Chapter 1 The Science of Biology
Summary

1–1 What Is Science?

The goal of science is to investigate and understand the natural world, to explain events in the natural world, and to use those explanations to make useful predictions.

Science is different from other human works:

- Science deals only with the natural world.
- Scientists collect and organize information in a careful, orderly way. They look for patterns and connections among events.
- Scientists propose explanations that can be tested by looking carefully at evidence. So, science is defined as an organized way of using evidence to learn about the natural world. Work in science usually follows a path that includes these steps:

    1. Make observations using the senses. The information gathered is called data. Scientists use data to make inferences. An inference is a logical explanation based on knowledge or experience.
    2. Suggest one or more hypotheses. A hypothesis is a likely explanation for a set of observations. Scientists form hypotheses using knowledge, inference, and informed imagination.
    3. Test the hypothesis. Some hypotheses are tested by doing controlled experiments. Others are tested by gathering more data.
    4. Draw valid conclusions from the data. To be valid, a conclusion must be based on logical analysis of reliable data.

1–2 How Scientists Work

A scientific investigation has several steps. These include:

- asking a question
- forming a hypothesis
- setting up a controlled experiment
- recording and analyzing results
- drawing a conclusion

Whenever possible, a hypothesis should be tested by an experiment in which only one variable is changed at a time. All other variables should be kept unchanged, or controlled. This type of experiment is called a controlled experiment.

- The variable that is changed is called the manipulated variable.
- A variable that changes in response to the manipulated variable is called the responding variable. A key idea in science is that experimental results can be repeated. As evidence from many studies builds up, a hypothesis may be so well supported that scientists regard it as a theory. In science, the word theory applies to a well-tested explanation that unifies a broad range of observations. Scientists use theories to predict what will happen in new situations.

1–3 Studying Life

Although all living things may look different, they all have certain things in common. All living things share the following characteristics:

1. Living things are made up of cells. A cell is living matter enclosed in a barrier. The barrier separates the cell from its surroundings. A cell is the smallest unit of an organism that can be thought of as alive.
2. Living things reproduce and produce new offspring. In sexual reproduction, two cells from different parents join to form the first cell of the new organism. In asexual reproduction, a unicellular organism divides and forms two new organisms.
3. Living things are based on a universal genetic code. The directions for inheritance are carried by a molecule called DNA.
4. Living things grow and develop. All living things grow. Many multicellular organisms go through a process called development in which cells divide and change in shape and structure.
5. Living things obtain and use materials and energy. Living things use energy and materials to stay alive, grow, develop, and reproduce. Metabolism is all the chemical reactions by which an organism builds up or breaks down materials as it carries out its life processes.
6. Living things respond to their environment. A stimulus is a signal to which an organism responds. Organisms detect and respond to stimuli from their environment.
7. Living things maintain a stable internal environment. The process by which they do this is called homeostasis.
8. Taken as a group, living things change over time. Evolution is change over time in living things.

Scientists study life at different levels. These levels include molecules, cells, organisms, populations of a single kind of organism, communities of different organisms in an area, and the biosphere. At all these levels, smaller living systems are found within larger systems.

1–4 Tools and Procedures

Most scientists use the metric system when collecting data and performing experiments. The metric system is a decimal system of measurement. Its units are based on standards and are scaled on multiples of 10.

A microscope is a device that forms a magnified image of structures too small to see with the unaided eye. Light microscopes and electron microscopes are two kinds of microscopes.

- Light microscopes produce magnified images by focusing visible light rays. A compound light microscope uses two lenses to form an image as they allow light to pass through the specimen. Most school microscopes are compound light microscopes.
- Electron microscopes produce magnified images by focusing beams of electrons. These microscopes produce more detailed images than light microscopes. There are two types of electron microscopes—scanning electron microscopes (SEMs) and transmission electron microscopes (TEMs). Scanning electron microscopes scan a narrow beam of electrons back and forth across the surface of an object. SEMs produce images of the surfaces of objects. Transmission electron microscopes shine a beam of electrons through a thin specimen. TEMs can be used to see structures inside cells.

Safety rules are important in the biology laboratory. The most important safety rule is simple: Always follow your teacher's instructions and the textbook directions exactly. It's also important to thoroughly wash your hands after every scientific activity.

Chapter 2 The Chemistry of Life

Summary

2–1 The Nature of Matter

The atom is the basic unit of matter. The particles that make up atoms are protons, neutrons, and electrons.

