AP Biology
Summer 2025
Summer Assignment

Complete the following assignments. Follow instructions carefully. These assignments are due the **first day we meet**.

1. Plant Wars: **START THIS RIGHT AWAY!**
   a. See the separate description of this assignment. You will be growing plants from seed for **6 weeks** so you need to start immediately.
   b. You will need certain materials: seed, soil, pots, composition notebook....
   c. Seeds should be planted and observations underway by JUNE 9 to allow for at least 6 weeks of data.
   d. If you will be gone on vacation, GSP etc, you must find a way to take care of your plants—parent, a neighbor, take them with you? Perhaps this might affect what plant you choose.

2. Biology Text (Biology for the AP Course) **CHECK OUT FROM THE MEDIA CENTER BEFORE YOU LEAVE FOR THE SUMMER**!!
   a. Read Module 0 (p. 1-11,13. You do not have to read "Analyzing Statistics and Data"). ALSO read Module 1 (p.26-27, 30-39) in the textbook
   b. Answer the following questions on your own paper. You can simply write the letter that matches the correct answer:
      - Review questions #1-7 on p. 15
      - MCQ #1-4 on p. 16
      - Review questions #1-7 on p. 40
      - MCQ #1-4 on p. 41

3. "The Case for a Creator" by Lee Strobel. **ISBN 0-310-24050-6**
   a. Read Chapters 1-4 and 8-9.
   b. Answer the questions in the packet. These should be answered thoroughly on **separate paper. You must handwrite your answers.**

*You may, of course, read all of the chapters in "The Case for a Creator" if you desire....

If you would like to learn more about the creation/evolution debate, I highly recommend watching "Is Genesis History" by Dr. Del Tackett. He interviews many PhD scientists from various fields. This video can be found on Amazon and on YouTube. This video is not required, but summer is a good time to delve into extra subject matter.

If you have any questions, feel free to email me at:
driley@caschools.us

Experience is a hard teacher because she gives the test first, the lesson afterwards.
-Vernon Saunders Law

PLANT WARS

AP BIOLOGY SUMMER ASSIGNMENT 2024

For this assignment, you need to **START IMMEDIATELY. You must grow a plant from a seed and take care of it throughout the ENTIRE summer**. The purpose of this task is to practice skills that will help make you successful in AP Biology next year: observation, data collection, drawing conclusions based on evidence, and data analysis.

Objective 1: To experience that plants are living, growing, responsive creatures that need care in the lab

Objective 2: To experience using research tools available to you and give you practice with documenting steps of your experiments as well as organizing your data.

Student Objectives for AP Biology Labs:
- Choose which variables to investigate (type of soil, amount of sunlight, fertilizer, etc)
- Design and conduct experiments (and to remember control group too!)
- Collect, analyze, interpret, and display data
- Determine how to present conclusions

Materials needed:
1. Composition book for your field notes
2. Seeds for plant of choice
3. Necessary items to grow chosen plant

Assignment:
- Design and conduct an experiment about plants. You may choose to investigate something to do with plant growth, light, fertilizer, root development, pollination, seed germination etc... Any topic about plants is okay. Do NOT use the amount of water as your variable! Be sure you water all your plants with enough water so they don't die from lack of water.
    - The type of plant is entirely up to you (it just has to start from a seed). A fast-growing plant is recommended.
    - Go online if you need to and search for ideas. Don't stress about this, instead have fun while learning! It is okay if everything doesn't turn out "right". This assignment is supposed to get you to think like a scientist, ask questions, and try to find answers.

Composition book setup:

- Create a front cover page that has the following information:
    - A picture of the plant you have chosen to grow (hand drawn or printed)
    - Your first and last name
    - The words: AP Biology – PLANT WARS

Requirements:

- Begin with writing out the steps of the experimental design (see below for more details)
    - Each section should be labeled with the appropriate heading
- **Purpose statement**
- **Background information about your plant**
    - Common and scientific name of the plant
    - Information on your seed/plant of choice
    - Range of natural habitat
    - Nutrition/soil requirements
    - Sunlight requirements
    - Watering requirements (be sure you follow these)
    - Anything else that helps the reader understand your experiment
- **Identify your experimental variables** (see below for more details)
- **Hypothesis for your experiment** (see below for more details)
- **Experimental procedure**
    - Growing plan
    - Type of soil used
    - Size of container –Be sure to use pots that are large enough to get through the summer as your plants grow and the same size (unless you are testing pot size)
    - Amount of sun and water needed to germinate and grow
    - Any other details that I would need to know in order to replicate your experiment
- **Data collected: THESE ARE THE FIELD NOTES!**
    - **FIELD NOTES REQUIREMENTS:**
        - **You must take A SELFIE with your plants (control and experimental) 1 time per week, at minimum.** If you are not in the picture too, it doesn't count.
        - **You must take field notes.** Your field notes will be **recorded in your composition book and MUST include:**
            - Photos (color, please)
            - Qualitative Data
                - Observations about your plant using words: color of leaves, overall plant health, etc. These are characteristics that you observe.
            - Quantitative Data
                - These are measurements you take: height, width of stem, number of leaves, length of leaves, number of flowers/fruit (if any), measurements of flowers/fruit, number of days until growth observed, etc.

  - **YOU MUST HAND-WRITE YOUR FIELD NOTES.**
    - **If your plant(s) dies**, you should document that, retain all field notes and photos for the first plant(s), **and begin again**.
    - The biggest thing is to **DOCUMENT EVERYTHING!!!**
- **Conclusion** (see below for more details)

<u>What you will turn in:</u>

- Your composition book with documentation of the steps of the experimental process and your field notes
- You will bring your plant to school during the first week (a specific date will be announced) and we will vote on prizes, such as "Best in Show" and "Most Pitiful Plant", etc..

<u>Steps for the Plant Experiment:</u>

Step 1: Stating the Purpose/Problem: What do you want to find out? Write a statement that describes what you want to do. It should be as specific as possible. Often, scientists read relevant information pertaining to their experiment beforehand. The purpose/problem will most likely be stated as a question such as: "What are the effects of______ on________?"

Step 2: Defining Variables

INDEPENDENT VARIABLE (IV) (also called the manipulated variable) — the variable that is changed on purpose for the experiment; this is what you, the scientist decides to test.

DEPENDENT VARIABLE (DV) (also called the responding variable) — The variable that acts in response to or because of the manipulation of the independent variable.

CONSTANTS (C) — All factors in the experiment that are not allowed to change throughout the entire experiment. Controlling constants is very important to assure that the results are due only to the changes in the independent variable; everything (except the independent variable) must be constant in order to provide accurate results.

CONTROL GROUP - For some experiments (including yours), a control (standard of comparison for checking or verifying the results of an experiment) is necessary. All variables must be held constant in the control group. **It is recommended that several seeds are planted for each group- a set of control seeds and a set of experimental seeds. These can be planted in different pots or the same pots depending on what works for your experiment. The reason to plant multiple seeds---If only one seed is planted and it does not germinate or it dies, there is no data.*

EXPERIMENTAL GROUP — The group(s) being tested with the independent variable; each experimental group has only one factor different from each other, everything else must remain constant. . **It is recommended that several seeds are planted for each group. If only one seed is planted and it does not germinate or it dies, there is no data.*

REPEATED TRIALS — The number of times that the experiment is repeated. The more times you repeat the experiment, the more valid your results will be. In this case, you might have several plants growing under each condition rather than just one plant. You won't be repeating the experiment this summer.

Step 3: Forming a Hypothesis. A hypothesis is an inferring statement that can be tested. The hypothesis describes how you think the independent variable will respond to the dependent variable. It is written prior to the experiment...never change your hypothesis. This should be written as an If...then statement. "**If** this is done **then** this will happen." Never use "I" in your hypothesis (i.e. I believe that...) The more specific your hypothesis is the better.

> For example: If the temperature of a reaction is increased by 20°C then the rate of the reaction will increase 2 fold.

Step 4: **Designing an Experimental Procedure:** This should be a numbered list of steps (your methods that you used/followed. It must be written in a way that someone can easily replicate your experiment.

Step 5: Results/Data (These are your field notes - see the requirements above too)
Qualitative Data is comprised of a description of the experimental results (i.e. color, texture....). Quantitative Data is comprised of numbers results (i.e. 5 cm, 10.4 grams) The results of the experiment will usually be compiled into a **table/chart** for easy interpretation. I expect that you will collect some quantitative data in a clearly labeled table. Be sure title tables and graphs.

At the end of your experiment, you should make a graph by hand. Choose the type of graph that makes the most sense for the type of data you collected. Here is video about types of graphs that you can watch for a refresher.
https://www.youtube.com/watch?v=9BkbYeTC6Mo&t=6s

Step 6: **Conclusion:** Briefly summarize what you did and what you found. Accept or reject your hypothesis. If your data supports your hypothesis, you accept it. If your data does not support your hypothesis, you reject it. You are not proving anything. Stay away from that word.

Step 7: **Citations**: All sources used for research must be cited using **APA format**

FAQ's:

Q: How do I take care of my plant?
A: Look it up! Be sure to record your sources. Use Citation Machine to put your resources in APA format (simply type "citation machine" into Google).

Q: Do these plants like sun or shade?
A: Look it up! Helpful hint: do not grow outdoor plants inside. Do not grow indoor plants outside.

Q: Am I allowed to feed my plants?
A: Yes! You may do anything to help your plants be all they can be! (Just make sure it's constant between all your plants- unless this is your independent variable.)

Q: How should I record my data?

A: You are the scientist so you decide! What do you think will help you clearly see and interpret if your efforts are working? If you are not sure how to make good data tables – look it up! Organized data is easier to understand and use for analysis. Plan your data collection before you begin! This is your first AP Bio grade, so better to have TOO MUCH DATA instead of not enough!

Enjoy and Have Fun!!!

Name ______________________________

AP Biology
Plant Wars Summer Work
Grading Sheet

Front cover page

_____ (1) Picture of plant
_____ (1) Student first and last name
_____ (1) "AP Biology – Plant Wars"

State the Purpose/Problem

_____ (2) Statement/Question

Background Info

_____ (1) Common and scientific name of plant
_____ (1) General Info
_____ (1) Natural habitat
_____ (1) Sunlight, watering
_____ (1) Additional Info

Identify the Variables

_____ (1) State Independent Variable
_____ (1) State Dependent Variable
_____ (1) Other

Hypothesis

_____ (2) Hypothesis statement

Experimental Procedure

_____ (2) Growing plan
_____ (1) Type of soil
_____ (1) Size of container
_____ (1) Sun/Water etc

Data

_____ (6) Selfie with plant – 6 weeks minimum
_____ (6) Qualitative Data – 6 weeks minimum
_____ (6) Quantitative Data – 6 weeks minimum
_____ (2) Graphs

_____ (1) Citations

Conclusion

_____ (5) Explanation of results

Total (50): ________

The Case for a Creator
By Lee Strobel

End of Chapter Questions

After reading each of the following chapters, please answer the following questions. Answer in thoughtful, complete sentences. You must handwrite your answers on separate paper.

Chapter 1

1. Have you ever met someone who was as hostile toward Christianity as the author was? Explain as much as you feel comfortable.

2. Is there any part of the author's attitude that you can personally relate to? How so?

3. Do you believe that Christianity is being eclipsed or enhanced by modern science? Why? On what do you base your assessment?

Chapter 2

4. Which "Images of evolution" described in the chapter do you believe are the most powerful in shaping our culture's belief in evolution? How so?

5. How do you respond to Harvard geneticist Richard Lewontin's opinion that science should be seen as "the only begetter of truth"? Is that a scientific or a philosophical statement? How much confidence do you put in science?

6. What do you believe are the limits of science? What ways are there to know about something apart from the scientific method?

Chapter 3

7. Which one of biologist Jonathan Well's disclosures was the most surprising to you? Why?

8. Consider each of the various icons of evolution that Wells discussed. As you evaluate each one, discuss whether you think it provides viable support for Darwinism. What makes you reach that conclusion?

9. In Well's opinion, the evidence for Darwinism "is not only grossly inadequate, it's systematically distorted," and that in twenty or thirty years "people will look back in amazement and say, 'How could anyone have believed this?'" In your opinion, what would need to happen before most people would reach that conclusion? How likely do you believe it is that this will occur?

Chapter 4

10. Meyer lists 6 ways in which modern science supports belief in God. Which one of these areas is most intriguing to you and why?

11. If Meyer is correct concerning these six categories of evidence, how strong is the case for a Creator? How well do you believe Meyer responded to the objections to intelligent design theory? Which of his answers were the most convincing and why?

Chapter 8

12. Charles Darwin conceded that his theory would "absolutely break down" if it could be shown that any complex organ "could not possible have been formed by numerous, slight modification." Behe claims he has passed this test. Why do you agree or disagree?

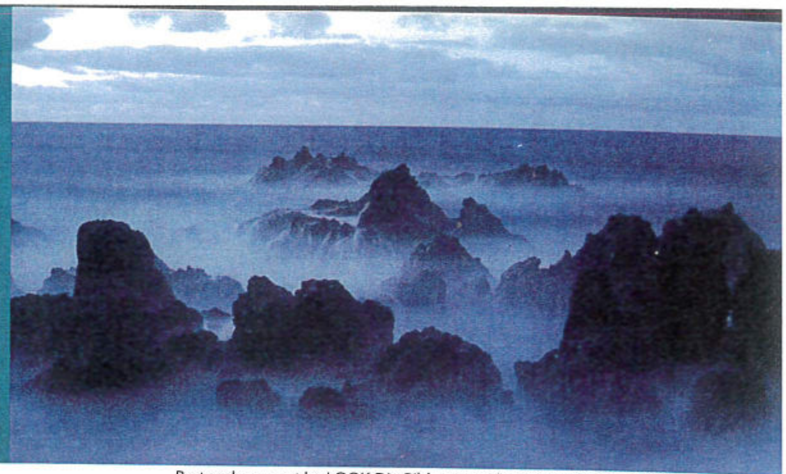
13. Which of the biological systems described by Behe—cilia, bacterial flagella, the cellular transport system, or blood-clotting—was the most impressive to you? Explain.

Chapter 9

14. While scientists are virtually unanimous in ruling out random chance for the origin of life, this theory is still prevalent in popular opinion. What's your assessment of the odds that life could have assembled by chance? Do you agree or disagree with Meyer's conclusions that believing in chance is like invoking a "naturalistic miracle"?

15. Darwin admitted that the Cambrian explosion was "inexplicable" and a "valid argument" against his theory, but he predicted future fossil discoveries would vindicate macroevolution. Today, do you believe that the direction of the fossil evidence points toward or away from Darwinism? In what ways does Darwinism successfully account for the Cambrian phenomenon? In what ways is the phenomenon consistent with intelligent design?

Unit 1
Chemistry of Life



Portugal seacoast by LOOK Die Bildagentur der Fotografen GmbH/Alamy

Module 0
Introduction

LEARNING GOALS ▶**LG 0.1** Four Big Ideas form a fundamental basis for understanding biology.
▶**LG 0.2** Scientific inquiry is a deliberate way of asking and answering questions about nature.

The ears of the snowshoe hare (*Lepus americanus*) stand tall as it listens carefully and its nose twitches as it smells the air for the scent of its predator, the Canada lynx (*Lynx canadensis*). At the same time, the lynx uses its keen eyesight, its sense of smell, and its ears to locate its prey, the hare. Having spotted the hare, the lynx quietly and deliberately moves toward it, slowly closing the distance between itself and the hare. Then, suddenly, the lynx springs upon the hare and the chase for life and food begins.

