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Biology
Today and Tomorrow
With Physiology

6e

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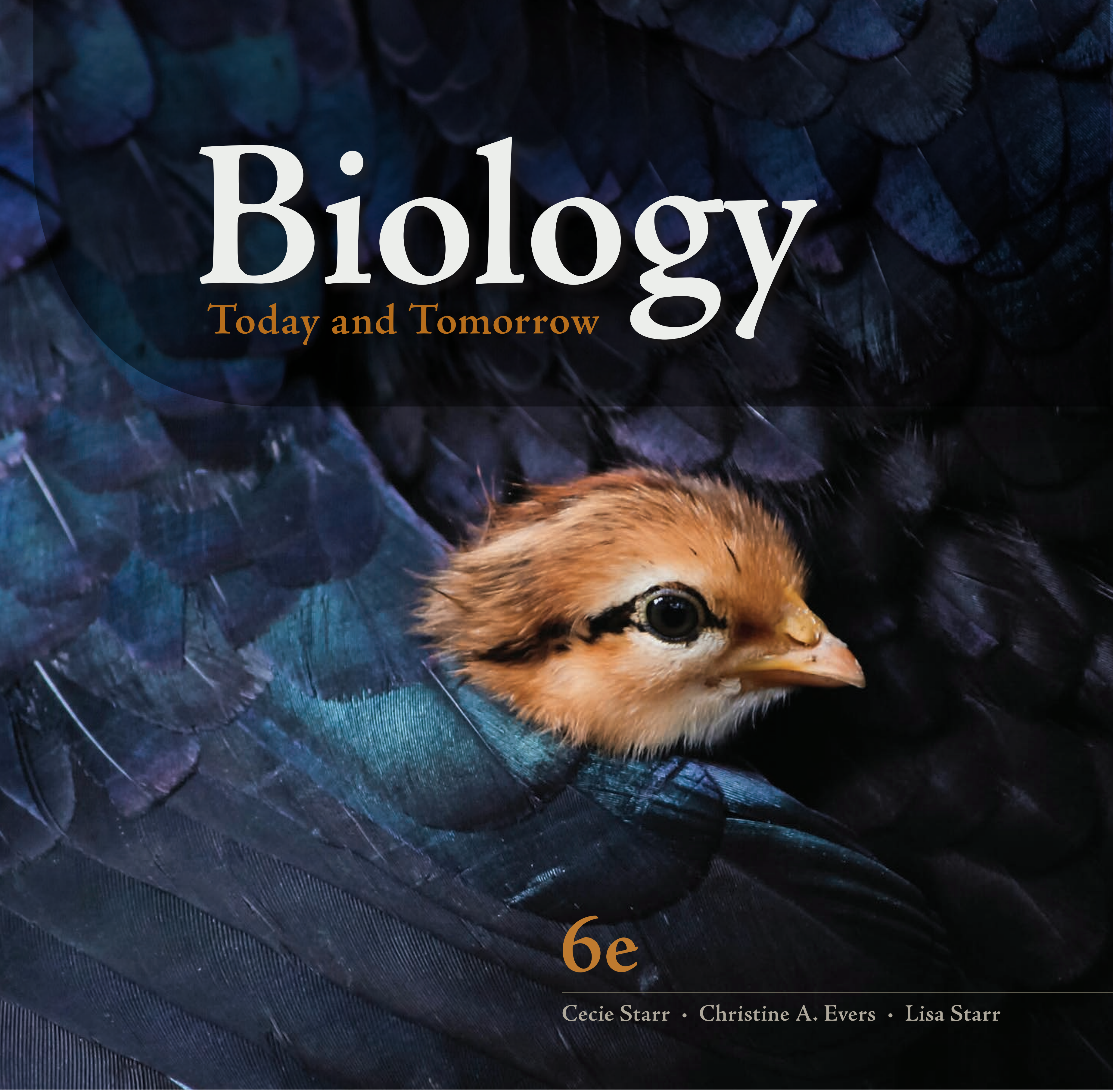

Biology

Today and Tomorrow

6e

Cecie Starr • Christine A. Evers • Lisa Starr

CENGAGE

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Biology: Today & Tomorrow,
Sixth Edition
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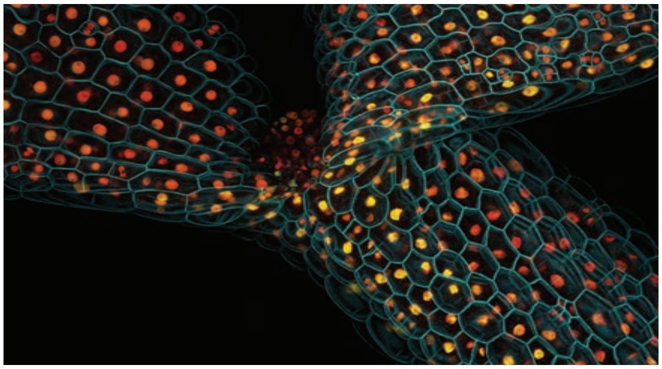

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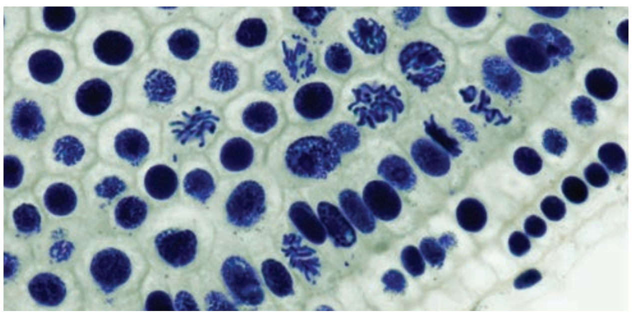
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PREFACE

The easy, instant availability of information on a global scale is both facilitating and complicating science education. Biology in particular is a huge field, with a wealth of new discoveries being made daily, and biology-related issues such as climate change, gene editing, and the global spread of diseases making headlines all the time. In an age when anyone can post anything, distinguishing fact from opinion is more challenging—and more important—than ever.

Biology: Today and Tomorrow presents accurate, up-to-date content in accessible language, with stunning images and beautiful art that bring the narrative to life. This book fosters scientific literacy skills by prioritizing active learning about the process of science, and it engages students with a host of real-world applications that illuminate the relevance of biology in everyday life.