- Protons and neutrons form the nucleus, or center of the atom. Protons are positively (+) charged. Neutrons have no charge. Protons and neutrons have about the same mass.
- Electrons are negatively (-) charged particles.

Atoms have equal numbers of electrons and protons. For this reason, atoms do not have a charge. A chemical element is a pure substance made up of only one type of atom. An element's atomic number is the number of protons in one atom of an element. Atoms of the same element can have different numbers of neutrons. These are called isotopes. All the isotopes of an element have the same number of protons and electrons. Because they have the same number of electrons, all isotopes of an element have the same chemical properties. A chemical compound is a substance formed by the joining of two or more elements in definite proportions. Chemical bonds hold the atoms in compounds together. The main types of chemical bonds are ionic bonds and covalent bonds.

- An ionic bond forms when one or more electrons are transferred from one atom to another.
- A covalent bond forms when electrons are shared between atoms. Atoms joined together by covalent bonds form molecules. A molecule is the smallest unit of most compounds.

2–2 Properties of Water

Water molecules (H_2O) are neutral. Yet, the oxygen end of a water molecule has a slight positive charge. The hydrogen end has a slight negative charge. A molecule in which there is an uneven distribution of charges between atoms is called a polar molecule.

A water molecule is polar.

Polar molecules can attract one another. A hydrogen bond forms from the attraction between the hydrogen atom on one water molecule and the oxygen atom on another. Cohesion is an attraction between molecules of the same substance. Adhesion is an attraction between molecules of different substances.

A mixture is formed by two or more elements or compounds that are physically mixed together but not chemically joined. Salt and pepper stirred together are a mixture. Two types of mixtures that can be made with water are solutions and suspensions.

- In a solution, all the components are evenly spread out. The substance dissolved in a solution is the solute. The substance in which the solute dissolves is the solvent. For example, in a salt-water solution, the salt is the solute and the water is the solvent.

- Mixtures of water and undissolved materials are suspensions. For example, if you mix sand and water, the water will become cloudy. However, once you stop mixing, the sand particles will filter out and settle to the bottom. This is an example of a suspension. A water molecule (H_2O) can form a hydrogen ion (H^+) and a hydroxide ion (OH^-). Chemists often measure the concentration of hydrogen ions. The pH scale indicates the concentration of H^+ ions in a solution. The pH scale ranges from 0 to 14.

- Pure water has a pH of 7.
- An acid forms H^+ ions in solution. Acidic solutions have higher concentrations of H^+ ions than pure water. They have pH values below 7.
- A base forms OH^- ions in solution. Basic, or alkaline, solutions have lower concentrations of H^+ ions than pure water. They have pH values above 7.

2–3 Carbon Compounds

Organic chemistry is the study of compounds with bonds between carbon atoms. Carbon compounds also are known as organic compounds. Many molecules in living things are very large. Very large molecules are called macromolecules. Macromolecules form through polymerization. In this process, smaller units, called monomers, join to form macromolecules, called polymers.

Four groups of organic compounds found in living things are carbohydrates, lipids, nucleic acids, and proteins.

Carbohydrates (starches and sugars) are compounds of carbon, hydrogen, and oxygen. Living things use carbohydrates as their main energy source. Plants and some animals also use carbohydrates for structural purposes. Simple sugars are called monosaccharides. When two or more monosaccharides join, they are called polysaccharides.

Lipids (fats, oils, and waxes) are made mostly of carbon and hydrogen. Lipid molecules are made up of compounds of fatty acids and glycerol.

In the body, lipids are used to:

- store energy
- form parts of membranes
- form waterproof coverings

Nucleic acids contain hydrogen, oxygen, nitrogen, carbon, and phosphorus. Nucleic acids store and transmit hereditary, or genetic, information. There are two kinds of nucleic acids:
DNA and RNA.

Proteins are made of nitrogen, carbon, hydrogen, and oxygen. Proteins are polymers of amino acids. Proteins are used to:

- control the rate of reactions
- regulate cell processes
- help form bones and muscles
- carry substances into or out of cells
- help fight disease

2–4 Chemical Reactions and Enzymes

Everything that happens in an organism is based on chemical reactions. A chemical reaction is a process that changes one set of chemicals into another set of chemicals. The elements or compounds that enter into the reaction are the reactants. The elements or compounds produced by the reaction are known as products.

Chemical reactions always involve breaking the bonds in reactants and forming new bonds in products.