The activities of predator and prey depend on a number of key processes that they both possess. For instance, both hare and lynx are strong and swift runners. Both are exquisitely adapted to sense their habitats, be aware of danger, and identify potential sources of food. All of the processes employed by the hare and the lynx are part of the study of **biology,** the science of life. **Biologists,** scientists who study life, have come to understand a great deal about these and other processes. They attempt to explain why biology works as it does. That is, they explore the underlying principles and processes that shape and mold biological **organisms,** which are the living beings that display all of the properties of life. We don't know everything about how life works and there is still so much to discover, but the study of biology provides us with an organized way of understanding ourselves, other living things, and the world.

The scope of modern biology is vast and the pace at which we acquire new knowledge continues to accelerate. For example, in recent decades, we have gained unprecedented understanding of the **gene,** which is the unit of heredity, and the **genome,** which is all of the genetic information that an organism contains. This information is helping us come up with new ways of fighting disease in humans, other animals, and plants. It is also helping us understand how different groups of organisms have evolved and how endangered species might be saved. Many new biological frontiers have opened up in recent decades, while others are still waiting to be explored. For example, researchers are only just beginning to understand how bacteria in our digestive system affect our health and well-being. Other researchers are looking at how the temperature and acidity of seawater affect the ecology of coral reefs.

By the time you finish this course, you will have an understanding of how life works. You will explore the structure and function of **cells,** which are the simplest self-reproducing unit that can exist independently. You will look at pathways that cycle carbon through the biosphere. You will understand many of the processes that have shaped the living world. You will see connections among the different ways of investigating life and gain a greater understanding of how to ask and answer scientific questions. This study will help you develop a basis for making informed decisions about issues in your life that have a direct relationship to biology.

In this module, we begin our study of biology with a first look at the four Big Ideas of AP® Biology: Evolution, Energetics, Information Storage and Transmission, and

Systems Interactions. These four Big Ideas provide a framework for understanding and examining biology. After we examine the four Big Ideas, we will consider how biologists use scientific inquiry to understand how scientists ask and answer questions about the natural world.

PREP FOR THE AP® EXAM

FOCUS ON THE BIG IDEAS

Think about ways that each of the big ideas can serve as a different lens to look at life.

0.1 Four Big Ideas form a fundamental basis for understanding biology

Let's return to the snowshoe hare and Canada lynx, which are pictured in **FIGURE 0.1**. We can view this interaction from four different lenses, each providing the perspective of one of the four Big Ideas. From the lens of *evolution*, we can ask how the ancestors of snowshoe hares and lynxes developed their keen senses and ability to run swiftly and skillfully. From the lens of *energetics*, we can explore the food sources of both animals and how they use the fuel they acquire from these sources. From the lens of information storage and transmission, we can learn how the lynx knows to hunt the hare and how the hare knows to run, as well as how this information is passed on to subsequent generations. From the lens of systems interactions, we can investigate the ecosystem dynamics that bring the hare and lynx together or we can examine how the collection of cells that make up each individual animal communicate to enable the lynx to pursue the hare and the hare to evade the lynx.

FIGURE 0.1 Canada lynx and snowshoe hare chase

The photograph shows the snowshoe hare running to escape its predator, the Canada lynx. The lynx gives chase to obtain its food, the hare. The hare runs for its life. The example of the hare and the lynx exemplifies the four Big Ideas of the AP® Biology curriculum.

Photo: Tom & Pat Leeson/Science Source

Every unit in this text examines topics from the perspective of these four Big Ideas. As you read the modules of this book, tie in one or more of the Big Ideas to what you are learning. Doing so will help you to learn about biology and will assist you in understanding how biologists study and learn about life.

In this section, we will take a quick first look at each Big Idea. Although we present them one at a time, they are not really separate or distinct. Instead, they are inseparable in nature. To tackle biological problems—whether building an artificial cell, stopping the spread of infectious diseases like malaria or a coronavirus, feeding a growing population, or preserving endangered species—we need to understand these ideas and how they work together.

Big Idea 1: Evolution

Have you ever noticed how ants have the same body plan, but may be big or small, black or red? In fact, there are more than 10,000 different *species* of ants. A **species** is a group of interbreeding organisms that produce fertile offspring. A species is often distinct from other groups in body form, behavior, or biochemical properties. **FIGURE 0.2** shows two ant species. While there are many different species of ants and each has distinct characteristics, all ants have similar traits that enable us to recognize them as ants. Such similarities and differences are widely observed, and biologists refer to them as the unity and diversity of life. The study of **evolution,** or change over time, explains this unity and diversity of life. Evolution—Big Idea 1—is the central concept that unites all of biology, and biologists recognize it as a key principle of life.

All ants have some shared features, such as their distinctive segmented bodies and bent antennae. Ants are also diverse. For example, they vary in size and color. Some tolerate colder climates while others require warm, tropical places. Ants are not unique in displaying unity and diversity. Unity and diversity occur in all living creatures, from the a.

b.

FIGURE 0.2 Unity and diversity in ants

All ants have common features, such as their segmented bodies and six legs. They also display considerable diversity, as evidenced by the shapes and sizes of their heads, mandibles (jaws), and abdomens (hindmost section). (a) This fire ant (*Solenopsis invicta*) is red and known for its painful sting. (b) This Costa Rican army ant (*Eciton burchellii*) has large mandibles and hunts in large groups. Photos: (a) Satrio Adi/EyeEm/Getty Images; (b) John Mason/ARDEA

smallest single-celled organisms to the great Sequoia trees and the largest animal ever, the 150-ton blue whale.

Evolution occurs by several different mechanisms that will be discussed in detail in Unit 7. Of these, perhaps the most significant is a process first described in the nineteenth century by Charles Darwin and Alfred Russel Wallace. Both of these naturalists suggested that species change over time by a process called *natural selection*. **Natural selection** is a mechanism of evolution in which some individuals survive and reproduce more than others in a particular environment as a result of variation among individuals that can be passed on to the next generation.

As Darwin recognized, farmers have used a principle similar to natural selection for thousands of years to develop crops, such as wheat, corn, cabbage, and broccoli. It is how people around the world have developed breeds of horses, pigeons, cats, and dogs, like the two shown in **FIGURE 0.3**. And it is why many bacteria and other disease-causing microorganisms have stopped responding to antibiotics, which is becoming a public health crisis. Life has been shaped by evolution since its origin, and the capacity for Darwinian evolution may be life's most fundamental property.

The concept of natural selection was in part inspired by observing strong competition for survival and reproduction. For example, among animals, individuals often compete for food. In a Canada lynx population, the fastest and most skilled hunters are more likely to succeed in catching hares, and therefore surviving and reproducing. Slower and less skilled Canada lynx are more likely to perish before they can reproduce. If the animals with better hunting skills reproduce more and have more viable offspring, their offspring will predominate in the next generation.

And just as natural selection has shaped predators, it has also shaped prey. Predator–prey interactions are important in every habitat on Earth. After all, every living animal can be classified as either "predator" or "prey"—and often both labels apply. The skills that a predator needs to hunt its prey and that its prey needs to escape depend in large part on

FIGURE 0.3 Dog breeds

Dog breeders use a process similar to natural selection to develop many different breeds of dogs, such as this husky and terrier. Photo: © Rob Brodman 2011 a host of features of their nervous, sensory, musculoskeletal, endocrine, circulatory, and respiratory systems. In short, natural selection has left a physical imprint on both predator and prey, from nose to tail.

As we examine a wide range of biological topics throughout the book, you will notice that evolution permeates these discussions—whether we are explaining the biochemistry of cells, how organisms function and reproduce, how species interact in nature, or the remarkable biological diversity of our planet.

Big Idea 2: Energetics

All life forms require *energy* to survive, grow, move about, and reproduce. **Energy** is the ability to do work and it is absolutely essential for life. The study of **energetics** examines the properties of energy and how energy is distributed in biological, chemical, or physical processes.

Strategies to capture and use energy vary among species and depend on their evolutionary history. Plants use the energy of sunlight to produce their own food to grow, reproduce, and carry out their functions. Humans and other animals obtain energy by eating other organisms. In fact, all organisms obtain energy from just two sources—the sun or chemical compounds. Losing or reducing access to sources of energy can have damaging and sometimes fatal consequences for organisms.

Consider what happens when you eat an apple. The apple contains sugars, which store energy. By breaking down sugar, our cells harness this energy and convert it into a form that can be used to do the work of the cell. Energy from the food we eat allows us to grow, move, communicate, and do all the other things that we do. Using sugar as a source of energy to power the cell is not a strategy that is just used by human cells. It is widespread among organisms and represents another unifying characteristic of most species. This observation suggests that the ability to use sugar as a source of energy evolved early in the history of life and has been retained over time. We will delve more deeply into how organisms access and use energy in Unit 3.

Big Idea 3: Information Storage and Transmission

Big Idea 3 looks at biology from the perspective of information storage and transmission. In this context, information refers to the instructions that all cells have that in part determine what they look like and how they function. For example, how does your skin cell "know" to be a skin cell and not a liver cell? The answer is that it contains information that is used by the cell, so it looks and acts like a skin cell. This information is stored in a cell's *DNA*. **DNA,** the abbreviation for **deoxyribonucleic acid,** is the carrier of genetic information for all organisms.

In addition to storing information, cells must also retrieve this information. In other words, they need to be able to access the information and use to it to grow and carry out their functions. Finally, cells need to be able to transmit their genetic information to the next generation. DNA is remarkable because it can store genetic information, allow this information to be retrieved and used by the cell, and transmit this information to the next generation. We will learn a lot more about DNA and its role later in this unit and throughout the book.

The transmission of genetic information from parents to their offspring enables species of organisms to maintain their identity through time. The genetic information in DNA guides the development of the offspring, ensuring that parental apple trees give rise to apple seedlings and parental geese give rise to goslings. Furthermore, variation in this genetic information allows some organisms to survive and reproduce in particular environments more than others. Through natural selection, these organisms pass on the genetic variants that account for their ability to do well in their environment. For example, if faster speed enhances survival and reproduction among hares and Canada lynx, the underlying genetic variation that accounts for this trait will likely be passed on to the next generation. Therefore, Big Idea 3—Information Storage and Transmission—is essential to the survival, growth, reproduction, and evolution of a species.

Big Idea 4: Systems Interactions

A **system** is a group of things that function together as a whole. We can consider systems at different levels of scale, from a single cell in a hare to an entire forest, which includes many interactions that occur among the organisms and nonliving materials it contains. Biologists refer to living organisms as **biotic,** and nonliving components as **abiotic.** A **biological system** is made up of both biotic and abiotic entities that interact. As a result of these interactions, biological systems show complex properties.

Big Idea 4 recognizes that biological systems exist at different levels, from the simple to the complex, and interactions among the parts of the system lead to new, emergent properties. An emergent property is a property of a system that the individual parts do not have on their own.

For example, the muscles in the leg of the hare in Figure 0.1 interact with the leg bones, tendons, and nerves to provide movement and remarkable agility. The Canada lynx, using its nervous, sensory, musculoskeletal, cardiovascular, and respiratory systems working together, is able to note the presence of the snowshoe hare, plan a strategy, hunt, chase, and possibly catch the hare.

If we examine the various components that interact with one another in an organism, we will observe the resulting emergent property, which is life. The interactions among the parts of a biological system are hallmarks of life and are found at all levels of biological organization. For example, when fresh water from a large river meets the ocean, the ocean's salty water becomes diluted with fresh water. The mixture of these waters results in a number of new environments where animals, plants, and microorganisms may live, including estuaries, like the one shown in **FIGURE 0.4**. The environment of the estuary is different from the river and ocean systems that created it and it provides a unique habitat for many different species.

From the molecular to the cellular to the organismal to the biosphere levels, biological systems are diverse and complex. These features enable biological systems to have a robustness that helps them to withstand, tolerate, and respond to the changes in the environment. Like evolution, energy, and information storage and transmission, biological systems interactions help ensure the survival and reproduction of organisms, populations, species, and—on a larger scale—life. **Visual Synthesis 1.1: The Four Big Ideas of AP® Biology,** on page 18, illustrates the connectedness of these concepts.

FIGURE 0.4 Estuaries as a biological system

Estuaries such as the Sado Estuary Natural Reserve in Portugal are formed in areas where salt water from oceans and fresh water from rivers mix. Photo: Maurício Abreu/AGE Fotostock

✓ Concept Check

1. **Describe** how a comparison of a fire ant and an army ant shows both the unity and diversity of life.
2. **Identify** why a lack of energy would result in the death of an organism.
3. **Describe** what would happen if organisms were unable to retrieve the information contained in their genes.
4. **Describe** an example of how a systems interaction allows an organism to adjust to its environment.

0.2 Scientific inquiry is a deliberate way of asking and answering questions about nature

How do we go about trying to understand the vastness and complexity of nature? **Scientific inquiry** is the process scientists use to ask questions and seek answers about the natural world in a deliberate and ordered way. Scientific inquiry is limited to investigations of the natural world. Examination of questions not in the natural world, such as questions about religion, faith, and morality, are outside the realm of scientific inquiry.

Scientific inquiry provides the opportunity to observe, investigate, and explain how natural phenomena occur. As shown in **FIGURE 0.5**, scientific inquiry consists of three parts: exploration, investigation, and communication. We will now examine how scientists use scientific inquiry to conduct an orderly and logical investigation of the natural world and communicate their findings with others.

Making Observations and Asking Questions

For most scientists, studies of the natural world begin with exploration. In the exploration phase, scientists make observations and ask questions. **Observation** is the act of viewing the world around us. Observations allow us to ask focused questions about nature. For example, Charles Darwin initially made many observations about anatomy, embryology, domesticated plants and animals, fossils, and the distribution of organisms on the Earth. These observations led him to ask questions. Why are organisms adapted, often exquisitely, to their environment? Why do some fossil organisms resemble living ones? Why are there penguins in the Southern Hemisphere but not the Northern Hemisphere? Why are islands home to so many species that are found nowhere else in the world?

Let's say you observe a hummingbird, like the one pictured in **FIGURE 0.6**, hovering near a red flower, occasionally dipping its long beak into the bloom. What motivates this behavior? Is the bird feeding on some substance within the flower? Is it drawn to the flower by its vivid color? What benefit, if any, does the flowering plant derive from the bird?

Having formulated these questions, the next step that scientists often take is to consult the scientific literature, which is the published information about observations and experiments that others have done. In our example, the scientist would likely review those papers that focus on hummingbird feeding habits and possibly on the effects hummingbirds have on plants they visit. Having reviewed the scientific literature, the scientist should have enough knowledge to start refining questions that would be interesting to investigate.

Regardless of where they come from or when they arise in the process, questions are the keys to scientific inquiry. Indeed, learning to ask good questions is a fundamental component of thinking like a scientist.

Formulating Hypotheses

Observations such as those about the hummingbird, the questions observations raise, and consulting the scientific literature allow us to move on to investigation. Scientists use observation and critical thinking to propose a *hypothesis*. A **hypothesis** is a tentative explanation for one or more observations, and it makes predictions that can be tested by experimentation or additional observations. A hypothesis is not just an idea or hunch. It is a working explanation that helps a researcher understand an observation and leads to a better understanding of the observation.