FEATURES OF THIS EDITION

As always, the text has been updated with new discoveries and current research. This edition has been aligned with "Vision and Change" recommendations: Core concepts emphasized and explored in every chapter facilitate learning from every perspective (molecular, cellular, ecological, organismal, and so on), and several new and enhanced features encourage active learning.

Setting the Stage Each chapter opens with an eye-catching photo and a brief **CONCEPTS CONNECTIONS** feature that links the chapter's content with concepts in previous and future chapters. The opening **APPLICATION** section explores an interesting current event or social issue related to the chapter's topic. For example, a discussion of binge drinking on college campuses introduces the concept of metabolism in Chapter 4. This Application section links the function of enzymes in the body's main alcohol-breakdown pathway to hangovers and cirrhosis. Open-ended **DISCUSSION QUESTIONS** at the end of each Application section are intended to facilitate classroom discussions and critical thinking about the Application's topic.

Emphasis on Relevance An expanded focus on applications that distinguishes this book allows students to understand the relevance of a topic while learning about it. At every opportunity, opening Application topics are revisited in section content, and in end-of-chapter assessments. For example, Section 4.4 (Enzymes and Metabolic Pathways) includes a paragraph about the role of the coenzyme NADH in the mechanism by which heavy drinking causes fatty liver; in Section 4.5 (Diffusion across Membranes), a discussion about osmotic pressure includes the mechanism by which body tissues swell with fluid in cirrhosis; and an end-of-chapter Critical Thinking question asks students to connect the alcohol flushing reaction with genetically based differences in the alcohol-breakdown pathway. (Discussions related to health and the environment are marked in the index with red and blue squares, respectively.)

Section-Based Learning Objectives **LEARNING OBJECTIVES** associated with each section are phrased as activities that students should be able to carry out after reading the text.

Chunked Content To decrease student cognitive load and facilitate chapter review, concepts have been titled in the core narrative of each section.

Take-Home Message At the end of each section, a **TAKE-HOME MESSAGE** box that provides a brief summary of section concepts is useful for study review.

Highly Visual Learning Beautiful art with extended callouts enhances visual learning of complex mechanisms in the new chapter-based **CLOSER LOOK** feature. The feature includes one or more **FIGURE IT OUT** questions designed to engage students in an active learning process; an upside-down answer allows a quick check of understanding.

On-Page Glossary An **ON-PAGE GLOSSARY** includes boldface key terms introduced in each two-page spread. This spread-based glossary can be used as a quick study aid. All glossary terms also appear in boldface in the Chapter Summary.

SELF-ASSESSMENT TOOLS

Many figure captions include a **FIGURE IT OUT** question. At the end of each chapter, **SELF-QUIZ** and **CRITICAL THINKING QUESTIONS** provide additional self-assessment material. Another active-learning feature, the in-text **DIGGING INTO DATA** activity, sharpens analytical skills by asking students to interpret data presented in graphic or tabular form. The data presented are relevant to the chapter and are from published scientific studies.

HIGHLIGHTS OF REVISION UPDATES

1 **Invitation to Biology** Much-expanded material in a new section, "The Nature of Science," includes detailed coverage of pseudoscience and how it differs from science. New Critical Thinking questions about cherry-picking climate change data and MMR vaccine pseudoscience.

2 **Molecules of Life** Application section updated with new FDA ban of PHOs. New content includes current research on pathogenesis of amyloid diseases. New figures: bond polarity;

patterns of protein secondary structure; prion structure changes. New Critical Thinking question about how using palm oil as a substitute for PHOs is exacerbating deforestation. Closer Look feature: How protein structure arises.

3 **Cell Structure** New content includes theory of living systems; discussion of nuclear pores, tau tangles, and Alzheimer's disease. New tables: eukaryotic organelles; collective properties of living systems. New photographs: micrographs of gut microbiota, nuclear membrane, and basement membrane. New Critical Thinking question about why some meat contaminated with toxic strains of bacteria is not safe to eat even after cooking. Closer Look features (2): Some interactions among components of the endomembrane system; cell junctions in animal tissues.

4 **Energy and Metabolism** New content: how heavy drinking causes fatty liver; fluid balance in the body. New figures: feed conversion ratio; comparing activation energy in energy-releasing and energy-requiring reactions; enzymes lower activation energy; firefly luciferase. New Critical Thinking question about the alcohol flushing reaction and alcohol metabolism. Closer Look feature: Examples of membrane-crossing mechanisms.

5 **Photosynthesis** For this edition, expanded material on photosynthesis and respiration has been separated into two chapters. New overview section includes discussion of autotrophs, heterotrophs, and stomata function. Other new content: special pairs; bacteria that carry out infrared photosynthesis; increased efficiency of the Calvin–Benson cycle in engineered plants. New Digging Into Data activity about CO_2 emissions from fossil fuels. New figures include atmospheric CO_2 level over the last 800,000 years; correlation between atmospheric CO_2 content and temperature since 1880; how photosynthesis sustains life; correlation between light wavelength and energy; red algae (photosynthetic pigment adaptation). New research correlating wildfire severity with rising global temperatures is included with a stunning photo of the 2018 Mendocino complex wildfire. Closer Look feature: Light-dependent reactions of photosynthesis, noncyclic pathway.

6 **Respiration** New content includes Application about mitochondrial diseases, cellular respiration, and oxidative stress; introductory section comparing aerobic respiration with fermentation; glycolysis reactions; ketogenic diet mechanism. New figures: glycolysis reactions, alcoholic fermentation reactions; lactate fermentation reactions. New Digging Into Data activity about the reprogramming of brown fat mitochondria by dietary fat overload. Closer Look features (2): Aerobic respiration continues in mitochondria; food to energy.

7 **DNA Structure and Function** New content includes introduction to PCR; expanded material on mutations includes dose-dependent DNA damage by ionizing radiation, and cancer-causing chemicals in foods and industrial/household products. New figures: components of a nucleotide; micrographs of DNA packing; mutated flowers from Chernobyl. Closer Look feature: DNA packing in eukaryotic chromosomes.

8 **From DNA to Protein** New content includes concepts of coding and noncoding strands; a beneficial hemoglobin mutation (HbC); and expanded material on epigenetics. New art: how transcription copies a gene into RNA form; comparison of uracil/thymine and ribose/deoxyribose; how transcription produces an RNA copy of a gene; RNA polymerase binding to promoter; alternative splicing; surface renders of ribosome subunits; effect of a mutation in a regulatory site; points of control over gene expression; replication of methylated DNA. New table compares features of DNA and RNA. Closer Look feature: Translation.