Some chemical reactions release energy; others absorb energy. Chemical reactions that release energy often occur spontaneously. Chemical reactions that absorb energy require a source of energy. Every chemical reaction needs energy to get started. The energy that starts a chemical reaction is called activation energy.

Some chemical reactions that make life possible are too slow. A catalyst is a substance that speeds up the rate of a chemical reaction. Catalysts work by lowering a reaction's activation energy.

Enzymes are proteins that act as biological catalysts. Enzymes speed up chemical reactions that take place in cells. In an enzyme-catalyzed reaction, the reactants are known as substrates. Substrates bind to a site on the enzyme called an active site. The fit of substrates binding to an active site is so specific that they are often compared to a lock and key. Substrates remain bound to the enzyme until the reaction is done. Once the reaction is over, the products are released.

Chapter 7 Cell Structure and Function
Summary

7–1 Life Is Cellular

Since the 1600s, scientists have made many discoveries about the cells of living things. These discoveries are summarized in the cell theory. The cell theory states:

- All living things are made up of cells.
- Cells are the basic units of structure and function in living things.
- New cells are produced from existing cells. All cells share two characteristics:
  - a barrier called a cell membrane that surrounds the cell,
  - and at some point in their lives they contain DNA. DNA is the molecule that carries biological information.

Cells fall into two broad groups, based on whether they have a nucleus. A nucleus is a membrane-enclosed structure that holds the cell's genetic material (DNA). The nucleus controls many of the cell's activities.

- Prokaryotes do not have nuclei. They have genetic material that is not contained in a nucleus. Bacteria are prokaryotes.
- Eukaryotes are cells that have nuclei. Eukaryotes have a nucleus in which their genetic material is separated from the rest of the cell. Plants, animals, fungi, and protists are eukaryotes.

7–2 Eukaryotic Cell Structure

Cell biologists divide the eukaryotic cell into two main parts: the nucleus and the cytoplasm. The cytoplasm is the part of the cell outside the nucleus.

In the Nucleus

The nucleus contains most of a cell's DNA. The DNA contains the coded instructions for making proteins and other important molecules.

- The nucleus is surrounded by a double membrane called a nuclear envelope.
- Inside the nucleus is granular material called chromatin. Chromatin is made up of DNA bound to proteins. When the cell divides, this chromatin condenses into chromosomes. Chromosomes are threadlike structures. They contain the genetic information that is passed from one generation of cells to the next.
- Most nuclei also have a small, dense region known as the nucleolus where the assembly of ribosomes begins.

In the Cytoplasm
Eukaryotic cells have structures called organelles within the cytoplasm.

- Ribosomes are small particles of RNA and protein spread throughout the cytoplasm. Proteins are made on ribosomes.
- The endoplasmic reticulum (ER) is an internal membrane system. The ER is where lipid components of the cell membrane are assembled, along with proteins and other materials that are exported from the cell. The part of the ER involved in the protein synthesis is called rough ER. Rough ER has ribosomes on its surface. Smooth ER does not have ribosomes on its surface. Smooth ER helps make lipids.
- Golgi apparatus appear as closely grouped membranes. The job of the Golgi apparatus is to change, sort, and package proteins and other materials from the ER for storage in the cell or secretion outside the cell.
- Lysosomes are small organelles filled with enzymes. Lysosomes help break down lipids, carbohydrates and proteins into small molecules that can be used by the rest of the cell.
- Vacuoles are saclike structures that are used to store materials.
- Almost all eukaryotic cells contain mitochondria. Mitochondria convert the chemical energy stored in food into compounds that are more convenient for the cell to use.
- Plants and some other organisms contain chloroplasts. Chloroplasts capture the energy in sunlight and convert it into chemical energy.
- The structure that helps support the cell is called the cytoskeleton. The cytoskeleton is a network of protein filaments that helps the cell maintain its shape. The cytoskeleton is also involved in movement.

7–3 Cell Boundaries

A thin, flexible barrier known as the cell membrane surrounds all cells. The makeup of most cell membranes is a double-layered sheet called a lipid bilayer. The cell membrane

- controls what enters and leaves the cell, and
- protects and supports the cell. Cells of plants, algae, fungi, and many prokaryotes also have a strong supporting layer called a cell wall surrounding the cell membrane. The main job of the cell wall is to support and protect the cell.

One of the most important functions of the cell membrane is to control the movement of dissolved molecules from the liquid on one side of the membrane to the liquid on the other side.