We might, for example, hypothesize that a hummingbird is carrying pollen from one flower to the next, facilitating reproduction in the plant. Or we might hypothesize that nectar produced by the flower provides nutrition for

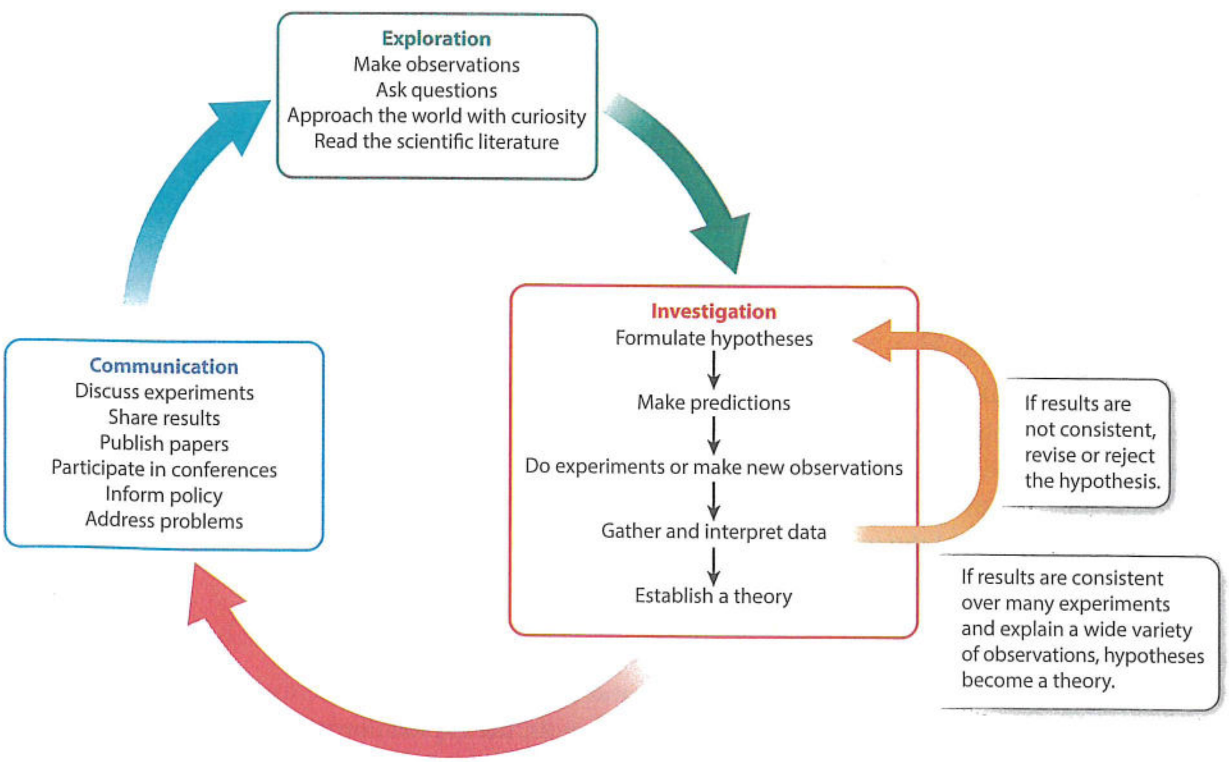


FIGURE 0.5 Scientific Inquiry

Scientific inquiry is the organized, deliberate process that scientists use to examine the natural world. It consists of three parts: exploration, investigation, and communication.

FIGURE 0.6 Observation

Observing a hummingbird visiting a flower may lead to a number of questions that a scientist can explore. Photo: Charles J. Smith

the hummingbird—that the hummingbird's actions reflect its need to take in food. Both hypotheses about the hummingbird's behavior provide a reasonable explanation of our observations, but they may or may not be correct. The predictions of the hypothesis lead to further observation or experimentation.

Because hypotheses make predictions, we can test them. That is, we can devise an experiment to test whether the predictions made by the hypothesis are supported by the evidence, or we can go into the field to make further observations predicted by the hypothesis.

Scientists collect data by observation or experimentation, or both. They will then analyze the data and determine if the data support the hypothesis. If the data do not support the hypothesis, the hypothesis is rejected. In this case, the researcher may generate a new hypothesis. If the data support the hypothesis, it gains support and further questions can be asked. These questions may refine or extend the hypothesis.

Returning to the hummingbird and flower, we can test the hypothesis that the bird is transporting pollen from one flowering plant to the next, enabling the plant to reproduce. Observation provides one type of test: if we catch and examine the bird just after it visits a flower, do we find pollen stuck to its beak or feathers? If so, our hypothesis is supported by the data.

The test, however, cannot prove the hypothesis. Pollen might be stuck on the bird for a different reason—perhaps it provides food for the hummingbird. However, if the birds didn't carry pollen from flower to flower, we would reject the hypothesis that they facilitate pollination. In other words, a single observation or experiment can lead us to reject a hypothesis, or it can support the hypothesis, but it cannot prove that a hypothesis is correct. To move forward, then, we might undertake a second set of observations. Does pollen that adheres to the hummingbird rub off when the bird visits a second flower of the same species? If so, we have stronger evidence and support for our hypothesis.

We might also use observations to test a more general hypothesis about birds and flowers. Does the color red generally attract birds and thereby facilitate pollination in a wide range of flowers? To answer this question, we might catalog the pollination of many red flowers and ask whether they are pollinated mainly by birds. Or we might go the opposite direction and catalog the flowers visited by many different birds—are they more likely to be red than chance alone might predict?

Designing Controlled Experiments

Our hummingbird example used observation to test several different hypotheses, but scientists often test hypotheses through experimentation. One of the most powerful types of experiment is a *controlled experiment*. In a **controlled experiment,** the researcher sets up at least two groups to be tested; the conditions and setup of the groups are identical, except the researcher deliberately introduces a single change, or variable, in one group to see its effect.

Suppose we want to understand the relationship between caffeine consumption and the heart rate when a person is not exercising, which is known as resting heart rate. We might hypothesize that caffeine causes an increase in resting heart rate. This hypothesis could be based on our own experience and observations, or perhaps the scientific literature. To test this hypothesis, we can carry out a controlled experiment. In this case, we might have two groups of people who are similar in terms of age, gender, socioeconomic background, health, and so on. One group is given caffeine, perhaps in the form of a cup of coffee. This group is called the **test group** or **experimental group** because this group experiences the variable—it receives caffeine. In a second group, the people are not given any caffeine. This group is called the **control group** because it is not exposed to the variable.

Why is it necessary to include a control group? Imagine for a moment that there was just a test group and no control group, and the resting heart rate of the people in the test group went up after they drank a cup of coffee. In this case, you might conclude that the hypothesis is supported and caffeine increased heart rate. But how do you know that the heart rate of people in the group didn't increase on its own? How do you know the variable that was changed caused the observed effect? The control group shows what happens without caffeine so researchers can compare what happens with and without the variable, holding every other factor the same. In this way, they can determine if the variable accounts for any changes in heart rate.

In a test of this hypothesis, the action of consuming caffeine is known as the **independent variable,** the variable that is manipulated to test the hypothesis. This variable is considered "independent" because the researchers can manipulate it as they wish. The result of the experiment—resting heart rate—is known as the **dependent variable.** This variable is considered "dependent" because it is expected to vary based on the independent variable.

Scientists use controlled experiments because they are extremely powerful. By changing just one independent variable at a time, the researcher is able to determine whether that variable is important. If many independent variables were changed at once, it would be difficult, if not impossible, to draw conclusions from the experiment because the researcher would not be able to determine which variable caused the outcome.

Our experiment testing the relationship between caffeine consumption and resting heart rate is very simple. In reality, we might include more than two groups of people. For example, we could test how the amount of caffeine affects resting heart rate by giving several groups different numbers of cups of coffee. In this case, there are several test groups, each of which receives the variable of caffeine. We could also include more than one control group. One could receive nothing to drink and the other a cup of water. In both cases, the control groups do not receive caffeine. However, by providing a cup of water, we control for the potential variable of drinking. Both of these control groups are also called **negative control groups** because the expectation is that we will see no effect. We could also include a **positive control group.** This is a group that receives a treatment or variable with a known result. In our example, we could give a medicine that is known to increase heart rate to be sure that heart rate increases as expected.

If observations or experiments do not support a hypothesis, the researcher modifies or rejects the hypothesis. If observations or experiments support a hypothesis, the researcher accepts the hypothesis and then subjects it to more scrutiny by making further observations and doing additional experiments. As we saw in the hummingbird example, a hypothesis may be supported, but it is never proven because we can never know for certain whether it is true in all cases.

FIGURE 0.7 Daffodils

Daffodils, like the ones shown here, were the subject of scientific inquiry by James Kirkham Ramsbottom, who tried to track down what was causing their deaths in the early 1900s. Photo: Victoria Ambrosi/EyeEm/Getty Images

Let's now turn our attention to a real-world experiment that demonstrates some of the features we have been discussing. "Practicing Science 0.1: Using observation and experimentation to examine a horticultural problem" shows how a young scientist used the process of scientific inquiry to determine the cause of death in daffodils, like the ones shown in **FIGURE 0.7**, and to create an effective treatment. This study also gives us a chance to review how to use percentages when evaluating data, described in "Analyzing Statistics and Data: Percent Change" on page 10.

PREP FOR THE AP® EXAM

AP® EXAM TIP

You should know how to design a controlled experiment with a clear and precise hypothesis. The design should include experimental and control groups, and independent and dependent variables.

Practicing Science 0.1

PREP FOR THE AP® EXAM

Using observation and experimentation to investigate a horticultural problem

Background Scientific inquiry is often called upon to address problems that arise in society and industry. In 1916, British horticulturalists were concerned with a disease that killed daffodils. Daffodils grow from bulbs, which are large underground stems that store energy and are seen in many plants, such as daffodils, tulips, and onions. However, the disease caused leaves to wither, bulbs to become discolored, and eventually death of the plant. The demise of the plants represented a substantial loss of commercial production and income to the horticultural industry. While some suspected a fungus caused the plant deaths, no one was able to determine the source of the problem.

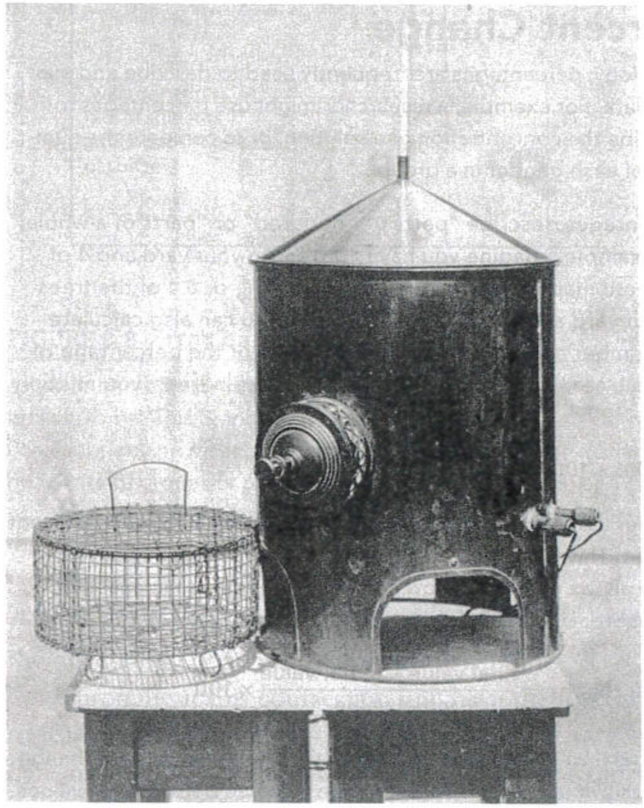
The British Royal Horticultural Society took up the cause and assigned the problem to James Kirkham Ramsbottom. At the time he was a top student at the Royal Horticultural Society's garden in Wisley, a community near London.

Observation and Hypothesis Ramsbottom began by making observations. He examined hundreds of diseased bulbs, preparing microscopic slides and studying them closely. While he did see fungi, Ramsbottom observed that all of the diseased bulbs contained a parasitic worm, *Tylenchus devastratix*. Ramsbottom hypothesized that the worm was the cause of the disease afflicting the plants and predicted that if he could devise a way to kill the worm without killing the bulbs, the disease would be eliminated.

Experimentation Ramsbottom launched a series of experiments where he examined a number of agents that might selectively kill the worm while keeping the plant alive. He tried chemical treatments, spraying the plants and dousing them. He experimented with both gas and formaldehyde. He settled on the use of heat. Ramsbottom immersed the bulbs for different amounts of time in hot water. The photograph shows the removable wire basket and copper boiler that permitted Ramsbottom to heat the daffodil bulbs for different periods of time. He determined that soaking them in 110°F (43°C) water for 2 to 4 hours left the bulbs intact while the parasite was eliminated. Untreated, infected daffodil bulbs failed to grow, died, and did not produce flowers. The heat-treated daffodil bulbs grew normally and produced the sought-after plant and flower. Today, the Ramsbottom heat treatment is still used in virtually the same manner as he developed it.

SOURCE

Flower Preservation, 1916. *The Scientist,* 2:64. Photo: His Majesty's Stationery Office/RHS Lindley Collections



AP® PRACTICE QUESTION

James Kirkham Ramsbottom used the process of scientific inquiry to figure out what was causing the death of daffodils. Organize the description of his experiment by identifying the following:

1. The scientific (testable) question
2. The hypothesis
3. The independent variable
4. The dependent variable
5. The experimental group
6. The control group

Analyzing and Interpreting Data

After conducting an observational or controlled experiment, the scientist has a collection of data. Data are the bedrock of science. Biologists collect, analyze, and interpret data to answer questions about the natural world. Hypotheses are supported or rejected on the basis of data, and our understanding of the world is ultimately built on a foundation of data.

What types of data will you encounter in your AP® Biology course? Data can take many forms, including observations, measurements, and facts. Data can be qualitative

ANALYZING STATISTICS AND DATA

PREP FOR THE AP® EXAM

Percent Change

In biology, percentages are frequently used to describe and analyze data. For example, a researcher might use percentages to describe the concentration of a solution, or to compare the numbers of each gender in a group.

Percentages describe "parts per hundred" or "parts of a whole." For example, imagine you have 10 trees in your yard and 4 of them are maple trees. You could say that $\frac{4}{10}$ or 0.4 of the trees in your yard are maple trees. However, you can also calculate the number of maple trees per 100 trees, or the percentage of maple trees. To find the percentage of maple trees, you multiply 0.4 by 100:

$$0.4 \times 100 = 40\%$$

In other cases, scientists might be interested in calculating percent change. This is useful to compare an initial value to a final value, which allows you to see how much something has increased or decreased. Use the following formula to calculate percent change:

$$\%\text{ change} = \frac{\text{final value} - \text{initial value}}{\text{initial value}} \times 100$$

If the final value is larger than the initial value, the percent change is a positive number, representing an increase between the values you are comparing. If the final value is smaller than the initial value, the percent change is a negative number, signifying a decrease between the values you are comparing.

PRACTICE THE SKILL

Let's look at an example of how percent change might be used. James Kirkham Ramsbottom discovered a way to eliminate parasites from daffodil bulbs by immersing them in hot water. Before he found an effective soaking time of 2 to 4 hours, he immersed 50 bulbs for 30 minutes and 50 bulbs for 1 hour. At the end of 30 minutes, 10 of the daffodil bulbs were free of parasites. After 1 hour, 25 of the bulbs were free of parasites. What was the percent change in the number of healthy, parasite-free bulbs as the immersion time increased?

