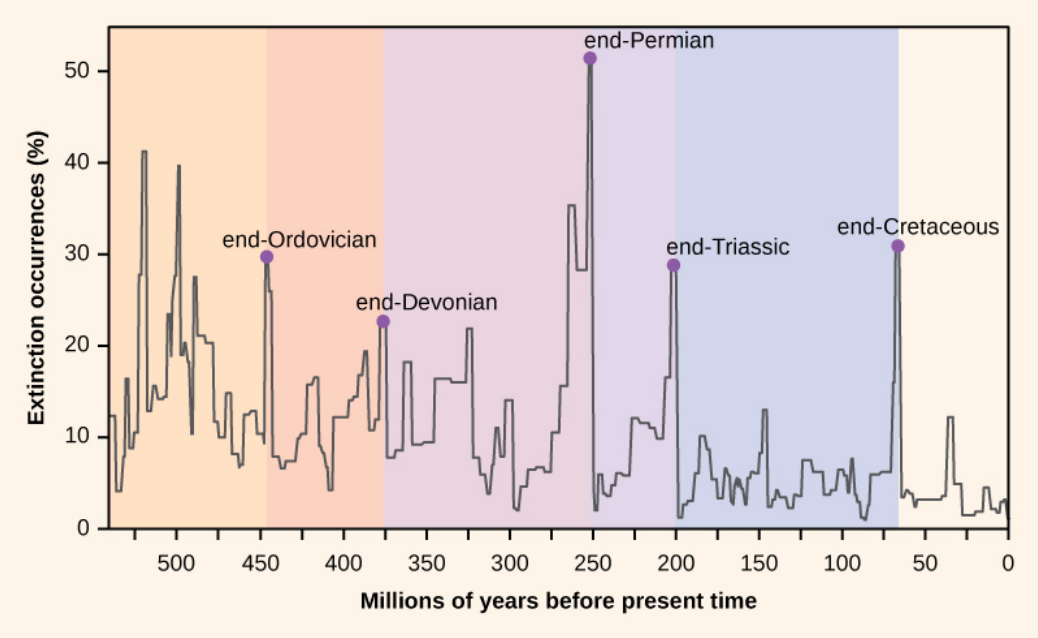
Conservation Biology and Biodiversity

In many ecosystems, the bottom of the food chain consists of photosynthetic organisms (plants and phytoplankton), called primary producers. The organisms that consume the primary producers are plant eaters, the primary consumers. Secondary consumers are usually carnivores that eat primary consumers. Tertiary consumers are carnivores that eat other carnivores. Higher-level consumers feed on the next lower tropic levels, up to the organisms at the top of the food chain — the apex consumers. Remember, decomposers support the energy cycle by converting dead plants and animals into the elements that participate in the ecosystem again.

Biodiversity exists at multiple levels of organization and is measured in different ways depending on the goals of those taking the measurements. These measurements include numbers of species, genetic diversity, chemical diversity, and ecosystem diversity. Estimates for the total number of species on Earth vary but are on the order of 10 million. Biodiversity is negatively correlated with latitude,

meaning that biodiversity is higher in the tropics. The mechanism for this pattern is not known with certainty, but several plausible hypotheses have been advanced.

Five mass extinctions with losses of more than 50 percent of extant species are observable in the fossil record. Biodiversity recovery times after mass extinctions vary, but have been up to 30 million years. Recent extinctions are recorded in written history and are the basis for one method of estimating contemporary extinction rates. The other method uses measures of habitat loss and species-area relationships. Estimates of contemporary extinction rates vary, but some rates are as high as 500 times the background rate, as determined from the fossil record, and are predicted to rise.



Percent extinction occurrences as reflected in the fossil record have fluctuated throughout Earth's history. Sudden and dramatic losses of biodiversity, called *mass extinctions*, have occurred five times.

Humans use many compounds that were first discovered or derived from living organisms as medicines: secondary plant compounds, animal toxins, and antibiotics produced by bacteria and fungi. More medicines are expected to be discovered in nature. Loss of biodiversity will impact the number of pharmaceuticals available to humans.

Catharanthus roseus, the Madagascar periwinkle, has various medicinal properties. Among other uses, it is a source of vincristine, a drug used in the treatment of lymphomas. (credit: Forest and Kim Starr)

Crop diversity is a requirement for food security, and it is being lost. The loss of wild relatives to crops also threatens ability of breeders to generate new varieties. Ecosystems support human agriculture through pollination, nutrient cycling, pest control, soil development and soil maintenance. Loss of biodiversity threatens these supports and risks making food production more expensive or impossible. Wild food sources are mainly aquatic, but few are being managed for sustainability. Fisheries' ability to provide protein to human populations is threatened when extinction occurs.

Biodiversity may provide important psychological benefits to humans. Additionally, there are moral arguments for the maintenance of biodiversity. The core threats to biodiversity are human population growth and unsustainable resource use. To date, the most significant causes of extinctions are habitat loss, introduction of exotic species, and overharvesting. Climate change is predicted to be a significant cause of extinctions in the coming century. Habitat loss occurs through deforestation, damming of rivers, and other activities. Overharvesting is a threat particularly to aquatic species, while the taking of bush meat in the humid tropics threatens many species in Asia, Africa, and the Americas. Exotic species have been the cause of a number of extinctions and are especially damaging to islands and lakes. Introduction of exotic species increase with increased human mobility and growing global trade. Climate change is forcing range changes that may lead

to extinction. It is also impacting resource availability negatively in seasonal environments. Climate changes are greatest in the arctic. Global warming will also raise sea levels, eliminating some islands and reducing the area of all others.