The cytoplasm of a cell is a solution of many substances in water. Particles in a solution move constantly. Particles tend to move from an area where they are more concentrated to an area where they are less concentrated. This process is called diffusion. Diffusion does not require energy.

- Water passes easily across most membranes. Osmosis is the diffusion of water through a selectively permeable membrane. A selectively permeable membrane is a membrane that some substances can pass through, while others cannot.
- Many cell membranes have protein channels that let certain molecules cross the membranes. These protein channels facilitate, or help, the diffusion of the molecules across the membrane. This process is called facilitated diffusion. It does not require the cell to use energy. Active transport requires energy. Active transport occurs when cells move materials from one side of a membrane to the other side against the concentration difference. Four types of active transport are:

- endocytosis: the process of taking material into the cell by means of infolding of the cell membrane
- phagocytosis: the extension of cytoplasm to surround a particle and package it within a food vacuole
- pinocytosis: the taking up of liquids from the environment
- exocytosis: the release of materials from the cell

7–4 The Diversity of Cellular Life

A unicellular organism is made up of only one cell. Unicellular organisms carry out all the essential functions of life. Multicellular organisms are made up of many cells. Cells throughout an organism can develop in different ways to perform different tasks. This process is called cell specialization.

Multicellular organisms have several levels of organization.

- Individual cells are the first level.
- Similar cells form units called tissues. A tissue is a group of cells that carry out a particular function.
- Groups of tissues that work together form an organ.
- A group of organs that work together to perform a specific function is an organ system.

Chapter 8 Photosynthesis

Summary

8–1 Energy and Life

Plants and some other living things can use light energy from the sun to make food. These organisms are called autotrophs. Many organisms cannot use the sun’s energy directly. These organisms, called heterotrophs, get energy from their food.

Adenosine triphosphate, or ATP, is a compound cells use to store and release energy. ATP is the basic energy source of all cells. Cells use energy from ATP to carry out many activities. These include active transport, synthesis of proteins and nucleic acids, and responses to chemical signals at the cell surface. ATP is made up of adenine, a 5-carbon sugar called ribose, and three phosphate groups.

Adenosine diphosphate (ADP) is a compound similar to ATP. Unlike ATP, ADP has only two phosphate groups. When energy is available, a cell can store small amounts of energy by adding a phosphate group to ADP to form ATP (ADP + P → ATP). Energy stored in ATP is released by breaking the bond between the second and third phosphate groups (ATP → ADP + P).

8–2 Photosynthesis: An Overview

Research into photosynthesis began centuries ago. The experiments of van Helmont, Priestly, and Ingenhousz led to work by other scientists. These scientists found that in the presence of light, plants change carbon dioxide and water into carbohydrates and give off oxygen. This process is called photosynthesis.

The overall equation for photosynthesis is:

$$\text{light} + 6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

(light plus carbon dioxide plus water produces sugar and oxygen)

Photosynthesis uses the energy of sunlight to convert water and carbon dioxide into high-energy sugars and oxygen. Plants get the carbon dioxide needed for photosynthesis from the air or from the water in which they grow. Plants use the sugars produced during photosynthesis to make complex carbohydrates such as starches.

Photosynthesis also requires light and chlorophyll. Plants gather the sun's energy with light-absorbing molecules called pigments. The main pigment in plants is chlorophyll. A compound that absorbs light also absorbs the light's energy. When chlorophyll absorbs sunlight, much of the light energy is sent directly to electrons in the chlorophyll molecules. This raises the energy levels of the electrons.

The visible spectrum is made up of wavelengths of light you can see. This spectrum contains all the colors. Chlorophyll absorbs light in the blue-violet and red regions of the visible spectrum well. Chlorophyll does not absorb light in the green region well. Plants look green because their leaves reflect this green light.

8–3 The Reactions of Photosynthesis

In plants and other photosynthetic prokaryotes, photosynthesis takes place inside the chloroplasts. Chloroplasts have saclike photosynthetic membranes called thylakoids. Proteins in the thylakoid membrane organize chlorophyll and other pigments into clusters known as photosystems. The photosystems are the light-collecting units of chlorophyll.

When sunlight excites electrons in chlorophyll, the electrons gain energy. The electron transfers its energy to another molecule. The energy continues to move from molecule to molecule until it gets to the end of the chain.

The reactions of photosynthesis occur in two parts: light-dependent reactions and light-independent reactions.