To start, we must find the two values we need to calculate percent change. After 30 minutes, 10 of the 50 bulbs were free of parasites. The initial value is 10 bulbs. At the end of 1 hour, 25 bulbs were free of parasites. So, the final value is 25 bulbs. Now we can plug these values into our formula:

$$\%\text{ Change} = \frac{25 - 10}{10} \times 100$$

$$\%\text{ Change} = \frac{15}{10} \times 100$$

$$\%\text{ Change} = 1.5 \times 100$$

$$\%\text{ Change} = 150\%$$

There was a 150% increase in parasite-free bulbs as Ramsbottom changed the immersion time from 30 minutes to 1 hour.

Your Turn

The emerald ash borer is an invasive species that has destroyed ash tree populations in North America. Before the insect arrived, one forest contained 300 ash trees. A number of years after the ash borer was introduced to the area, only 60 ash trees remained. By what percent did the ash tree population decrease?

or quantitative. Qualitative data are descriptive. For example, the stem of a corn plant can be described as "short" or "tall." Quantitative data are expressed numerically. For example, a corn stem might measure 2.04 m or 2.76 m in length. Similarly, the heart rate data that we collected in our controlled experiment is an example of quantitative data. Scientists often deal with quantitative data because numbers lend themselves to statistical analysis.

Statistical analysis helps scientists interpret the data they collect. For example, when several measurements are made, they are typically not all the same. In this case, the researcher might report the average of the measurements. The researcher might also indicate the extent to which the observed measurements deviate from the average. The spread of the data can be calculated in various ways, each of which provides an indication of how tightly the data points are clustered around the average.

Statistics can also help researchers understand whether the data collected for the experimental and control groups reflect a real, or what is termed a statistically significant, difference. For example, in the caffeine experiment, let's say we observe that resting heart rate is higher in the test group compared to the control group. Is this difference the result of caffeine, in which case scientists call it a real difference? Or is the difference just due to chance?

To answer this question, researchers begin by stating a **null hypothesis,** which predicts that the intervention or treatment has no effect at all. In other words, any difference between the test and control groups is due to chance alone and nothing else is responsible for the difference between the two groups. In this case, the null hypothesis is that caffeine does not cause an increase in heart rate. They also state an **alternative hypothesis,** which predicts that the intervention or treatment has an effect, so the difference between the test and control groups is real. In this case, the alternative hypothesis is that caffeine causes an increase in resting heart rate.

A statistical test normally yields a number, called the *p*-value, that expresses the likelihood that an observed result could have been observed merely by chance. A *p*-value is a probability. If $p \leq 0.05$ (5%), there is less than or equal to a 5% chance that the observed results are the result of chance. This is a relatively small chance. In this case, it is likely that the observed results in a dataset are real and not due to chance. In other words, the null hypothesis is rejected. By contrast, if $p > 0.05$, there is greater than a 5% chance that the observed results could have been obtained by chance, so you fail to reject the null hypothesis. The phrasing "the null hypothesis has failed to be rejected" reminds us that although the results do not support the alternative hypothesis, it does not mean that the null hypothesis is correct. Rather, it simply means that the null hypothesis has not been disproven.

Finally, scientists are often interested in determining how confident they should be in their data. Uncertainty can be shown graphically as an error bar. An error bar is typically a short vertical line showing a range of values. For example, **FIGURE 0.8** shows results from our controlled experiment investigating the relationship between caffeine and resting heart rate. The data points indicate the average heart rate of the people in the groups. The vertical lines through the data points are error bars. In spite of its name, an error bar doesn't represent an error or a mistake. Instead, it shows a range of values that incorporates small differences among the individuals and perhaps even inaccuracies in the measurements.

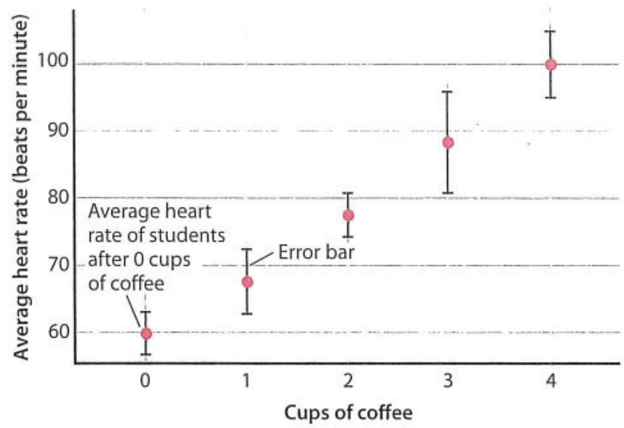


FIGURE 0.8 Error bars

An error bar represents a range of values within which the true value is likely to be. This graph shows the relationship between caffeine consumption and resting heart rate. It plots the average resting heart rate of groups of people who consumed 0, 1, 2, 3, or 4 cups of coffee, with error bars giving an indication of the uncertainty of the data.

As a result, you can think of the error bar as a way to show the uncertainty of a measurement or data point.

Throughout this course, you will have the opportunity to learn some of the techniques researchers use to evaluate data and to work with data yourself. "Tutorial 1: Statistics" on page 20 walks you through some of the statistics tools you will encounter. "Analyzing Statistics and Data: Averages" gives you a chance to practice working with these concepts.

PREP FOR THE AP® EXAM

AP® EXAM TIP

When evaluating the results of an experiment, you should be able to explain whether the alternative hypothesis is supported or not, and whether the null hypothesis should be rejected or fail to be rejected. You should know that data are often analyzed statistically to determine if real differences exist between the data collected from the experimental and control groups.

ANALYZING STATISTICS AND DATA

PREP FOR THE AP® EXAM

Averages

For a detailed explanation of how to calculate mean, median, and mode, see page 20 for "Tutorial 1: Statistics." Here we review how to apply the concepts of mean, median, and mode and offer a problem for you to try.

PRACTICE THE SKILL

Below is a table listing several different ant species and the number of queens commonly found in a colony of each species. Considering the entire dataset, which measurement of the number of queens is largest: the mean, median, or mode?

Ant species	Number of queens in a small colony
Carpenter ant (*Camponotus pennsylvanicus*)	1
Red imported fire ant (*Solenopsis invicta*)	30
Pavement ant (*Tetramorium caespitum*)	5
Crazy ant (*Paratrechina longicornus*)	12
Pharaoh ant (*Monomorium pharaonis*)	2
Ghost ant (*Tapinoma melanocephalum*)	20
Little black ant (*Monomorium minimum*)	5
Argentine ant (*Linepithema humile*)	7

Data from https://www.environmentalscience.bayer.us/-/media/prfunitedstates/documents/resource-library/product-guide/ant-id-guide.ashx

To determine which number is the largest of all of the measurements, we'll have to calculate the mean, median, and mode. Let's begin by calculating the mean of the dataset. In order to do this, we add together all of the values in the dataset and divide the sum by the number of values in the dataset. The sum of the values is:

$$1 + 30 + 5 + 12 + 2 + 20 + 5 + 7 = 82$$

We divide this sum by the number of values in the dataset, which in this case is 8:

$$82 \div 8 = 10.25$$

So, the mean is 10.25.

We can also do this calculation using the following equation, where $\overline{x}$ is the mean, n is the number of values in the dataset, and $\sum_{i=1}^{n} x_i$ is the sum of all of the values in the dataset:

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$\overline{x} = \frac{1}{8}\sum_{i=1}^{8}(1 + 30 + 5 + 12 + 2 + 20 + 5 + 7)$$

$$\overline{x} = \frac{1}{8}(82) = 10.25$$

We can find the median and mode by placing the values in numerical order:

1, 2, 5, 5, 7, 12, 20, 30

The median is the midpoint of this dataset of eight values. Because we have an even number of values, the median is the mean of the two middle values, 5 and 7.

$$5 + 7 = 12$$
$$12 \div 2 = 6$$

So, the median is 6.

We can now find the mode. The mode is the most frequent value in a dataset. If we look at the number of queens, we can see that the number 5 appears twice, more than any other value. So, the mode is 5.

The mean is 10.3, the median is 6, and the mode is 5. The largest of the three values in this case is the mean. Each of these numbers describes the dataset in a different way, which is described in "Tutorial 1: Statistics."

Your Turn

A researcher has planted bean seedlings under different light, moisture, and nutrient conditions and monitored their growth over several weeks. The data are recorded in the table. What are the mean, median, and mode for seedling height?

Bean seedling plant	Seedling height (cm)
1	20
2	6
3	15
4	23
5	5
6	15
7	21

Communicating Findings

We have seen that scientific inquiry encompasses several careful and deliberate ways of asking and answering questions about the unknown. We ask questions, make observations, collect field or laboratory samples, and design and carry out experiments to make sense of things we initially do not understand.

Another critical step in scientific inquiry, shown in Figure 0.5, is communication with other scientists and the public. Scientists publish their work in journals and present data at meetings and conferences. Sharing this information is crucial because it informs both other scientists and the public. By making the studies and data known, the results from scientific investigation are shared so that others may use the information to inform and guide future research and perhaps public action.

Scientific inquiry is typically not a linear process that proceeds in an orderly way from question to hypothesis to experiment to communication. It more accurately resembles a circle, where questions lead to experiments that lead to more questions. And there are frequent failures, false starts, and rejected hypotheses. These are all part of the process of scientific inquiry. In fact, the ability to make corrections, refine explanations, and reject hypotheses makes scientific inquiry a powerful method to understand the world around us.

Every scientist experiences failure, but good scientists learn from failed experiments, using the results to plan new ways of approaching problems. Once we obtain results that provide new understanding, we communicate what we find with other scientists and the public. Discussing and sharing ideas and results often leads to new questions, which in turn can be tested by more observations and experiments.

Establishing Theories

A hypothesis may initially be tentative. It often provides one of several possible ways to explain an observation. With repeated observation and experimentation, a good hypothesis gathers strength and researchers have more and more confidence in it. When a number of related hypotheses survive repeated testing and come to be accepted as good bases for explaining what we see in nature, scientists articulate a broader explanation that accounts for these hypotheses and the results of their tests. We call this statement a **theory,** a general explanation of the world supported by a large body of experimental evidence and observations. Examples of well-established theories include the theory of gravity, the chromosome theory, the germ theory, the cell theory, and the theory of evolution.

Scientists use the word "theory" in a very particular way. In general conversation, "theory" is often synonymous with "hypothesis," "idea," or "hunch." For example, you might say, "I've got a theory about why the car won't start." But in a scientific context, the word "theory" has a specific meaning. Scientists speak in terms of theories only if hypotheses have withstood testing to the point where they provide a general explanation for many observations and experimental results.

Just as a good hypothesis makes testable predictions, a good theory both generates hypotheses and predicts their outcomes. For example, the theory of gravity arises from a set of hypotheses you test every day by walking down the street or dropping a fork. Similarly, the theory of evolution is not just one explanation among many for the unity and diversity of life. Instead, it is a set of hypotheses that has been tested for more than a century and shown to provide an extraordinarily powerful explanation of biological observations. In fact, as we discuss throughout this book, evolution is one of the most significant theories in all of biology. It provides the most general and powerful explanation of how life works.

✓ Concept Check

5. **Describe** how a scientist turns an observation into a hypothesis and investigates that hypothesis.
6. **Describe** the differences between an experimental (test) group and a control group, and why it is important for an experiment to include both types of groups.
7. **Identify** the differences among a guess, hypothesis, and theory.

Module 0 Summary

PREP FOR THE AP® EXAM

REVISIT THE BIG IDEAS

Using the content of this module, pick your favorite organism and **describe** it in four different ways, using each of the four Big Ideas.

LG 0.1 Four Big Ideas form a fundamental basis for understanding biology.

- Evolution is the unifying principle of biology. Page 2
- Evolution explains how organisms are similar and how they are different from one another. Page 2
- Natural selection is one of the major mechanisms of evolution. Page 3
- Energy is required by all life forms in order to survive, grow, and reproduce. Page 4
- Organisms harness energy from the sun or from chemical compounds. Page 4
- DNA stores and transmits genetic information in all organisms. Page 4
- The ability to store, retrieve, and transmit genetic information is necessary for cellular function and the process of evolution. Page 4
- Cells, organisms, and the biosphere are all systems that work in an integrated and coordinated fashion to sustain life. Page 4
- Interactions of the components of a system often result in emergent or new properties that are more than a simple addition of the individual components. Page 4
- Systems interactions are diverse and occur at every level, from cells to organisms to communities to the biosphere. Page 5

LG 0.2 Scientific inquiry is a deliberate way of asking and answering questions about nature.

- Scientific inquiry involves making observations, asking questions, doing experiments or making further observations, and drawing and sharing conclusions. Page 5
- Observations are used to generate a hypothesis, a tentative explanation that makes predictions that can be tested. Page 6
- On the basis of a hypothesis, scientists design experiments and make additional observations which test the hypothesis. Page 7
- A controlled experiment involves different groups in which all the conditions are the same except for a single variable. In the test group, a variable is deliberately introduced to determine whether that variable has an effect. In the control group, the variable is not introduced. Page 8
- The independent variable in a controlled experiment is the factor that is changed by the researcher; the dependent variable is the effect or result that is being observed or measured. Page 8
- The null hypothesis predicts that an intervention or treatment in an experiment will have no effect; the alternative hypothesis predicts that the intervention or treatment will have an effect. Page 11
- Hypotheses cannot be proven, but they can be modified or rejected based on observation or experiments. Page 13
- If a hypothesis is supported by continued observation and experiments over time, it is elevated to a theory, a sound and broad explanation of some aspect of the world. Page 13

Key Terms

Biology
Biologist
Organism
Gene
Genome
Cell
Species
Evolution
Natural selection
Energy
Energetics
Deoxyribonucleic acid (DNA)
System
Biotic
Abiotic
Biological system
Scientific inquiry
Observation
Hypothesis
Controlled experiment
Test group
Experimental group
Control group
Independent variable
Dependent variable
Negative control group
Positive control group
Null hypothesis
Alternative hypothesis
Theory

Review Questions

1. Biology is the
   (A) study of components that make up organisms.
   (B) study of life.
   (C) categorization of organisms into similar groups.
   (D) study of how organisms give rise to offspring.

2. One mechanism of evolution, or change over time, is
   (A) biotic.
   (B) systems interactions.
   (C) natural selection.
   (D) DNA.

3. Many organisms use sugars as a source of energy to power the cell. This observation suggests that the pathways that break down sugars
   (A) arose relatively recently.
   (B) arose early in life's history.
   (C) are different in different species.
   (D) sugars are not necessary for life.

4. A hypothesis is
   (A) the cause of a scientific phenomenon.
   (B) the solution to a scientific problem.
   (C) a hunch or guess.
   (D) a tentative explanation of how nature functions.

5. An independent variable is
   (A) the factor that differs in the test group compared to the control group.
   (B) the order in which one measures the data collected in an experiment.
   (C) a factor that is larger or smaller than other factors in an experiment.
   (D) the result of the experiment that is being observed or measured.