New technological methods such as DNA barcoding and information processing are facilitating our catalog of biodiversity. There is also a legislative framework for biodiversity protection. International treaties such as CITES regulate the transportation of endangered species across international borders. Legislation within individual countries protecting species and agreements on global warming have had limited success. In the US, the Endangered Species Act protects listed species but is hampered by procedural difficulties and a focus on individual species. The Migratory Bird Act is an agreement between Canada and the United States to protect migratory birds. The non-profit sector is also very active in conservation efforts in a variety of ways.

Conservation preserves are a major tool in biodiversity protection. Presently, 11% of Earth's land surface is protected in some way. The science of island biogeography has informed optimal design of preserves. Climate change will limit the effectiveness of preserves in the future. A downside of preserves is that they may lessen the pressure on human societies to function more sustainably outside the preserves.

Habitat restoration has the potential to restore ecosystems to previous biodiversity levels before species become extinct. Examples of restoration include reintroduction of keystone species and removal of dams on rivers. Zoos have attempted to take a more active role in conservation and can have a limited role in captive breeding programs.

Key Takeaways

1. Biodiversity can be measured in species, genetic, chemical and ecosystem diversity. Mass extinction events with losses >50% have been described five times in the fossil record.
2. Threats to biodiversity include habitat loss and overharvesting.
3. Efforts to preserve biodiversity include DNA barcoding, conservation and habitat restoration.

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PART VI

ANCILLARY MATERIALS

20. Presentation Information

The Behavioral Risk Factor Surveillance System (BRFSS) is the nation's premier system of health-related telephone surveys collecting US data regarding health-related risk behaviors, chronic health conditions, and use of preventive services. BRFSS completes more than 400,000 adult interviews each year, making it the largest continuously conducted health survey system in the world.

PLACES provides access to this health data for small areas across the country. This allows local health departments and jurisdictions, regardless of population size and rurality, to better understand the burden and geographic distribution of health measures in their areas and assist them in planning public health interventions.

Public health data is important to all of us as members of a community. It is vital to our current health care system and initiatives. This data is free and available to anyone. We will begin exploring the data in a lab assignment that generates a proposal for presentations.

Data, template, and example are accessibly linked within this page. Consider the following topic prompts when generating your proposal.

1. Do counties reporting higher percentages of adult smokers also have higher rates of COPD according to the dataset?
2. Do counties reporting higher percentages of adults sleeping less than 7 hours a night also reported more adults with high blood pressure?
3. Do counties reporting the higher percentages of high cholesterol also report more strokes?
4. Do counties with higher obesity rates report more diabetes?
5. Do counties reporting lack of physical activity also report more days of mental health not good in the past thirty days?

The presentation rubric is visible in this linked template (TCC Presentation Template). You are welcome to express your creativity with the format and add more slides. The template provides the minimum number of slides with titles and descriptions. Details for what should appear in each section are visible in the template as italicized instructions. If you would like to see an example presentation, click here.

Colleague collaborators can find all assignment information linked here (UR PROJECT).

21. Metacognition

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://open.ocolearnok.org/introductorybiology/?p=325#oembed-1

One primary goal of this course is to help support your understanding of how you learn. This will require goal setting, developing a plan and evaluation of progress. We have structured activities in our course for this purpose. My hope is that you will find ways to learn more effectively and optimize your study habits. Motivation and insight will be tools to drive the process.

Cognitively-active learning behaviors will help you in this course and those that follow. Our exams contain application questions, which are not identical to those in assignments. This requires understanding of vocabulary and applying it in sentences you have not previously seen. The chart below is from a referenced, peer-reviewed journal article of survey responses from college biology students about their own behaviors.

Cognitively passive learning behaviors	Cognitively active learning behaviors
I previewed the reading before class.	I asked myself: “How does it work?” and “Why does it work this way?”
I came to class.	I drew my own flowcharts or diagrams.
I read the assigned text.	I broke down complex processes step-by-step.
I reviewed my class notes.	I wrote my own study questions.
I rewrote my notes.	I reorganized the class information.
I made index cards.	I compared and contrasted.
I highlighted the text.	I fit all the facts into a bigger picture.
I looked up information.	I tried to figure out the answer before looking it up.
I asked a classmate or tutor to explain the material to me.	I closed my notes and tested how much I remembered.
	I asked myself: “How are individual steps connected?” and “Why are they connected?”
	I drew and labeled diagrams from memory and figured out missing pieces.
	I asked myself: “How does this impact my life?” and “What does it tell me about my body?”

References

Sebesta, A. J., & Bray Speth, E. (2017). How Should I Study for the Exam? Self-Regulated Learning Strategies and Achievement in Introductory Biology. CBE life sciences education, 16(2), ar30. https://doi.org/10.1187/cbe.16-09-0269

Stanger-Hall K. F. (2012). Multiple-choice exams: an obstacle for higher-level thinkinginintroductory science classes. CBE life sciences education, 11(3),294–306. https://doi.org/10.1187/cbe.11-11-0100

This is where you can add appendices or other back matter.