9 **How Cells Reproduce** New content includes current research and paradigms on cytoplasmic division and senescence; concept of polygenic inheritance; Mary Claire-King's discovery of *BRCA1*. New figures: micrograph showing mitosis in a human embryo; micrograph of mitotic spindle; fluorescence micrographs of checkpoint proteins; different modes of reproduction; meiosis halves the chromosome number, and fertilization restores it. New table comparing asexual and sexual reproduction. New Critical Thinking question about HPV and cancer. Closer Look features (2): Mitosis; meiosis.

10 **Patterns of Inheritance** New content includes current paradigms for CF, Huntington's, progeria, Tay–Sachs, and DMD; and concept of developmental flexibility in plant phenotype. New photos: cells lining trachea; seasonal changes in plants; albino iris; IVF. Closer Look feature: Breeding experiments with the garden pea.

11 **Biotechnology** New content includes forensic genealogy case; AquAdvantage Salmon; mechanism, applications, and social implications of CRISPR gene editing. New figures: Exponential amplification of DNA by PCR; photo of Golden Rice; example of CRISPR gene editing. New table lists human genome statistics. Closer Look feature: An example of cloning.

12 **Evidence of Evolution** Cetacean evolutionary sequence updated to reflect currently accepted narrative. New art: photo of *Dorudon atrox* fossil; stem reptile; plate tectonics; paleogeography Mercatur projections. Closer Look feature: Geologic time scale correlated with sedimentary rock in the Grand Canyon.

13 **Processes of Evolution** New content includes updated material on antibiotic resistance and overuse of antibiotics in livestock; forensic phylogenetics case; phylogeny of ST131 superbug. New figures: photos of variation in earlobe attachment; genetic drift, bottleneck, and the founder effect; evolution of ST131. Art updates to reflect current research: *HbS* allele frequency vs. incidence of malaria; sympatric speciation in wheat. New Critical Thinking question about the EPA's 2019 approval of medically important antibiotics in the treatment of citrus greening disease. Closer Look feature: How reproductive isolation prevents interbreeding.

14 **Prokaryotes, Protists, and Viruses** Updated information about the role of the human microbiome in health and disease and the

proposed fossil evidence of early life. Increased emphasis on the ecological importance of bacteria. Updated figures illustrating binary fission and bacteriophage replication. New information about antibiotic mechanisms. Discussion of protists now organized around ecology, rather than phylogeny. New Critical Thinking questions about the human virome, and the effects of pesticides on pollinator microbiomes. Closer Look feature: Replication of HIV.

15 Plants and Fungi Updated figures depicting plant and fungal life cycles. New table compares plant, fungal, and animal traits. New figure illustrating the hyphae in a mushroom. New photo of peat bog. Updated information about white-nose syndrome in bats. New Critical Thinking question about plant defenses against wheat stem rust. Closer Look features (2): Moss life cycle; fern life cycle.

16 Animal Evolution New content about and photo of the oldest known fossil animal. New graphic of sea star anatomy. Updated discussion of early *H. sapiens* migrations. New Critical Thinking question about medicinal compounds derived from spider venom. Closer Look feature: One model of human evolution.

17 Population Ecology New content about human overharvesting of horseshoe crabs lowering the carrying capacity of the environment for migratory red knot sandpipers. Updated nation-based age structure diagrams. New Critical Thinking questions, estimating size of a Canada goose population, predation on horseshoe crabs, effect of house sparrow introduction on bluebird populations, factors affecting human population growth. Closer Look feature: Logistic growth.

18 Communities and Ecosystems Revised table better depicts the variety of interspecific interactions. New content includes biological pest control, biological accumulation and magnification of toxins, nutrient pollution and algal blooms, and ocean acidification. Updated coverage of the rise in atmospheric carbon dioxide and added information about the data that indicate this increase is a result of fossil fuel use. New Critical Thinking questions about studying the history of the atmosphere and pollutant accumulation in marine mammals. Closer Look feature: The nitrogen cycle.

19 The Biosphere and Human Effects New opening Application about the decline of monarch butterflies. Content reorganized: Deforestation discussed with forest biomes, desertification with desert biomes. New content includes current threats to Brazilian rainforest. Updated coverage of acid rain, ozone depletion, and biodiversity hot spots. New Digging Into Data activity about marine plastic pollution. New Critical Thinking questions about preserving monarch butterflies, effects of ozone depletion on phytoplankton, and how Brazilian deforestation alters local climate.

20 Animal Tissues and Organs New content includes carcinomas, hyperthermia, and hypothermia. Revised figure illustrating thermal homeostasis. New Critical Thinking questions about inducing fibroblasts to become pluripotent, organelle abundance in secretory epithelia, effects of vitamin C deficiency on tissues, and benefits of epithelia turnover. Closer Look feature: Structure of human skin.

21 How Animals Move Revised art depicting actin-myosin interactions. New content includes joint injuries and disorders, creatine supplementation. New Critical Thinking question about effects of prolonged sitting. Closer Look feature: Actin-myosin interaction.

22 Circulation and Respiration New content includes blood transfusions and blood banking, strokes, sleep apnea, and health effects of smoking marijuana and of vaping. New Data Analysis question compares effects marijuana and tobacco smoking on lung function. New Critical Thinking questions about "canary in a coal mine," hands-only cardiac resuscitation, and artificial hemoglobin. Closer Look feature: Capillary exchange.

23 Immunity New content includes use of antibodies in research; CAR T cell therapy; role of keratinocytes as immune cells in contact allergies; lymphocyte maturation. Much-expanded material on herd immunity, with narrative about an unvaccinated child contracting measles. New photos: macrophages attacking parasitic worm; Pap smear comparison; bacteria on mobile phone; mast cell in situ; oral bacteria on a cheek cell; complement pore; phagocytosis of fungal cells by a dendritic cell; immunofluorescence; cell-to-cell transmission of HIV; baby with measles. New art: antigen display by MHC molecules. New table comparing antibody-mediated and cell-mediated responses. New Critical Thinking questions: Different types of vaccine preparations; CAR T cell therapy. Closer Look features (3): Example of inflammation as a response to bacterial infection; an example of an antibody-mediated response; an example of a cell-mediated response.