1. The light-dependent reactions produce oxygen gas and convert ADP and $NADP^+$ into ATP and NADPH. These reactions need light and they occur in the thylakoid membranes. The light-dependent reactions can be divided into four processes: light absorption, oxygen production, electron transport, and ATP formation. The light-dependent reactions use water, ADP, and $NADP^+$. They produce oxygen, ATP, and NADPH.
2. The light-independent reactions are also called the Calvin cycle. These reactions do not need light. The Calvin cycle uses ATP and NADPH from the light-dependent reactions to produce high-energy sugars. The Calvin cycle takes place in the stroma of chloroplasts. The Calvin cycle uses carbon dioxide in its reactions. As photosynthesis proceeds, the Calvin cycle works steadily to remove carbon dioxide from the atmosphere and turn out energy-rich sugars. Six carbon dioxide molecules are needed to make a single 6-carbon sugar. Many factors affect the rate of photosynthesis. Such factors include water availability, temperature, and the intensity of light.

Chapter 10 Cell Growth and Division

Summary

10–1 Cell Growth

In most cases, living things grow by producing more cells. There are two main reasons why cells divide:

1. The larger a cell gets, the more demands it places on its DNA.
2. As a cell gets larger, it has more trouble moving enough nutrients (food) and wastes across its cell membrane. The rates at which materials move through the cell membrane depend on the cell's surface area—the total area of its cell membrane. However, the rate at which food and oxygen are used up and waste products are formed depends on the cell's volume. As a cell grows, its volume increases faster than its surface area. That is, as a cell becomes larger, its ratio of surface area to volume decreases. Before a cell gets too large, it divides, forming two "daughter" cells. Cell division is the process by which a cell divides into two new daughter cells.

10–2 Cell Division

A cell must copy its genetic information before cell division begins. Each daughter cell then gets a complete copy of that information.

- In most prokaryotes, the rest of cell division is a simple matter of separating the contents of the cell into two parts.
- In eukaryotes, cell division occurs in two main stages, mitosis and cytokinesis. Mitosis is the division of the nucleus. Cytokinesis is the division of the cytoplasm. The cell cycle is a series of events cells go through as they grow and divide. During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells. Each daughter cell then begins the cycle again.

The phases of the cell cycle include interphase and cell division.

- Interphase is divided into three phases: G1, S, and G2.

  During the G1 phase, cells increase in size and make new proteins and organelles.
  In the S phase, replication (copying) of chromosomes takes place.
  During the G2 phase, many of the organelles and molecules needed for cell division are produced.

•The M phase, or cell division includes mitosis and cytokinesis.

Biologists divide the events of mitosis into four phases: prophase, metaphase, anaphase, and telophase.

1. Prophase. During prophase, the chromosomes condense and become visible. There are two tiny structures located in the cytoplasm near the nuclear envelope. These structures are called centrioles. The centrioles separate and move to opposite sides of the nucleus. The spindle is a structure that helps move chromosomes apart. During prophase, the chromosomes attach to fibers in the spindle. At the end of prophase, the nuclear envelope breaks down.
2. Metaphase. During metaphase, chromosomes line up across the center of the cell. The centromere of each chromosome attaches to the spindle.
3. Anaphase. During anaphase, the centromeres joining the sister chromatids split. The sister chromotids become individual chromosomes. The two sets of chromosomes move apart.
4. Telophase. During telophase, the chromosomes move to opposite ends of the cell. They lose their distinct shapes. Two new nuclear envelopes form. Cytokinesis usually occurs at the same time as telophase. In most animal cells, the cell membrane pinches the cytoplasm into two nearly equal parts. In plant cells, a cell plate forms midway between the divided nuclei. A cell wall then begins to form in the cell plate.

10–3 Regulating the Cell Cycle

In a multicellular organism, cell growth and cell division are carefully controlled. For instance, when an injury such as a cut in the skin occurs, cells at the edge of the cut divide rapidly. When the healing process is nearly complete, the rate of cell division slows and then returns to normal.

Cyclins—a group of proteins—regulate the timing of the cell cycle in eukaryotic cells. Cyclins are one group of proteins involved in cell cycle regulation. Other proteins, called regulatory proteins, regulate the cell cycle in different ways.

Controls on cell growth can be turned on and off by the body. Cancer is a disorder in which some of the body's cells lose the ability to control growth. Cancer cells do not respond to the signals that control the growth of most cells. As a result, cancer cells divide uncontrollably. Cancer cells do not stop growing when they touch other cells. Instead, they continue to grow and divide until their supply of nutrients is used up.