6. You decide to test whether helium is light enough to cause balloons to rise. In the first group, you fill the balloons with helium. In the second group, you fill the balloons with air. What is the dependent variable in your experiment?
   (A) The presence or absence of helium
   (B) The group of balloons that receives the helium
   (C) The group of balloons that receives the air
   (D) Whether the balloons rise or not

7. A hypotheses is
   (A) supported when data contradict it.
   (B) proven when data can support it.
   (C) modified when data contradict it.
   (D) rejected when data support it.

Module 0
AP® Practice Questions

PREP FOR THE AP® EXAM

Section 1: Multiple-Choice Questions

Choose the best answer for questions 1–4.

1. Survival in some mushroom species is enhanced by the presence of gills with large surface areas. Mushrooms with larger gill surface areas produce more spores and reproduce more successfully than those with smaller gill surface areas in a particular environment. Identify which of the four Big Ideas of biology this example best describes.
   (A) Evolution
   (B) Energetics
   (C) Information Storage and Transmission
   (D) Systems Interactions

2. A student accidentally spilled a bag of rock salt on some plants while moving the bag to the garage. After some time, the student noticed that the plants in this area were turning brown and withering. The student formulated a hypothesis that the plants were dying because they do not grow well in salty soil. Among the proposed experiments below, identify the most effective way of testing this hypothesis.
   (A) Keeping a weekly record of any plant regrowth
   (B) Planting some seeds in a container of healthy soil and some in a container of salty soil and observing plant growth in each over a period of weeks
   (C) Removing the rock salt from the area, replanting grass seed, and observing any change in growth
   (D) Spreading rock salt over a larger portion of the lawn to see if the rest of the grass dies

3. A scientist is doing an experiment to see which conditions are best for bacterial growth. The scientist has set up an array of several petri dishes and will subject the bacterial cultures to various cool and warm temperatures, while comparing them to petri dishes at room temperature. Identify how the condition of temperature is used in this experiment.
   (A) As a dependent variable
   (B) As an independent variable
   (C) As a control group
   (D) As an experimental group

4. The table below shows differences in mass among males in four different species of frogs at two different life stages. A metamorph is a young individual that has nearly completed the change from tadpole to frog. Metamorphs have four legs and still have a tail. A fully grown adult frog has no tail.

	Metamorph mass (g)	Adult mass (g)
Green frog	1.1	20.2
Leopard frog	0.98	18.9
Wood frog	0.82	7.9
Gray tree frog	0.57	7.1

   Which species has the largest percent change in mass from metamorph to adult?
   (A) Green frog
   (B) Leopard frog
   (C) Wood frog
   (D) Gray tree frog

Section 2: Free-Response Question

Write your answer to each part clearly. Support your answers with relevant information and examples. Where calculations are required, show your work.

An experiment was performed on a wild population of Anna hummingbirds (*Calypte anna*) to see if they preferred feeding from a specific color of sugar water. Scientists had previously observed the hummingbirds feeding from a glass feeder with a clear sugar water solution. The scientists placed five identical glass feeders side by side and filled each with a different colored sugar water solution: red, yellow, green, blue, and clear. Every 15 minutes, the scientists changed the positions of the feeders relative to one another to eliminate any position bias. The scientists recorded the color of the first sugar water solution that each hummingbird visited. The experiment was carried out for 2 days. The results of the experiment are shown in the table.

(a) **Identify** the independent and dependent variables.

(b) **Identify** the control group and the experimental group.

(c) **State** an alternative hypothesis and the corresponding null hypothesis.

(d) **Explain** what the data tell us about the hummingbirds' preference.

Average Number of Birds Approaching and Drinking from Each of Five Containers Containing Different Colored Solutions

Color	Mean counts
Red	33.9
Yellow	13.1
Green	8.4
Blue	4.3
Clear	5.3

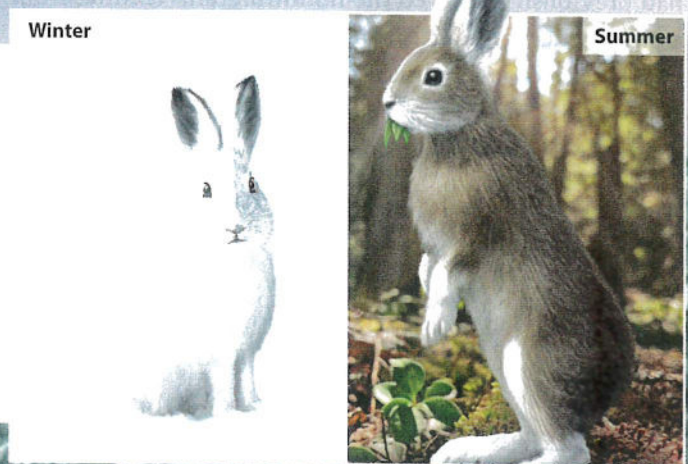
Data from https://sora.unm.edu/sites/default/files/journals/wilson/v092n01/p0053-p0062.pdf

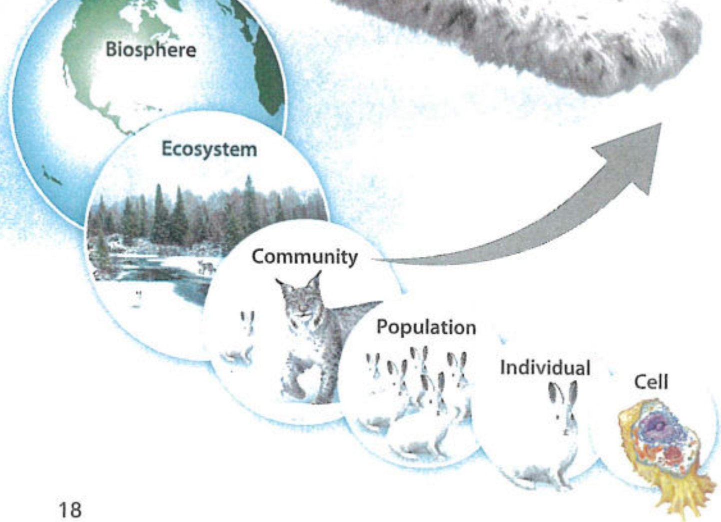
VISUAL SYNTHESIS 1.1 THE FOUR BIG IDEAS OF AP® BIOLOGY

We can describe four Big Ideas that connect and unite the many dimensions of biology: Evolution, Energetics, Information Storage and Transmission, and Systems Interactions. These four ideas are introduced in Unit 1 and will be visited again and again throughout the book. By the time you finish this book, you will have an understanding of how life works, from the molecular

The Four Big Ideas of AP® Biology

Evolution investigates changes in the genetic makeup of a population over time. Through the process of natural selection, species become adapted to their environments. For example, ancestors of the snowshoe hare and Canada lynx evolved to have adaptations that increased their survival and reproduction. This includes the hare's ability to change coat color with the seasons.





Systems Interactions examines the way the components of biological systems interact with and affect one another. A system can be as small as a cell or as large as the biosphere. New properties of biological systems emerge through the interactions of organisms such as Canada lynx and snowshoe hares, and through interactions between species and their environment.

machines inside cells and the metabolic pathways that cycle carbon through the biosphere, to the process of evolution, which has shaped the living world that surrounds and includes us. The four Big Ideas are fundamental to understanding and organizing such diverse aspects of biology.

Energetics considers the processes used by cells and organisms to exchange matter and energy with their environment. For example, Canada lynx and showshoe hares acquire, store, and use the energy and matter obtained from the environment to maintain homeostasis, grow, and reproduce.

Information Storage and Transmission explores how information is stored, used, and transmitted by cells and organisms. Using information stored in DNA and through experience, the Canada lynx knows how to hunt its prey and the snowshoe hare knows how to evade its predator. These behaviors are transmitted to offspring through DNA and through the process of learning.

Module 1

Elements of Life

LEARNING GOALS
- **LG 1.1** Matter and energy govern the properties of life.
- **LG 1.2** The atom is the fundamental unit of matter.
- **LG 1.3** Atoms combine to form molecules linked by chemical bonds.
- **LG 1.4** Carbon is the backbone of organic molecules.

Take a look around you. Everything you see and feel is made of matter, the material that makes up physical objects. **Matter** is anything that has mass and takes up space. Matter may be a gas, a liquid, or a solid. Even you are made of matter. To grow, reproduce, and maintain their organization, all organisms exchange matter with their environment. They also require energy. The study of biology is based on an understanding of the pathways and transformations of matter and energy. Therefore, to understand why organisms look and act as they do, we need to gain a basic understanding of matter and energy. In this module, we will examine the fundamentals of both. We will look at properties of the basic unit of matter, the **atom.** We will also look at the use and flow of energy. We will explore how chemical bonds enable atoms to form a wide variety of **molecules,** which are chemicals made up of two or more atoms, and will examine the chemical properties of molecules that are used by all living things.

PREP FOR THE AP® EXAM

FOCUS ON THE BIG IDEAS

ENERGETICS: Look for the elements that make up all organisms, and the way in which organisms exchange these elements with the environment.

1.1 Matter and energy govern the properties of life

Because organisms are composed of matter and require energy, it follows that organisms are subject to the physical laws and principles that govern matter and energy. In this section, we will first review some of the properties of matter and energy, and how they flow through communities of living organisms.

Flow of Matter

Let's begin by following the path of matter as it flows through living systems. Imagine that we could tag a carbon atom at its moment of origin and then follow its trip through time and space. Formed in a nuclear blast furnace deep within an ancient star and then ejected into space as the star exploded in death, our atom was eventually swept up with other materials to form Earth, a small planet orbiting a newer star we now call the sun. Volcanoes introduced our carbon atom into Earth's early atmosphere as carbon dioxide (CO_2). Slowly, over millions of years, this carbon dioxide reacted with water and rocks, transferring the carbon from the air to the seafloor. Here, our atom sat for many millions of years, until earthquakes, erosion, or other geologic activities returned it to the atmosphere as carbon dioxide once again. Slowly but surely, geologic processes on early Earth cycled carbon from atmosphere to rocks and back again. This slow movement of carbon between Earth and atmosphere continues today.

Sometime between 4 and 3.5 billion years ago, as life took hold on Earth, our carbon atom began to cycle more rapidly—much more rapidly. Microorganisms were able to convert the carbon dioxide in the environment into **organic molecules,** which are biological molecules that contain carbon. Other microorganisms broke down organic molecules and returned carbon dioxide to the environment. To this day, carbon cycles continuously from the atmosphere and oceans to organisms and back again.

This intricately linked network of geological and biological processes that shuttles carbon among rocks, soil, ocean, air, and organisms is called the carbon cycle. Why focus on carbon? The carbon cycle provides an organizing principle for understanding life on Earth. The chemistry of life is, in no small part, the chemistry of carbon because organic molecules are made up of carbon.

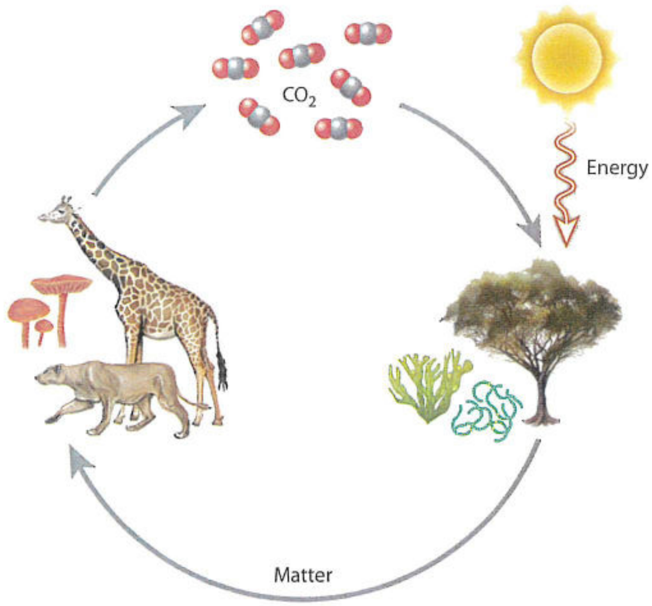


FIGURE 1.1 Flow of matter and energy

Matter, such as a carbon atom, cycles among organisms and the physical environment. Energy, like solar and chemical energy, is harnessed by organisms to do work and needs to be constantly added to the system to sustain life.

The carbon cycle also teaches that matter moves through organisms and the physical environment in a cycle, as shown in **FIGURE 1.1**. In other words, the same atoms are reused over and over. Organisms must exchange matter with other organisms and the environment to grow, reproduce, and maintain organization. For instance, when a leaf or a plant in the forest dies, it is usually consumed by the animals or microbes in the forest. These organisms use the dead leaf to build their biomass. In turn, these organisms recycle matter through the wastes they release or when they die. The released matter is used by other organisms, including plants, animals, and microbes, to build their biomass.

Flow of Energy

As organisms move carbon, they also transfer energy. Carbon and energy are closely intertwined for the simple reason that the energy sources for many organisms are the carbon-rich organic molecules in the organisms they eat or the molecules they build themselves. Unlike carbon, energy does not move in a cycle. Instead, energy must continually be harvested from the environment to sustain the community. In essentially all habitats where sunlight is available, the sun provides the entry point for energy into living systems, as shown in Figure 1.1. Plants, algae, and certain bacteria capture energy from the sun and use it to synthesize energy-rich organic molecules. Where sunlight is absent, especially in the vast depths of the ocean, energy instead comes from chemical compounds.

Organisms transform energy. That is, they acquire energy from the environment and convert it into a chemical form that their cells can use. For instance, some of the solar energy striking a forest is captured by plants, which transform it into chemical energy in the form of sugars. Some of this energy is used by the organism to do work—such as building cellular components, moving, and reproducing. The rest of this energy is dissipated as heat and is no longer available for the organism to use. We will look more closely at the flow of energy and the cycling of matter in Units 3 and 8. "Analyzing Statistics and Data: Standard Deviation and Error Bars" gives you an opportunity to practice using data analysis skills on a question involving plants and energy capture.

PREP FOR THE AP® EXAM

AP® EXAM TIP

You should know that matter and energy both flow through communities, but they take different paths. Matter travels in a cycle, with the same atoms moving back and forth among organisms and the physical environment. By contrast, energy is not recycled. Instead, an input of energy from the environment is constantly required to sustain cells and organisms. Be prepared to give examples of the ways that matter and energy flow through communities and therefore sustain life.

PREP FOR THE AP® EXAM

AP® EXAM TIP

Make sure you understand that no overlap between error bars indicates a statistically significant difference.

✓ Concept Check

1. **Describe** how matter and energy flow through living systems.
2. **Describe** how the flow of matter depends on the flow of energy in communities.

Your Turn

Researchers in an aquatic biology lab have collected data on the mass of algae in a recent experiment. The data are shown in the following table:

Experimental tank	Algae mass (g)	Experimental tank	Algae mass (g)
1	0.36	9	0.66
2	0.51	10	0.31
3	0.25	11	0.22
4	0.42	12	0.29
5	0.22	13	0.33
6	0.25	14	0.32
7	0.28	15	0.48
8	0.27		

1. What is the standard deviation of this dataset?
2. If you were to graph error bars for these data, what range of values would represent a 95% confidence interval of the mean?

1.2 The atom is the fundamental unit of matter

When biologists speak of diversity, they commonly point to the 2 million or so species named and described to date, or to the 10–100 million living species thought to exist in total. Life's diversity can also be found at a very different level of observation: in the molecules within cells. Life depends critically on many essential functions, which ultimately depend on the chemical characteristics of the organic molecules that make up cells and organisms.