24 Digestion and Excretion New content includes discussion of screening methods for obesity, role of the microbiota in digestive health and disease, and importance of basal metabolic rate. New Critical Thinking questions about obesity-related alleles and paying kidney donors. Closer Look feature: How urine forms.

25 Neural Control and the Senses Updated information about concussions in football players. New content about neuromodulators, fibromyalgia. Simplified figure comparing sympathetic and parasympathetic effects. Revised figures depicting action potential, visual accommodation, organization of the retina. New Critical Thinking questions about head injury, loss of sweetness receptor in carnivores, pain perception in insects, and effects of alcohol on the cerebellum. Closer Look feature: Action potential.

26 Endocrine Control Improved illustration of pituitary function. New content includes hormonal effects of BPA (bisphenol A), phthalates, and light pollution; discovery of insulin. New Critical Thinking questions about action of endocrine disruptors, phthalates and developmental delays, climate change and seasonal hormonal changes. Closer Look feature: Two mechanisms of hormone action.

27 **Animal Reproduction and Development** New content about surgical deliveries. Improved figure showing changes in hormone levels during the female reproductive cycles. Contraception, infertility, and STDs now covered in a final section. New Critical Thinking questions about IVF and female infertility. Closer Look feature: Hormones and the female reproductive cycle.

28 **Plant Form and Function** New content includes use of sunflowers in phytoremedation of Hiroshima, Chernobyl, and Fukushima. New art shows external structure of monocot and eudicot stems. New Critical Thinking question about hyperaccumulators in phytoremediation. Closer Look features (3): Internal structure of a typical eudicot leaf; cohesion–tension theory; and translocation of sugars in phloem from source to sink.

29 **Plant Reproduction and Development** New content includes role of *Varroa* mites and deformed wing virus in CCD; nastic movements. New photos: *Varroa* mite on honeybee; pollinators sharing pathogens; embryonic leaves in a peanut; monocot embryo; and Venus flytrap capturing a fly. Detail added to plant life cycle art for accuracy. New Critical Thinking question about the keruru as the last surviving dispersal agent for puriri seeds. Closer Look feature: Life cycle of a typical eudicot.

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Chapter Homework Assign chapter homework that encourages students to apply what they have learned.

Chapter Quiz Assign chapter quizzes to assess student performance and inform class learning needs.

Chapter Case Study Build real-world data analysis and critical thinking skills with short chapter-level cases.

Tom McHugh/Science Source

ACKNOWLEDGMENTS

Writing, revising, and illustrating a biology textbook is a major undertaking for two full-time authors, but our efforts constitute only a small part of what is required to produce and distribute this one. We are truly fortunate to be part of a huge team of very talented people who are as committed as we are to creating and disseminating an exceptional science education product.

Biology is not dogma; paradigm shifts are a common outcome of the fantastic amount of research in the field. Ideas about what material should be taught and how best to present that material to students changes from one year to the next. It is only with the ongoing input of our many academic reviewers and advisors (previous page) that we can continue to tailor this book to the needs of instructors and students while integrating new information and models. We continue to learn from and be inspired by these dedicated educators.

On the production side of our team, the indispensable Lori Hazzard orchestrated a continuous flow of files, photos, and illustrations while managing schedules, budgets, and whatever else happened to be on fire at the time. Lori, thank you for your patience and dedication. Thank you also to Ragav Seshadri, Kelli Besse, and Christine Myaskovsky for your help with photoresearch. Copyeditor Heather McElwain and proofreader Heather Mann, your valuable suggestions kept our text clear and concise.

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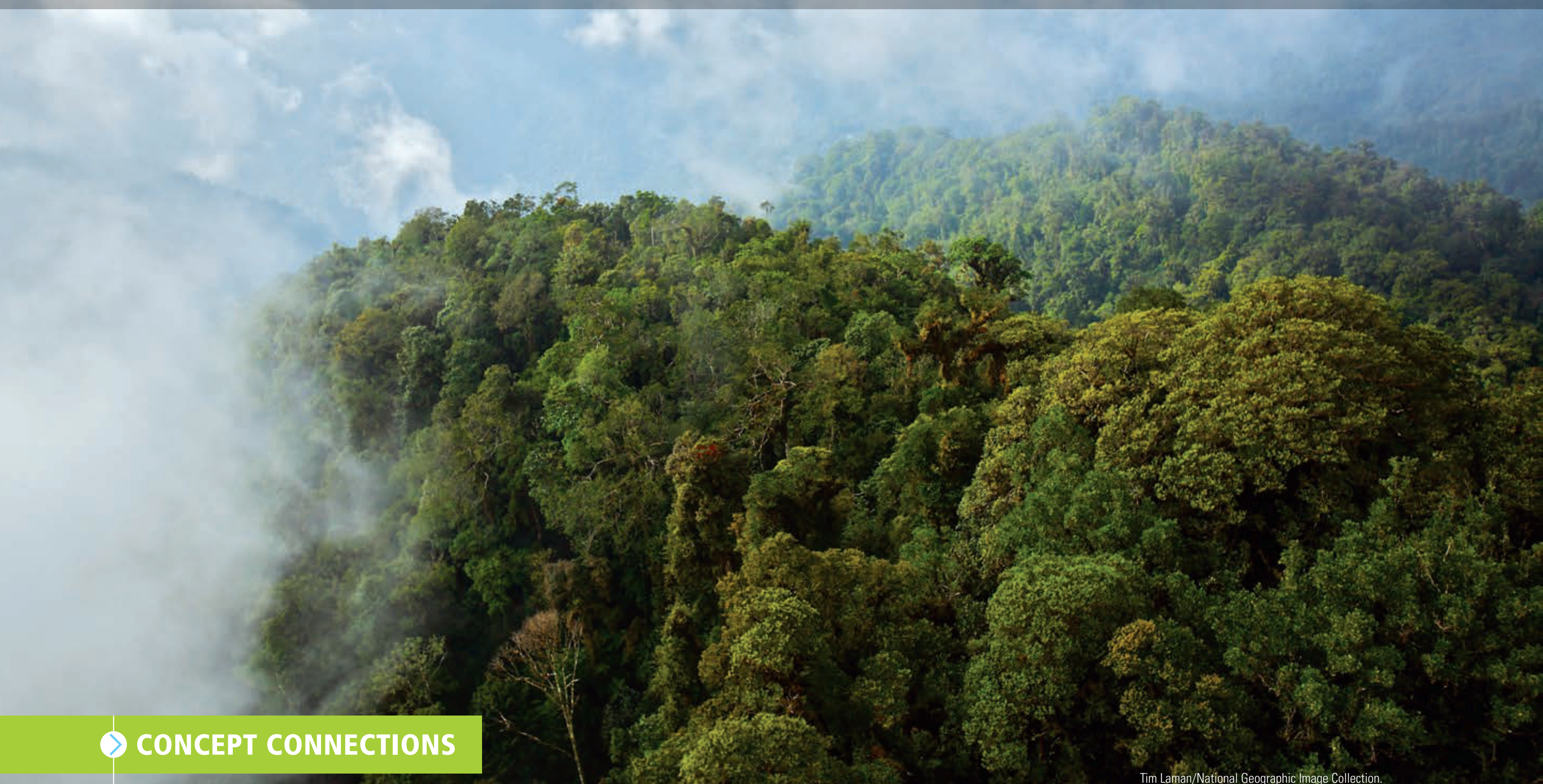
Cengage acknowledges and appreciates Lisa Starr's contribution of more than 300 pieces of art to this edition.

1

Invitation to Biology

The cloud forest that covers about 2 million acres of New Guinea's Foja Mountains is extremely remote and difficult to access, even for native people of the region. Explorers are still discovering new species in it.



Tim Laman/National Geographic Image Collection.

CONCEPT CONNECTIONS

Whether or not you have studied biology, you already have an intuitive understanding of life on Earth because you are part of it. Every one of your experiences with the natural world—from the warmth of the sun on your skin to the love of your pet—has contributed to that understanding.

The organization of this book parallels nature's levels of organization, from atoms to the biosphere. Learning about the structure and function of atoms and molecules will prime you to understand how living cells work. Learning about processes that keep a single cell alive can help you understand how multicelled organisms survive. Knowing what it takes for organisms to survive can help you see why and how they interact with one another and their environment.

APPLICATION

1.1 The Secret Life of Earth

Could there possibly be any places left on Earth that humans have not yet explored? Actually there are, and many of these places remain unexplored because they are difficult or impossible for us to access. Consider a mile-high cloud forest in the Foja Mountains of western New Guinea. This forest is huge, covering around 2 million acres of the region, but extremely rugged terrain kept it completely isolated from humans. Recently, persistent explorers found an opening in the forest large enough for a helicopter to drop them off. Since then, about forty new **species**—unique types of organisms—have been found in this forest, including a rhododendron plant with flowers the size of dinner plates, a rat the size of a cat, and a frog with an erectile nose (**Figure 1.1A**).

Today, researchers no longer need to leave their offices to find places that are untouched by humans. In 2012, conservation scientist Julian Bayliss was perusing Google Earth when he spied a curious pimple rising from a jungled plain in Mozambique, Africa. The pimple was Mount Lico, a 2,300-foot extinct volcano with a lush rain forest on top of it. Bayliss realized that Lico's smooth, vertical rock face would be extremely difficult to climb, so he suspected that the forest had remained hidden and isolated. Six years later, two professional rock climbers helped Bayliss and his team of experts make the arduous ascent up Mount Lico. Exhaustion quickly gave way to excitement when the mud-caked scientists reached the summit because, as Bayliss had suspected, the forest was pristine. Over the next ten days, the team members discovered a host of new species: snakes, frogs, fish, butterflies, crabs, flowering plants, and so on (**Figure 1.1B**).

New species are discovered all the time, even in unexpected places. In 2018, for example, a new type of tardigrade (a tiny animal) was found in the parking lot of an apartment complex. Each discovery is a reminder that we do not yet know all of the species that share our planet. We don't even know how many to look for.

How do we know what species a particular organism belongs to? What is a species, anyway, and why should discovering a new one matter to anyone other than biologists? You will find the answers to such questions in this book. They are part of the scientific study of life, **biology**, which is one of many ways we humans try to make sense of the world around us.

Trying to understand the immense scope of life on Earth gives us some perspective on where we fit into it. Ironically, the more we learn about the natural world, the more we realize we have yet to learn. Whether or not we are aware of it, humans are intimately connected with the world around us. Our activities are profoundly changing the entire fabric of life on Earth. These changes are, in turn, affecting us in ways we are only beginning to understand.

biology The scientific study of life.
species A unique type of organism.

A. Paul Oliver discovered this tiny tree frog perched on a sack of rice during the first survey of a cloud forest in the Foja Mountains of New Guinea. It was named the Pinocchio frog because the male's long nose inflates and points upward during times of excitement.

B. Ana Gledis da Conceição Miranda discovered an as-yet unidentified mouse during the first survey of the rain forest atop Mount Lico, in Mozambique.

Figure 1.1 Discovering new species in unexplored places.
(A) Tim Laman/National Geographic Image Collection; (B) Jeffrey Barbee/Allianceearth.org.

DISCUSSION QUESTIONS

1. Hundreds of new species are discovered every year, but about 20 species become extinct every minute in rain forests alone—and those are only the ones we know about. Human activities are responsible for a massive acceleration in the rate of extinctions. Unless this trend is reversed, we will never know about most of the species that are alive on Earth today. Why does that matter?
2. How could the discovery of a new species of plant or animal impact humans beyond adding to our knowledge of the world?
3. Explain the statement "the more we learn about the natural world, the more we realize we have yet to learn."

Figure 1.2 The same materials, assembled in different ways, form objects with different properties.
The property of "roundness" emerges when these squares are assembled in a certain way.

1.2 Life Is More Than the Sum of Its Parts

LEARNING OBJECTIVES

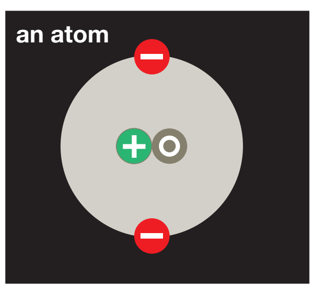
- Describe the successive levels of life's organization.
- Use examples to explain how complex properties can emerge from interactions among simpler components.

Biologists study life. What, exactly, is "life"? We may never actually come up with a satisfying definition, because living things are too diverse, and they consist of the same basic components as nonliving things. When we try to define life, we end up with a long list of properties that differentiate living from nonliving things. These properties often emerge from the arrangements or interactions of basic components (**Figure 1.2**).