In spite of the diversity of molecules and functions, the chemistry of life is based on just a few types of organic molecules, which in turn are made up of just a few types of atoms. In this section, we will look at the structure of atoms and identify the major atoms that make up organic molecules.

Atomic Structure

The study of life begins with the basic unit of matter, the atom. An atom contains a dense central **nucleus.** The nucleus is made of positively charged particles called **protons** and electrically neutral particles called **neutrons.** A third type of particle, the negatively charged **electron,** moves around the nucleus at some distance from it. For example, a carbon atom, illustrated in **FIGURE 1.2**, typically has six protons, six neutrons, and six electrons. The number of protons is known as the **atomic number.** The atomic number specifies an atom as a particular **element,** a chemical that cannot be further broken down by the methods of chemistry. For example, the atom with one proton is hydrogen (H) and the atom with six protons is carbon (C).

Each proton and neutron, by definition, has a mass of 1 atomic mass unit, whereas electrons have negligible mass. Together, protons and neutrons determine an atom's **atomic mass,** which is the total mass of the atom.

The number of neutrons in atoms of a single element can differ, which changes its mass. **Isotopes** are atoms of the same element that have different numbers of neutrons. The atomic mass is sometimes indicated as a superscript to the left of the chemical symbol. ^{12}C is the isotope of carbon with six neutrons and six protons. If we want to symbolize both the atomic number and atomic mass for an element or isotope, we indicate the atomic mass by a superscript and the atomic number by a subscript. For example, the carbon isotopes with the mass of 12 and 14 would be written as $^{12}_{6}C$ and $^{14}_{6}C$, respectively.

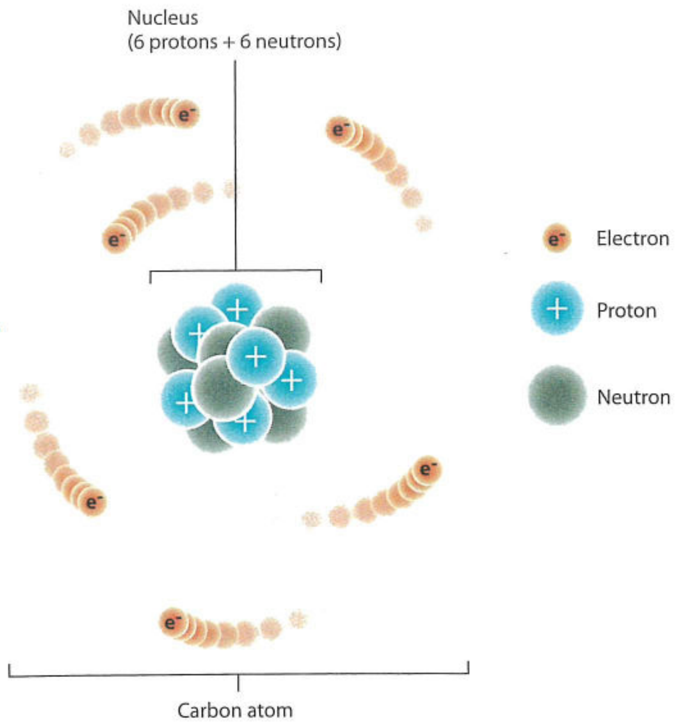


FIGURE 1.2 A carbon atom

Most carbon atoms have six protons, which are positively charged; six neutrons, which are neutral; and six electrons, which are negatively charged.

Typically, an atom has equal numbers of protons and electrons. As you can see in Figure 1.2, carbon possesses six positively charged protons and six negatively charged electrons. The charges add up to zero, so this carbon atom is electrically neutral.

Certain chemical processes cause an atom to either gain or lose electrons. An atom that has lost an electron is positively charged, and one that has gained an electron is negatively charged. Electrically charged atoms are called **ions.** The charge of an ion is specified as a superscript to the right of the chemical symbol. For example, H^+ indicates a hydrogen ion that has lost an electron and is positively charged. Positively charged ions are called cations and negatively charged atoms are anions.

Electrons

The movement of electrons from one molecule to another is the foundation of energy transfer in many biological reactions. Therefore, understanding electron transfer is essential to the study of cellular biochemistry.

Electrons move around the nucleus as a cloud of points that is denser where the electron is most likely to be. The exact path of an electron varies, but it is possible to identify a region in space where an electron is present most of the time. The area in space where electrons circle around the nucleus is known as an **energy level** or **electron shell.** The innermost energy level may contain one or two electrons. As you can see in **FIGURE 1.3**, hydrogen has one electron in the first energy level, which is also its only energy level. Many elements that are important in biology, such as carbon, nitrogen, and oxygen, contain two energy levels. In these atoms, the second energy level may hold up to eight electrons. Figure 1.3 shows how carbon's six electrons are placed in the energy levels: two are in the first energy level and four are in the second energy level.

The amount of energy in a level depends on its location. Electrons closer to the nucleus have less energy and are less reactive than those further from the nucleus. Atoms are most stable when their energy levels are full. When electrons fill the energy levels closest to the nucleus, rather than ones further away, the element becomes more stable. If an electron gains energy and moves or "jumps" to a level further away from the nucleus, the atom is less stable. As we will see later, molecules are often formed when atoms share electrons to fill their outermost energy levels.

Since chemicals often react to complete their outermost energy levels, simple diagrams like those in Figure 1.3 give a sense of how many electrons an element must gain or lose to have a full outermost energy level. In the case of carbon, it must gain four electrons in the outer shell for a total of eight electrons. Hydrogen may either gain one electron or lose an electron to have its outermost shell complete. If an electron is lost, a hydrogen ion (H^+) forms because it now has one more proton than electrons. We will study hydrogen in greater detail when we discuss cellular energetics in Unit 3.

Chemical Properties of Elements

The electrons in an element's outermost energy level are known as the **valence electrons.** The **periodic table of**

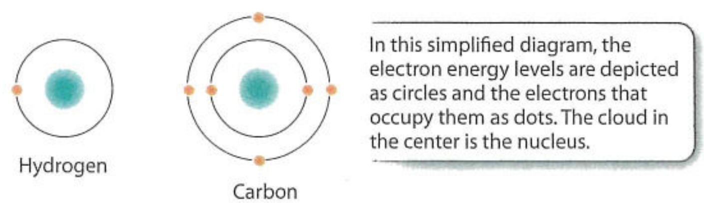


FIGURE 1.3 Energy levels for hydrogen and carbon

The hydrogen atom contains one energy level with a single electron, while the carbon atom has two energy levels with two electrons in the first energy level and four electrons in the second. The energy levels are depicted as circles and the electrons as orange dots.

Abundance in cells: High | Low | Trace | Rare or none

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71 La-Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103 Ac-Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

FIGURE 1.4 The periodic table of the elements

Elements are arranged by increasing number of protons, the atomic number. The atomic number is shown above the element. The elements in a column share similar chemical properties.

the elements, shown in **FIGURE 1.4**, describes valence electrons and other properties of elements. In the periodic table, the elements are indicated by their chemical symbols and arranged in order of increasing atomic number. For example, the second row of the periodic table begins with lithium (Li), which has 3 protons and ends with neon (Ne), which has 10 protons.

For the second and third horizontal rows in the periodic table, elements in the same row have the same number of energy levels. Moving across a row, each element has one more proton and one more electron than the preceding element.

Let's take a look at the second row of elements, those that span from lithium (Li) to neon (Ne), shown in **FIGURE 1.5**. All of these elements have two energy levels. The innermost level of all of these elements is full. Only the outermost energy level has a varied number of electrons, starting with one for lithium and progressively adding one electron to the outer shell of the elements as we move from left to right across the row, ending with eight electrons in neon's outer energy level. At the right end of the row, the energy level has a full complement of electrons.

The elements in a vertical column of the periodic table are called a group or family. Members of a group all have the same number of electrons in their outermost level. For example, carbon (C) and lead (Pb) both have four electrons in their outermost level. The number of electrons in the outermost level determines in large part how elements interact with other elements to form a diversity of molecules, as we will explore in the next section.

All living organisms are made up of atoms that can be combined to make molecules. The four elements common to every organism on the planet are carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). Although organisms use elements in the first five rows of the periodic table, these most highly used elements belong to rows 1 and 2. Phosphorus, a member of the third row, is also present in large amounts in organic molecules.

✓ Concept Check

3. **Describe** the components of an atom.
4. **Describe** how the rows and columns of the periodic table of the elements are organized.
5. **Identify** what the superscripts of ^{14}N and ^{15}N signify.
6. **Calculate** how many additional electrons would be needed to fill the outer energy level of C.
7. **Identify** the location of the electrons around an atom that have the most energy associated with them.

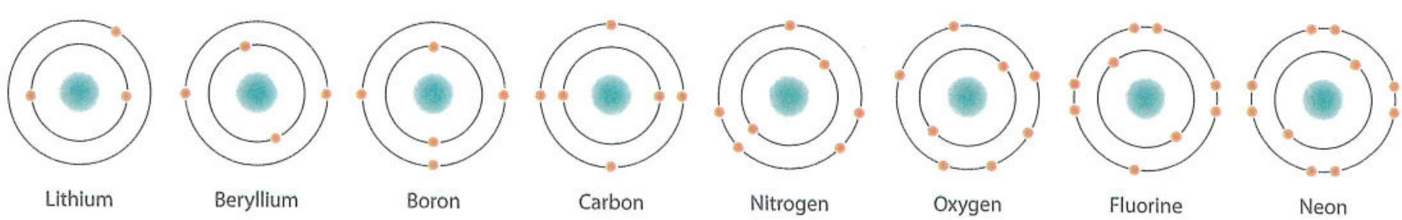


FIGURE 1.5 Number of electrons across row 2 of the periodic table

Moving from left to right, each atom contains one more electron than the last, from lithium to neon. Neon has a full complement of eight electrons in its outer energy level.

1.3 Atoms combine to form molecules linked by chemical bonds

Atoms combine to make a great diversity of molecules in cells, which in turn leads to the diversity of life. Atoms bond with other atoms to form molecules, which are groups of two or more atoms bonded together that act as a single unit. An example of a molecule is hydrogen gas (H_2), made when two atoms of hydrogen bond, as you'll see below. Note that a chemical formula is written as the letter abbreviation for each element, followed by a subscript giving the number of that type of atom in the molecule. When molecules form, the individual atoms interact through what is called a **chemical bond,** a type of attraction between atoms that holds them together. For example, joining one atom of carbon with four atoms of hydrogen creates the compound methane (CH_4), which is also known as natural gas and is used in cooking, heating, and industry. There are several ways in which atoms can interact with one another, forming different types of chemical bonds. In this section, we will look at these chemical bonds.

Covalent Bonds

The ability of atoms to combine with other atoms is determined in large part by the electrons furthest from the nucleus, the valence electrons. When atoms combine with other atoms to form a molecule, the atoms share valence electrons with each other. Specifically, when the outermost energy levels of two atoms come in close proximity, the shells may overlap with one another so that electrons are shared between the two atoms. When a pair of electrons are shared between the two atoms, a **covalent bond** is formed.

Molecules tend to be the most stable when the two atoms forming a bond share enough electrons to completely fill the outermost energy level. Chemical stability occurs when an atom or molecule has the lowest possible energy state. Stable molecules are less likely to react because they require significant inputs of energy to change bonding partners, which is what happens during chemical reactions. Very little energy is required, for example, to get dynamite to react. A stable molecule, such as nitrogen gas, requires a large amount of energy to react.

FIGURE 1.6 shows an example of the formation of covalent bond between one carbon (C) atom and four fluorine (F) atoms. Each fluorine atom (F) has seven valence electrons. When each of these F atoms forms a covalent bond with the carbon (C) atom, the outermost shells overlap due to the sharing of electrons, allowing each atom to fill its outer shell with electrons. The resulting compound, carbon tetrafluoride (CF_4), consists of one C atom covalently bound to four F atoms.

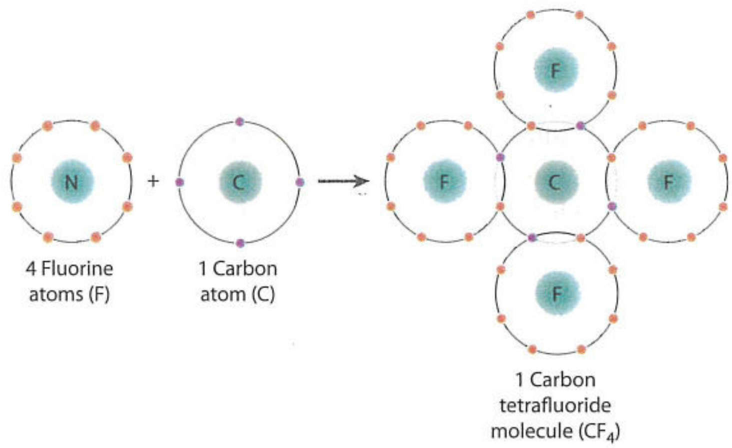


FIGURE 1.6 Covalent bonds

Covalent bonds form when atoms share a pair, or pairs, of electrons in their outermost energy levels. Four individual F atoms, each containing seven electrons in its outermost energy level, form covalent bonds with a single C atom. The C atom shares four electrons, one with every F atom, while each individual F atom shares a single electron with the C atom. By sharing electrons, each F atom and the C atom fill their outer levels.

When two atoms share two electrons in a covalent bond, a **single bond** is formed. When two atoms share two pairs of electrons covalently, a **double bond** is formed. In practice, the word "covalent" is often omitted, as it is understood that these bonds arise through a sharing of electrons and are thus covalent. A double bond is denoted by a double line connecting the two chemical symbols for the atoms. **FIGURE 1.7** shows how double bonds are represented in ethylene, a molecule that is made of two carbon atoms and four hydrogen atoms. The two carbon atoms share four electrons with each other, creating a C═C double bond. By contrast, each carbon atom shares only two electrons with a single H atom, creating a C—H single bond.

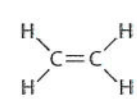


FIGURE 1.7 The double covalent bond of carbon atoms in ethylene

The double line represents four electrons shared between the two carbon atoms; each line denotes two shared electrons. The single lines connecting carbon and hydrogen represent single covalent bonds.

Polar Covalent Bonds

In molecules such as hydrogen (H_2) and oxygen (O_2) gases, electrons are shared equally by the atoms. In many covalent bonds, however, the electrons are not shared equally. A notable example, shown in **FIGURE 1.8**, is the water molecule (H_2O). A water molecule consists of two hydrogen atoms, each of which is covalently bound to a single oxygen atom. In a molecule of water, the region around the oxygen atom has a partial negative charge, while the area around each of the two hydrogen atoms has a partial positive charge. In the figure, charges are shown using the symbol δ^+ for a partial positive charge near the H atoms, and the δ^- symbol for a partial negative charge near the O atom.

Electrons are shared unequally because of a difference in the ability of the atoms to attract electrons, a property known as **electronegativity.** Oxygen is more electronegative than hydrogen. As a result, in a molecule of water, oxygen has a partial negative charge, while the two hydrogen atoms have a partial positive charge. When electrons are shared unequally between two atoms, the interaction is described as a **polar covalent bond.**

By contrast, a covalent bond where atoms are shared equally is sometimes referred to as a **nonpolar covalent bond.** The molecules of hydrogen gas (H_2), oxygen gas (O_2), and nitrogen gas (N_2) all have nonpolar covalent bonds. If two different kinds of atoms have similar electronegativities, then the covalent bonds between them also tend to be nonpolar because the electrons are shared equally, or nearly equally, by the atoms. Of the atoms commonly found in organic molecules, C and H frequently form nonpolar covalent bonds. For example, methane gas (CH_4) is a nonpolar compound.