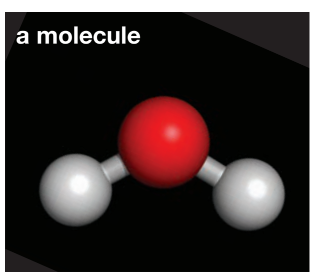
Consider a complex behavior called swarming that is characteristic of honeybees. When the bees swarm, they fly en masse to establish a hive in a new location. Each bee is autonomous, but the new hive's location is decided collectively based on an integration of signals from hive mates. A swarm's collective intelligence is a property that does not appear in the swarm's components (individual bees).

Life's Organization

Biologists view life in increasingly inclusive levels of organization. Interacting components of one level compose larger, more complex structures and systems of the next. The interactions give rise to new properties that emerge at each level. Later chapters detail these systems; here, we give a preview.

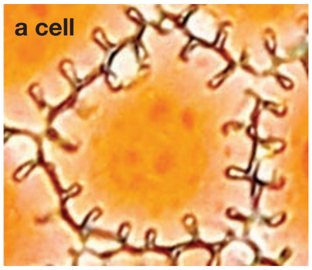


Atoms An **atom** is the smallest unit of matter. All matter consists of atoms and the fundamental particles that compose them. No atoms are unique to living things.

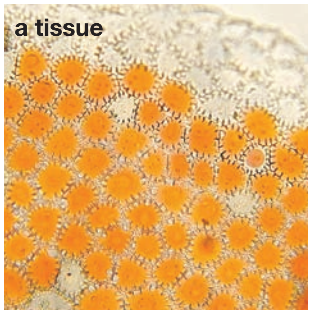


Molecules A **molecule** consists of atoms that are bonded together. Some molecules are unique to life, and these are more complex than the water molecule depicted here.

atom The smallest unit of matter.
biosphere All regions of Earth where organisms live.
cell Smallest unit of life.
community All populations of all species in a defined area.
ecosystem A community interacting with its environment.
molecule Two or more atoms bonded together.
organ In multicelled organisms, a structure that consists of tissues engaged in a collective task.
organ system In multicelled organisms, a set of interacting organs and tissues that carry out one or more body functions.
organism An individual that consists of one or more cells.
population A group of interbreeding individuals of the same species living in a defined area.
tissue In multicelled organisms, specialized cells organized in a pattern that allows them to perform a collective function.

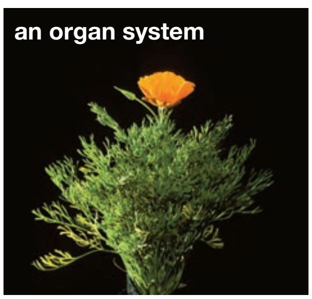


Cells The property we call "life" emerges as molecules organize to form cells. The **cell** is the smallest unit of life. Some, like this plant cell, live and reproduce as part of a multicelled organism; others do so on their own.



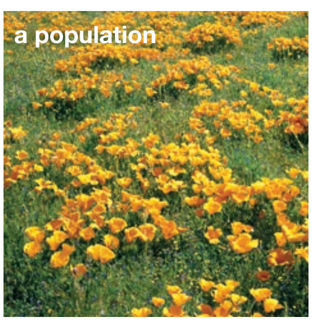
Tissues A **tissue** consists of specific types of cells organized in a particular pattern. The arrangement allows the cells to collectively perform a special function. This is dermal tissue on the outer surface of a flower petal.

Organs An **organ** is a structure composed of tissues that collectively carry out a particular task or set of tasks. Flowers are the reproductive organs of some plants.



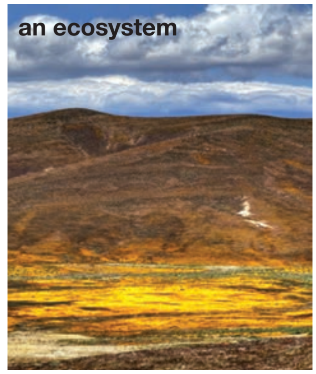
Organ Systems An **organ system** is a set of interacting organs and tissues that fulfill one or more body functions. Leaves, stems, flowers, and fruits form the shoot system of this plant. A plant's body consists of two organ systems: shoots and roots.

Organisms An **organism** is an individual that consists of one or more cells. Humans consist of many cells, as do other organisms such as this California poppy plant.



Populations A **population** is a group of interbreeding individuals of the same species living in a given area. This population of California poppy plants is in the Antelope Valley California Poppy Reserve.

Communities Populations interact in communities. A **community** consists of all populations of all species in a given area. This one includes all of the populations of plants, animals, microorganisms, and so on living in the Antelope Valley California Poppy Reserve.



Ecosystems An **ecosystem** is a community interacting with its physical and chemical environment through the transfer of energy and materials. Sunlight and water sustain the community in the Antelope Valley.

The Biosphere The **biosphere** is the sum of all ecosystems, and it encompasses all regions of Earth's crust, waters, and atmosphere in which organisms live.

Top to bottom (left): Umberto Salvagnin; Umberto Salvagnin; California Poppy, © 2009, Christine M. Welter; Lady Bird Johnson Wildflower Center; SPL/Science Source; James Randklev/Exactostock-1672/SuperStock. Top to bottom (right): © Sergei Krupnov, www.flickr.com/photos/7969319@N03; © Mark Koberg Photography; Source: NASA.

TAKE-HOME MESSAGE 1.2

- Biologists study life by thinking about it at successive levels of organization. Interactions among the components of each level give rise to complex properties that emerge at the next.
- All matter consists of atoms and the fundamental particles that compose them.
- Molecules consist of atoms that are bonded together. The property we call "life" emerges as molecules unique to life become organized into cells.
- An organism is an individual that consists of one or more cells. Many multicelled organisms have tissues that are organized as organs and organ systems.
- Interacting individuals compose populations, and interacting populations form communities.
- A community interacting with its environment constitutes an ecosystem. All ecosystems on Earth form the biosphere.