Electronegativity tends to increase across a row in the periodic table. As the number of positively charged protons across a row increases, negatively charged electrons are held more tightly to the nucleus. This principle helps to explain why O is more electronegative than N and why N is more electronegative than either C or H.

You can think of electronegativity as the "greed" of an atom for electrons. Oxygen (O) is greedier for electrons than is nitrogen (N), carbon (C), or hydrogen (H). Note, too, that carbon, hydrogen, nitrogen, and oxygen vary in their electronegativity. Carbon and nitrogen (C—N) and carbon and oxygen (C—O) each form polar covalent bonds because electrons are not shared equally between two atoms. Atoms that are closer together in electronegativity, such as carbon and hydrogen, form covalent bonds that are not polar. When a covalent bond is established between two atoms of the same type, for instance, between two H atoms or two O atoms, both of the atoms have the same degree of electronegativity and hence the electrons are shared equally.

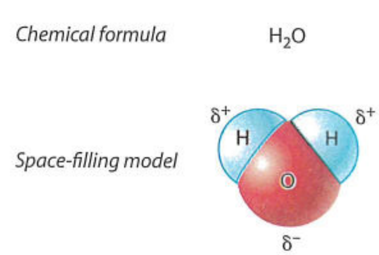


FIGURE 1.8 A polar covalent bond

In a polar covalent bond, the two atoms do not share the electrons equally. In water, the shared electrons spend more time near the O atom than either of the H atoms. The result is that the O atom has a partial negative charge, written as δ^-, while the H atoms have partial positive charges, noted as δ^+.

PREP FOR THE AP® EXAM

AP® EXAM TIP

Nonpolar and polar covalent bonds govern many of the properties of organic molecules. Knowing these concepts will help you understand how these molecules function, which will help you succeed on the AP® Biology Exam.

Ionic Bonds

In a molecule of water, the difference in electronegativity between the oxygen and hydrogen atoms leads to unequal sharing of electrons. In more extreme cases, when an atom of high electronegativity is paired with an atom of low electronegativity, the difference in electronegativity may be so great that the electronegative atom "steals" the electron from its less electronegative partner. This creates an electrically charged atom, which you may recall is known as an ion. The atom with the extra electron contains more electrons than protons, which gives it a negative charge. The atom that lost the electron has a positive charge because it now has more protons than electrons. The two ions form an **ionic bond,** a chemical bond in which two ions with opposite electrical charges associate with each other because of the differences in charge. Some atoms may gain or lose more than one electron when they form an ionic bond. For instance, the calcium ion, which is often used by cells, may be either a single (Ca^+) or a double (Ca^{++}) positively charged ion.

Sodium chloride (NaCl), which is common table salt, is an example of a compound formed by the attraction of

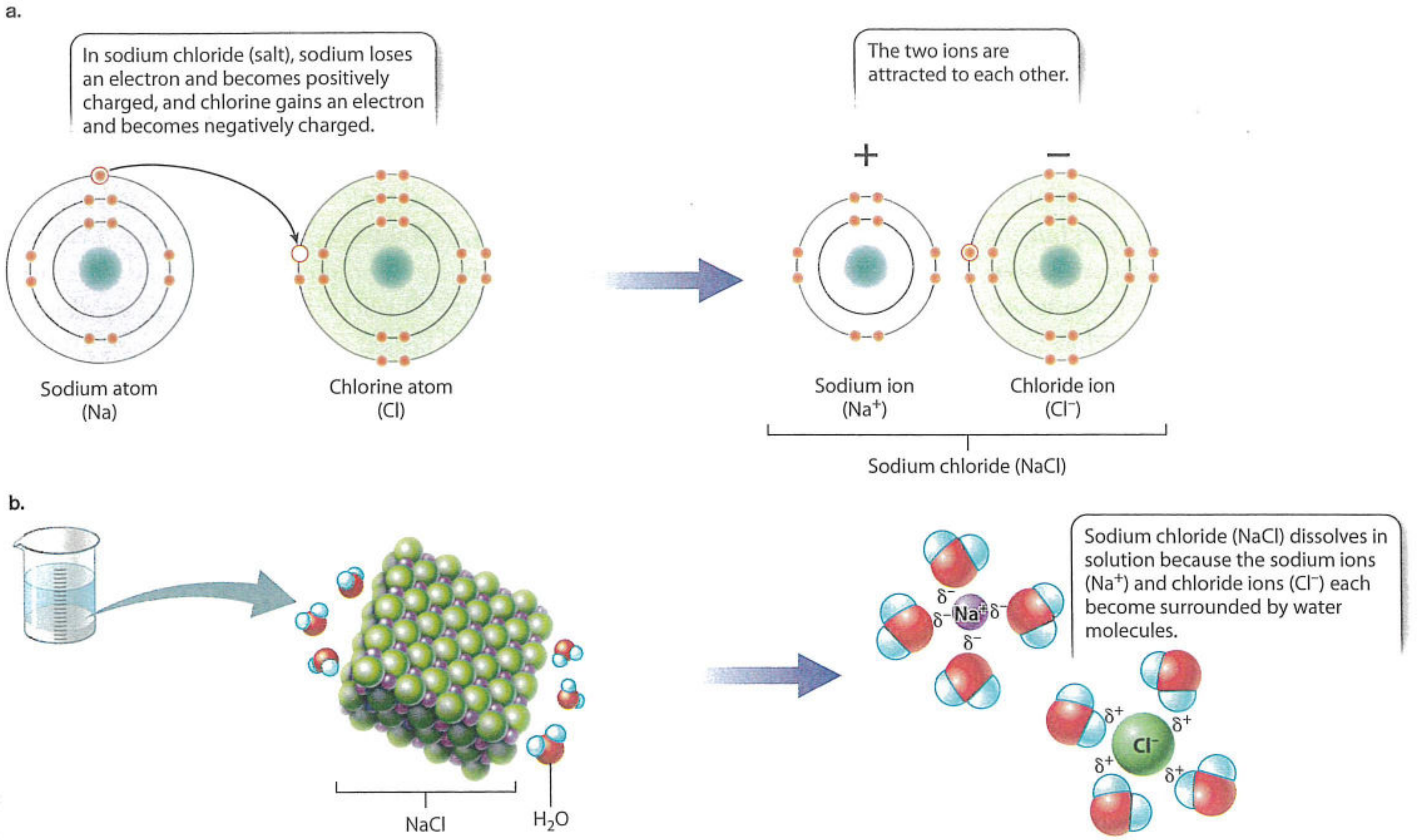


FIGURE. 1.9 An ionic bond

This figure shows how sodium chloride is formed and dissolved. (a) Sodium chloride is formed when a sodium atom gives up an electron to a chloride atom, forming Na^+ and Cl^- ions. The two ions are then attracted to each other by their opposite charges. (b) In solution, the polarity of water causes the ions to dissociate from each other and to become surrounded by water molecules, with water's negative (oxygen) ends surrounding the Na^+ ions and its positive (hydrogen) ends surrounding the Cl^- ions.

positive and negative ions. **FIGURE 1.9** illustrates the formation of sodium chloride. Sodium loses an electron and becomes a positively charged cation, while chloride gains an electron and becomes a negatively charged anion, as shown in Figure 1.9a. The two ions are then attracted to each other by their opposite charges. While covalent bonds are represented by lines like those shown in Figure 1.7, ionic bonds are indicated by superscripts showing charge, such as Na^+Cl^-.

Figure 1.9b illustrates what happens when sodium chloride is placed in water. The negatively charged ends of water molecules are attracted to the positively charged sodium ions, and the positively charged ends of water molecules are attracted to the negatively charged chloride ions. The ions are pulled apart in the water and become surrounded by polar water molecules as sodium chloride dissolves in the water. Chemicals that dissolve well in water tend to have polar or charged regions in the molecule.

In solution, sodium and chloride ions are completely surrounded by water molecules. If the water is then removed from this solution, ionic bonds will again form between the sodium and chloride ions. As the water evaporates, the concentrations of Na^+ and Cl^- increase and the two ions come together to the point where they join and precipitate as salt crystals.

Chemical Reactions

The chemical bonds that link atoms in molecules can change in a **chemical reaction,** a process by which atoms or molecules are transformed into different molecules. The atoms or molecules that are changed in a chemical reaction are called **reactants.** The molecules formed from the reaction are known as **products.** In biological systems, chemical reactions provide a way to build and break down molecules for use by the cell, as well as to harness energy.

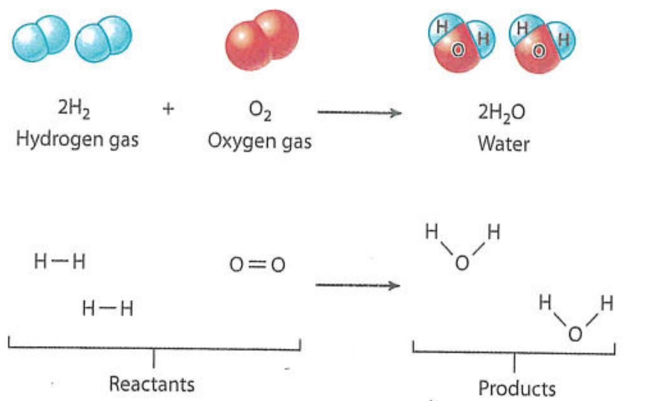


FIGURE 1.10 A chemical reaction

During a chemical reaction, atoms retain their identity, but their connections change as bonds are broken and new bonds are formed. In this reaction, a hydrogen molecule (H—H) reacts with one of the O atoms of an oxygen molecule (O═O), exchanging bonding partners and establishing H—O—H, also written as H_2O. Because this happens twice, two H_2O molecules are formed.

FIGURE 1.10 shows an example of a chemical reaction. In this case, two molecules of hydrogen gas ($2H_2$) and one molecule of oxygen gas (O_2) react to form two molecules of water ($2H_2O$). In this reaction, the numbers of each type of atom are conserved, meaning that the number of atoms does not change, but their arrangement in the reactants is different from the arrangement in the products. Specifically, the H—H single bond in hydrogen gas and the O═O double bond in oxygen gas are broken. At the same time, each oxygen atom forms new covalent bonds with two hydrogen atoms, making the products of the reaction two molecules of water.

In fact, this reaction is the origin of the word "hydrogen," which literally means "water former." The reaction releases a good deal of energy and is used in some rockets as a booster in satellite launches. Certain microorganisms also perform this reaction in a much smaller and more controlled manner. These microorganisms benefit from the released energy, which they use to perform some of their cellular biochemistry.

In biological systems, chemical reactions provide a way to build and break down molecules for use by the cell, as well as to harness energy, which can be held in chemical bonds. We explore these topics in more detail in Unit 3.

✓ Concept Check

8. **Describe** the differences among covalent bonds, polar covalent bonds, nonpolar covalent bonds, and ionic bonds.
9. Use the polar property of water to **describe** the process by which water (H_2O) dissolves sodium chloride (NaCl).
10. In the reaction $3H_2 + N_2 \rightarrow 2NH_3$, **identify** the reactants and the products.

1.4 Carbon is the backbone of organic molecules

When you first learned to read, you probably began by learning the shapes and sounds of the letters of the alphabet. After that you learned letter combinations and then simple words. Our introduction to the basic chemistry of life is similar. Now that we've reviewed the basic nature of atoms and molecules, we can turn to the chemistry of life. As we mentioned earlier, the chemistry of life is based on carbon. In this section, we will examine what makes carbon well suited to its role as the chemical backbone of living things, and introduce the four major types of organic molecules.

The Chemistry of Carbon

Hydrogen and helium are by far the most abundant elements in the universe. In contrast, the solid Earth is dominated by silicon, oxygen, aluminum, iron, and calcium. In other words, Earth is not a typical sample of the universe. Similarly, the cell is not a typical sample of the solid Earth. **FIGURE 1.11** shows the relative abundance by mass of chemical elements present in human cells after all the water has been removed. Just four elements—carbon (C), oxygen (O), hydrogen (H), and nitrogen (N)—account for approximately 90% of the total dry mass, and the most abundant element is carbon.

While other types of cells may vary somewhat, virtually all contain about the same ratios of these elements. Human life, and all life as we know it, is based on carbon. Carbon-containing molecules play such an important role in living organisms that they have a special name, as we saw earlier—they are called organic molecules. Carbon has the ability to combine with many other elements to form a wide variety of molecules, each specialized for the functions it carries out in the cell. For example, carbon-based molecules make up the structure of cells, participate in and speed up chemical reactions, and store energy for use by the cell.

Why has life evolved with carbon as its key element? Of the elements commonly observed in cells, carbon is unique in its bonding capacities. Of a carbon atom's six electrons, four are in its outermost shell and are available to form

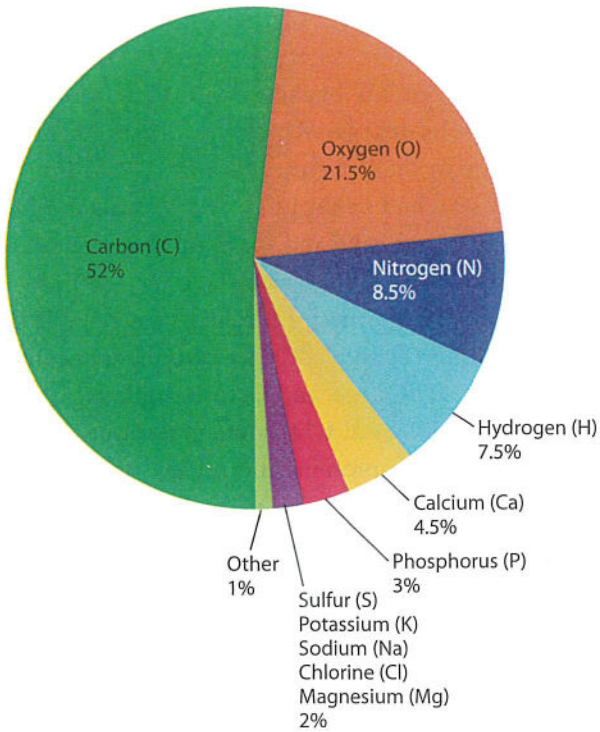


FIGURE 1.11 Approximate percentages by dry mass of chemical elements found in human cells

Carbon is the most abundant element in human cells when all of the water has been removed. Oxygen, nitrogen, and hydrogen are also relatively common. While other organisms may vary somewhat, virtually all use about the same ratios of these elements.

covalent bonds. Carbon commonly forms covalent bonds with itself, oxygen, nitrogen, and hydrogen.

FIGURE 1.12 shows methane gas (CH_4), which is formed when one atom of carbon combines with four atoms of hydrogen. Each of the four valence electrons of carbon becomes part of a covalent bond with an electron from an H atom. The bonds formed can move, or rotate, freely about their axis. In addition, the carbon atom lies at the center of a specific three-dimensional structure, called a tetrahedron, and the four covalent bonds with H extend the H atoms toward the four corners of this structure.