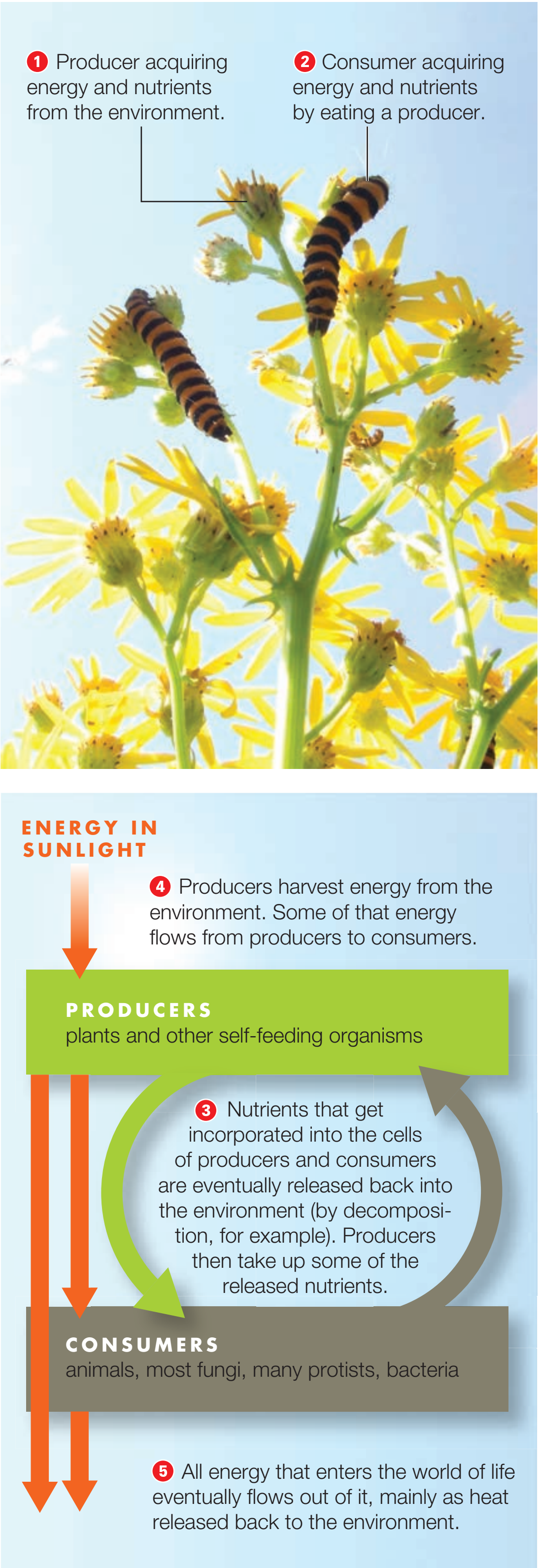


Figure 1.3 The one-way flow of energy and the cycling of materials in the world of life.

Top, © Victoria Pinder, http://www.flickr.com/photos/vixstarplus.

1.3 How Living Things Are Alike

LEARNING OBJECTIVES

- Distinguish producers from consumers.
- Describe the movement of nutrients and energy through the world of life.
- Explain why homeostasis is important for sustaining life.

All living things share a particular set of key features. You already know one of these features: Because the cell is the smallest unit of life, all organisms consist of at least one cell. For now, we introduce three more: All living things require ongoing inputs of energy and raw materials; all sense and respond to change; and all use DNA as the carrier of genetic information (**Table 1.1**).

TABLE 1.1 Some Key Features of Life

Cellular basis	All living things consist of one or more cells.
Requirement for energy and nutrients	Life is sustained by ongoing inputs of energy and nutrients.
Homeostasis	Living things sense and respond to change.
DNA is hereditary material	Genetic information in the form of DNA is passed to offspring.

Organisms Require Nutrients and Energy

Not all living things eat, but all require raw materials—nutrients—and energy on an ongoing basis. A **nutrient** is a substance that an organism needs for growth and survival but cannot make for itself.

Producers and Consumers Both nutrients and energy are essential to maintain life, so organisms spend a lot of time acquiring them. However, the source of energy and the type of nutrients required differ among organisms. These differences allow us to classify all living things into two broad categories: producers and consumers (**Figure 1.3**). A **producer** makes its own food using energy and simple raw materials it obtains from nonbiological sources 1. Typical plants are producers. By a process called **photosynthesis**, plants use the energy of sunlight to make sugars from carbon dioxide (a gas in air) and water. Consumers, by contrast, cannot make their own food. A **consumer** obtains energy and nutrients by feeding on other organisms 2. Animals are consumers. So are decomposers, which feed on the wastes or remains of other organisms. Nutrients released from decomposing consumers return to the environment, where they are taken up by producers. Said another way, nutrients cycle between producers and consumers 3.

The One-Way Flow of Energy Unlike nutrients, energy is not cycled. It flows through the world of life in one direction: from the environment 4, through organisms, and to the environment 5. This flow maintains the organization of every living cell and body, and it also influences how individuals interact with one another and their environment. The energy flow is one-way, because with each transfer, some energy escapes as heat, and cells cannot use heat as an energy source. Thus, energy that enters the world of life eventually leaves it (Chapter 4 returns to this topic).

Organisms Sense and Respond to Change

An organism cannot survive for very long unless it responds appropriately to specific stimuli inside and outside of itself. Consider how humans and some other animals perspire (sweat) when the body's internal temperature rises above a certain point (**Figure 1.4**). The moisture cools the skin, which in turn helps cool the body.

All of the internal fluids that bathe the cells in your body are collectively called your internal environment. Temperature and many other conditions in that environment must be kept within certain ranges, or your cells will die (and so will you). By sensing and adjusting to change, all organisms keep conditions in their internal environment within ranges that favor cell survival. **Homeostasis** is the name for this process, and it is one of the defining features of life.

Figure 1.4 Living things sense and respond to their environment.

Sweating is a physiological response to an internal body temperature that exceeds the normal set point. The response cools the skin, which in turn helps return the internal temperature to the set point.

iStock.com/gvillani.

DNA Is Hereditary Material

Inheritance and Reproduction With little variation, the same types of molecules perform the same basic functions in every organism. For example, information in an organism's **DNA** (a molecule called deoxyribonucleic acid) guides ongoing cellular activities that sustain the individual through its lifetime. These activities include **growth**: increases in cell number, size, and volume; **reproduction**: processes by which individuals produce offspring; and **development**: in multicelled species, the process by which the first cell of a new individual gives rise to an adult. **Inheritance**, the transmission of DNA to offspring, occurs during reproduction. All organisms inherit their DNA from one or two parents.