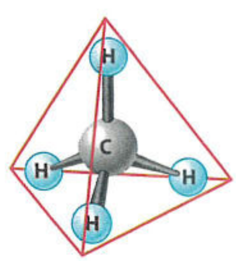


FIGURE 1.12 The shape and structure of methane

In methane gas (CH_4), a carbon atom is covalently bonded to four hydrogen atoms. The carbon atom lies at the center of a three-dimensional structure, called a tetrahedron, and the four covalent bonds with hydrogen extend the hydrogen atoms toward the four corners of this structure.

Because of its shape and because its single bonds rotate freely, carbon is able to make compounds in a variety of three-dimensional shapes. This ability to form many varied structures enables carbon to perform a wide variety of functions necessary to sustain and promote life.

Carbon has other special properties that contribute to its ability to form a diversity of molecules. For example, carbon atoms can link with other carbon atoms through covalent bonds, forming long chains. These chains can be branched, or two carbons at the ends of the chain or within the chain can link to form a ring. We also discussed earlier how carbon can form single and double bonds with other carbon atoms.

As a result of all of these properties, carbon-based molecules are structurally and functionally diverse. In other words, they can form an astonishing variety of molecules that can perform many different of roles in the cell. We might ask whether carbon is uniquely suited for life. Put another way, if we ever discover life on a distant planet, will it be based on carbon? Silicon, which is found just below carbon in the periodic table (see Figure 1.4), is the one other element that is both abundant on Earth and characterized by an outer shell with four valence electrons. Some scientists have speculated that silicon might therefore provide an alternative to carbon as a chemical basis for life. However, silicon readily binds with oxygen. On Earth, nearly all of the silicon atoms found in molecules are covalently bound to oxygen. Studies of Mars and meteorites show that silicon is tightly bound to oxygen throughout our solar system. As a result, the diversity of silicon-based molecules is far less than the millions of carbon-based molecules. If we ever discover life beyond Earth, very likely its chemistry will be based on carbon.

Organic Molecules

Four classes of organic molecules are of particular significance in biological systems: *proteins, nucleic acids, carbohydrates,* and *lipids.* Although they have different structures and roles, they share at least two properties. First, as we just discussed, they all contain carbon. Second, most of them are long chains, called **polymers,** built from smaller repeating subunits, called **monomers.** A polymer is like a necklace made of beads, and a monomer is a single bead, as shown in **FIGURE 1.13** on page 38. Here we take a first look at these four types of organic molecules. Later in this unit, we will examine each in greater detail.

Proteins are organic molecules that do much of the cell's work. They speed up chemical reactions and provide structural support for the cell. The white of an egg, for

FIGURE 1.13 Polymer

A polymer is a long chain of repeating subunits called monomers, similar to this necklace made up of individual beads. Photo: LionGate/Alamy Stock Photo

example, is mostly made up of proteins. Proteins are composed of subunits called **amino acids.** Returning to our necklace example, we would say that a protein is a necklace, and an amino acid is a bead.

A single cell has thousands of proteins with different functions. For example, some proteins form scaffolds that help to determine the shape of cells. Other proteins serve as chemical messengers, traveling from one cell to another to convey a message. Still other proteins accelerate the rate of chemical reactions. These various functions depend on the structure, or shape, of the protein. In fact, structure and function are closely connected. As a result, scientists can sometimes infer what a protein does by examining its shape. Furthermore, anything that disrupts the shape of a protein will often disrupt its function. The shape of a protein is determined by its sequence of amino acids. We will discuss proteins in more detail in Module 4.

Nucleic acids are responsible for encoding and transmitting genetic information. There are two types of nucleic acids. Module 0 mentioned deoxyribonucleic acid (DNA). The second nucleic acid is **ribonucleic acid (RNA).** Like proteins, nucleic acids are long polymers made up of repeating subunits, called **nucleotides.**

Nucleic acids are examples of informational molecules—that is, large molecules that carry information in the sequence, or order, of nucleotides that make them up. This molecular information is much like the information carried by the letters in an alphabet, but, in the case of nucleic acids, the information is in chemical form. DNA is the genetic material in all organisms. It is transmitted from parents to offspring, and it contains the information needed to specify the amino acid sequence of proteins. RNA has multiple functions, but one of its most important is in the synthesis of proteins. We will discuss nucleic acids in more detail in Module 5.

Many of us, when we feel tired, reach for a candy bar for a quick energy boost. The energy in a candy bar comes from sugars, which are quickly broken down to release energy. Sugars are **carbohydrates,** which are organic molecules that store energy in their chemical bonds. In addition, they are sometimes attached to proteins on the surface of cells, such as your red blood cells, and make up the external layer of the cells in plants, algae, and bacteria.

Carbohydrates are sometimes called sugars. Table sugar (sucrose) is a familiar example. Other carbohydrates include the sugars glucose, galactose, and lactose (milk sugar). Fruit, like that shown in **FIGURE 1.14**, contains a variety of sugars, including fructose. Like proteins and nucleic acids, carbohydrates are composed of repeating units of individual sugars, called monosaccharides.

As we have seen, proteins, nucleic acids, and carbohydrates all are polymers made up of smaller, repeating units. Lipids are different. Instead of being defined by a chemical structure, they share a particular property: **lipids** are organic molecules that are *hydrophobic.* **Hydrophobic** means "water fearing" and it describes nonpolar molecules that don't dissolve in water. Instead, they tend to associate with other lipids and minimize their contact with water. Think of what happens when oil, which is hydrophobic, is mixed with water. The oil forms droplets that minimize their contact with water, as pictured in **FIGURE 1.15**. By contrast, **hydrophilic** means "water loving" and it describes polar molecules that readily associate with and dissolve in water. For example, when sugar is placed in water, it dissolves as the individual sugar molecules associate with water molecules.

Because they share a property rather than a structure, lipids are chemically and functionally diverse. Their hydrophobic property allows them to be effective membranes, or barriers,

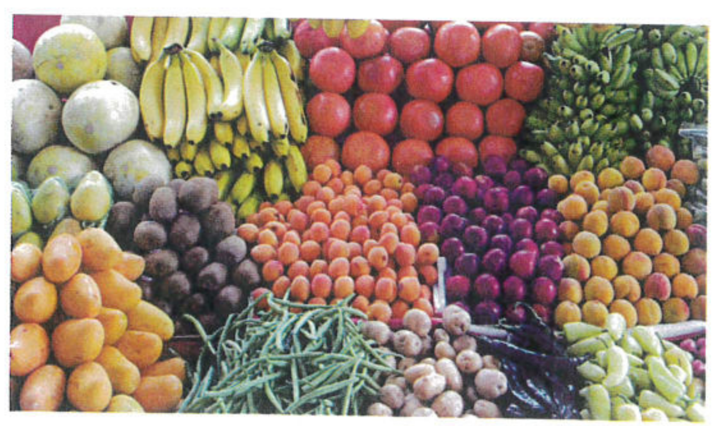


FIGURE 1.14 Carbohydrates

Fruit, such as these items at a market, contains fructose along with several other types of sugars. Sugars are types of carbohydrates. Photo: OGphoto/Getty Images

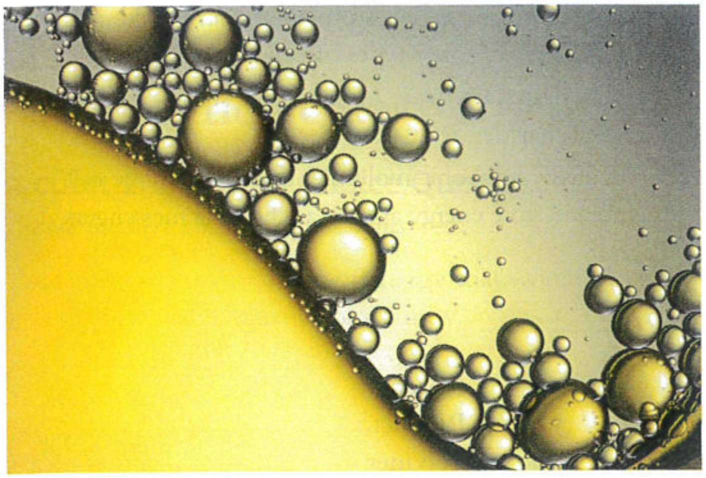


FIGURE 1.15 Lipids

When oil, which is a lipid, is mixed in water, it forms droplets to minimize its contact with water. Oil, like all lipids, is hydrophobic.

Photo: ThomasVogel/Getty Images

between a cell's watery internal and external environments. They also include signaling molecules and familiar fats that store energy and make up part of our diet. Lipids will be discussed along with carbohydrates in more detail in Module 3.

✓ Concept Check

11. **Identify** the four most common atoms in organic molecules.
12. **Describe** how the number of valence electrons in a carbon atom is responsible for carbon's ability to form a large diversity of molecules.
13. **Identify** the four major types of organic molecules.
14. **Describe** a polymer.
15. **Describe** the property of lipids that allows them to function as a barrier between a cell's interior and external environments.

Module 1 Summary

PREP FOR THE AP® EXAM

REVISIT THE BIG IDEAS

ENERGETICS: Using the content in this module, **identify** the key elements that all organisms obtain from the environment and exchange with the environment.

LG 1.1 Matter and energy govern the properties of life.

- All organisms are made up matter and require energy to sustain life. Page 26
- Organisms obtain matter from other organisms and the environment, and matter therefore moves in a cycle, with the same atoms used and reused. Page 26
- Energy from the sun or chemical compounds is used by organisms to do work but cannot be reused. Page 27

LG 1.2 The atom is the fundamental unit of matter.

- Atoms consist of protons, neutrons, and electrons. Page 30
- The atomic number is the number of protons an element contains, and it determines the identity of the element. Page 30
- The atomic mass is the number of protons and neutrons an element contains. Page 30
- Isotopes are elements with the same number of protons but different numbers of neutrons. Page 30
- Electrons occupy energy shells or levels that move around the nucleus. Page 31
- The periodic table organizes all of the elements in a way that describes their properties. Page 31

LG 1.3 Atoms combine to form molecules linked by chemical bonds.

- Valence electrons are the electrons in an atom's outermost energy shell and determine the ability of an atom to combine with other atoms to form molecules. Page 31
- Covalent bonds arise when two elements share one or more pairs of electrons. Page 33
- Covalent bonds may be either nonpolar or polar. Page 34
- Ionic bonds result from the attraction of oppositely charged ions. Page 34
- Chemical reactions involve the breaking and forming of chemical bonds, forming new molecules. Page 35

LG 1.4 Carbon is the backbone of organic molecules.

- Carbon's electron configuration allows it to form four covalent bonds. Page 36
- Carbon's bonding allows a diversity of molecules to be formed. Page 37
- The four major classes of organic molecules are proteins, nucleic acids, carbohydrates, and lipids. Page 37
- Proteins play a role in the structure of cells and can speed up the rate of chemical reactions. Page 37

- Proteins are made up of subunits called amino acids. Page 38
- Nucleic acids are information molecules and the molecules of heredity. Page 38
- Nucleic acids are made up of subunits called nucleotides. Page 38
- Carbohydrates, or sugars, store energy and make up the external layer of some types of cells. Page 38
- Carbohydrates are made up of simple sugars, called monosaccharides. Page 38
- Lipids are hydrophobic molecules that make up the cell membrane, store energy, and act as chemical messengers. Page 38

Key Terms

Matter
Atom
Molecule
Organic molecule
Nucleus
Proton
Neutron
Electron
Atomic number
Element
Atomic mass
Isotope
Ion
Energy level
Electron shell
Valence electron
Periodic table of the elements
Chemical bond
Covalent bond
Single bond
Double bond
Electronegativity
Polar covalent bond
Nonpolar covalent bond
Ionic bond
Chemical reaction
Reactant
Product
Polymer
Monomer
Protein
Amino acid
Nucleic acid
Ribonucleic acid (RNA)
Nucleotide
Carbohydrate
Lipid
Hydrophobic
Hydrophilic

Review Questions

1. Using the periodic table shown in Figure 1.4, identify which atom is most likely to have properties similar to nitrogen.
   (A) Oxygen (O)
   (B) Bismuth (Bi)
   (C) Lead (Pb)
   (D) Carbon (C)

2. The element sodium (Na) has an atomic number of 11 and an atomic mass of 23. Calculate the number of protons and neutrons in Na.
   (A) 11 protons and 11 neutrons
   (B) 11 protons and 10 neutrons
   (C) 11 protons and 12 neutrons
   (D) 10 protons and 13 neutrons

3. Which type of bond is formed between a sodium ion and a chloride ion?
   (A) Ionic
   (B) Neutral
   (C) Polar covalent bond
   (D) Nonpolar covalent bond

4. Which type of bond is formed between two oxygen atoms?
   (A) Ionic
   (B) Neutral
   (C) Polar covalent bond
   (D) Nonpolar covalent bond

5. When two molecules undergo a chemical reaction, they
   (A) lose atoms.
   (B) keep the same bonding partners that they had as reactants.
   (C) establish new bonding partners.
   (D) incorporate atoms from the air and water as well as from the reactants.

6. Proteins, nucleic acids, and carbohydrates are all
   (A) information molecules.
   (B) signaling molecules.
   (C) polymers made up of repeating subunits.
   (D) monomers that combine to form polymers.

7. Two organic molecules that store energy for use by the cell are
   (A) carbohydrates and nucleic acids.
   (B) carbohydrates and lipids.
   (C) proteins and nucleic acids.
   (D) nucleic acids and lipids.

Module 1
AP® Practice Questions

PREP FOR THE AP® EXAM

Section 1: Multiple-Choice Questions

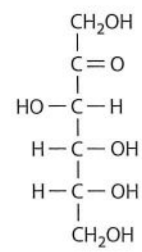
Choose the best answer for questions 1–5.

1. Identify the main source of energy that would sustain a shallow water aquatic community.
   (A) Carbon
   (B) Sunlight
   (C) Chemical compounds
   (D) Heat

2. Which is the best example of the flow of matter through a community?
   (A) Sunlight is necessary for trees to grow → leaves wash into a cave where they are colonized by fungi and bacteria → small mites graze on the bacteria for food → insects and spiders feed on the mites.
   (B) Deep-sea volcanic activity forms vents on the ocean floor → superheated water dissolves minerals and metals → bacteria use these minerals to survive → many organisms depend on the bacteria as a food source.
   (C) The decomposition of animals from millions of years ago formed oil → oil is used by humans as a fossil fuel → burning fossil fuels releases CO_2 into the atmosphere → CO_2 is used by plants to produce O_2 → O_2 is consumed by many living animals.
   (D) A meadow of wildflowers absorbs solar energy → each flower converts this into sugars → the flowers use the sugars to grow and reproduce.

3. Fluorine (F) is a strongly electronegative element with seven valence electrons in its outermost energy level. Compared to the less electronegative sodium (Na), which has one valence electron in its outermost level, fluorine
   (A) holds electrons loosely around its nucleus.
   (B) is not as greedy to gain electrons.
   (C) will have a partial positive charge when it bonds to other elements.
   (D) is likely to become an anion.

Questions 4 and 5 refer to the chemical structure of the sugar fructose shown below.



4. Identify the type of bond linking the oxygen and hydrogen atoms.
   (A) Covalent
   (B) Ionic
   (C) Electronegative
   (D) Double

5. Name the organic molecule that has this structure.
   (A) Protein
   (B) Nucleic acid
   (C) Carbohydrate
   (D) Lipid