DNA Is the Basis of Life's Unity and Diversity Individuals of every natural population are alike in most aspects of body form and behavior because their DNA is very similar: Humans look and act like humans and not like poppy plants because they inherited human DNA, which differs from poppy plant DNA in the information it carries. Individuals of almost every natural population also vary—just a bit—from one another: One human has blue eyes, the next has brown eyes, and so on. Such variation arises from small differences in the details of DNA molecules, and herein lies the source of life's diversity. As you will see in later chapters, differences among individuals of a species are the raw material of evolutionary processes.

TAKE-HOME MESSAGE 1.3

- Energy and nutrients are required to maintain life. Energy flows from the environment, through organisms, and back to the environment. Nutrients cycle between producers and consumers.
- Organisms sense and respond to conditions inside and outside themselves. They make adjustments that keep conditions in their internal environment within ranges that favor cell survival, a process called homeostasis.
- All organisms use information in the DNA they inherited from parents to guide activities such as growth, reproduction, and (in multicelled organisms) development. DNA is the basis of similarities and differences among organisms.

consumer Organism that acquires energy and nutrients by feeding on the tissues, wastes, or remains of other organisms.

development In multicelled species, the process by which the first cell of a new individual gives rise to an adult.

DNA Deoxyribonucleic acid. Molecule that carries hereditary information. That information guides growth, reproduction, and other cellular activities.

growth Increases in the number, size, and volume of cells.

homeostasis Process in which organisms keep their internal conditions within tolerable ranges by sensing and responding appropriately to change.

inheritance Transmission of DNA to offspring.

nutrient A substance that an organism must acquire from the environment to support growth and survival.

photosynthesis Process by which producers use light energy to make sugars from carbon dioxide and water.

producer An organism that makes its own food using energy and nonbiological raw materials from the environment.

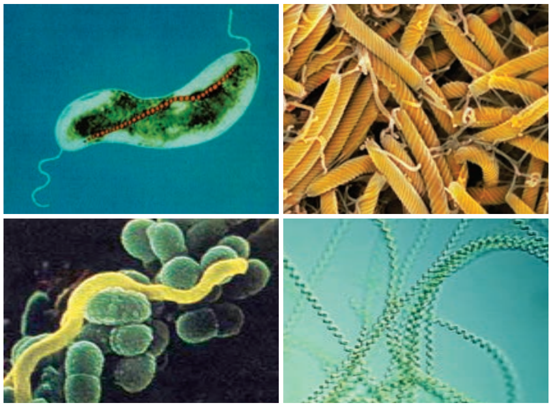
reproduction Processes by which individuals produce offspring.

1.4 How Living Things Differ

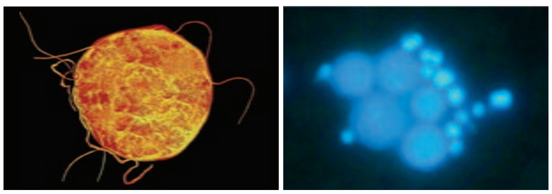
LEARNING OBJECTIVES

- Name the prokaryotic groups and how they differ from eukaryotes.
- Describe the four main groups of eukaryotes.
- Discuss how and why we name species.
- Describe the way species are grouped in taxa.
- Explain why DNA can be used to determine relative relatedness.

You will see in later chapters how differences in the details of DNA molecules are the basis of a tremendous range of differences among types of organisms. Various classification schemes help us organize what we understand about this variation, which we call Earth's biodiversity.



A. Bacteria are the most numerous organisms on Earth. Clockwise from upper left, a bacterium with a row of iron crystals that serves as a tiny compass; a common bacterial resident of mouse stomachs; photosynthetic bacteria; bacteria found in dental plaque.



B. Archaea resemble bacteria, but are more closely related to eukaryotes. Left, an archaeon that grows in sulfur hot springs. Right, two types of archaea from a seafloor hydrothermal vent.

Figure 1.5 A few representative prokaryotes.

(A) top left, Dr. Richard Frankel; top right, Dr. Kari Lounatmaa/Science Photo Library/Getty Images; bottom left, Source: www.zahnarzt-stuttgart.com; bottom right, © Susan Barnes; (B) left, Dr. Terry Beveridge/Visuals Unlimited/Corbis; right, Source: © Dr. Harald Huber, Dr. Michael Hohn, Prof. Dr. K.O. Stetter, University of Regensburg, Germany.

The Prokaryotes

Organisms can be grouped on the basis of whether they have a nucleus, which is a saclike structure that contains a cell's DNA. **Bacteria** (singular, bacterium) and **archaea** (singular, archaeon) are the organisms whose DNA *is not* contained within a nucleus (**Figure 1.5**). All bacteria and archaea are single-celled, which means each individual consists of one cell. Collectively, these organisms are the most diverse representatives of life. Different kinds of bacteria and archaea are producers or consumers in nearly all regions of Earth, some inhabiting such extreme environments as frozen desert rocks, boiling acid hot springs, and nuclear reactor waste. The first cells on Earth may have faced similarly hostile conditions.

Traditionally, organisms without a nucleus have been called **prokaryotes**, but the designation is now used only informally. This is because bacteria and archaea are less related to one another than we once thought, despite their similar appearance. Archaea turned out to be more closely related to **eukaryotes**, which are organisms whose DNA is contained within a nucleus. Some eukaryotes live as individual cells; others are multicelled.

The Eukaryotes

Protists, fungi, plants, and animals are the four groups of eukaryotes (**Figure 1.6**).

Protist is the common term for a eukaryote that is not a fungus, plant, or animal. Collectively, protists vary dramatically, from single-celled consumers to giant multicelled producers.

Fungi (singular, fungus) are eukaryotic consumers that secrete substances to break down food externally, then absorb nutrients released by this process. Many are decomposers. Most fungi, including those that form mushrooms, are multicellular. Fungi that live as single cells are called yeasts.

Plants are multicelled eukaryotes, and the vast majority of them are photosynthetic producers that live on land. Besides feeding themselves, plants also serve as food for most other land-based organisms.

Animals are multicelled eukaryotic consumers that ingest other organisms or components of them. Unlike fungi, animals break down food inside their body. They also develop through a series of stages that lead to the adult form. All animals actively move about during at least part of their lives.

animal A multicelled eukaryotic consumer that develops through a series of stages and moves about during part or all of its life.

archaea Singular, archaeon. Group of prokaryotes that are more closely related to eukaryotes than to bacteria.

bacteria Singular, bacterium. Largest and most well-known group of prokaryotes.

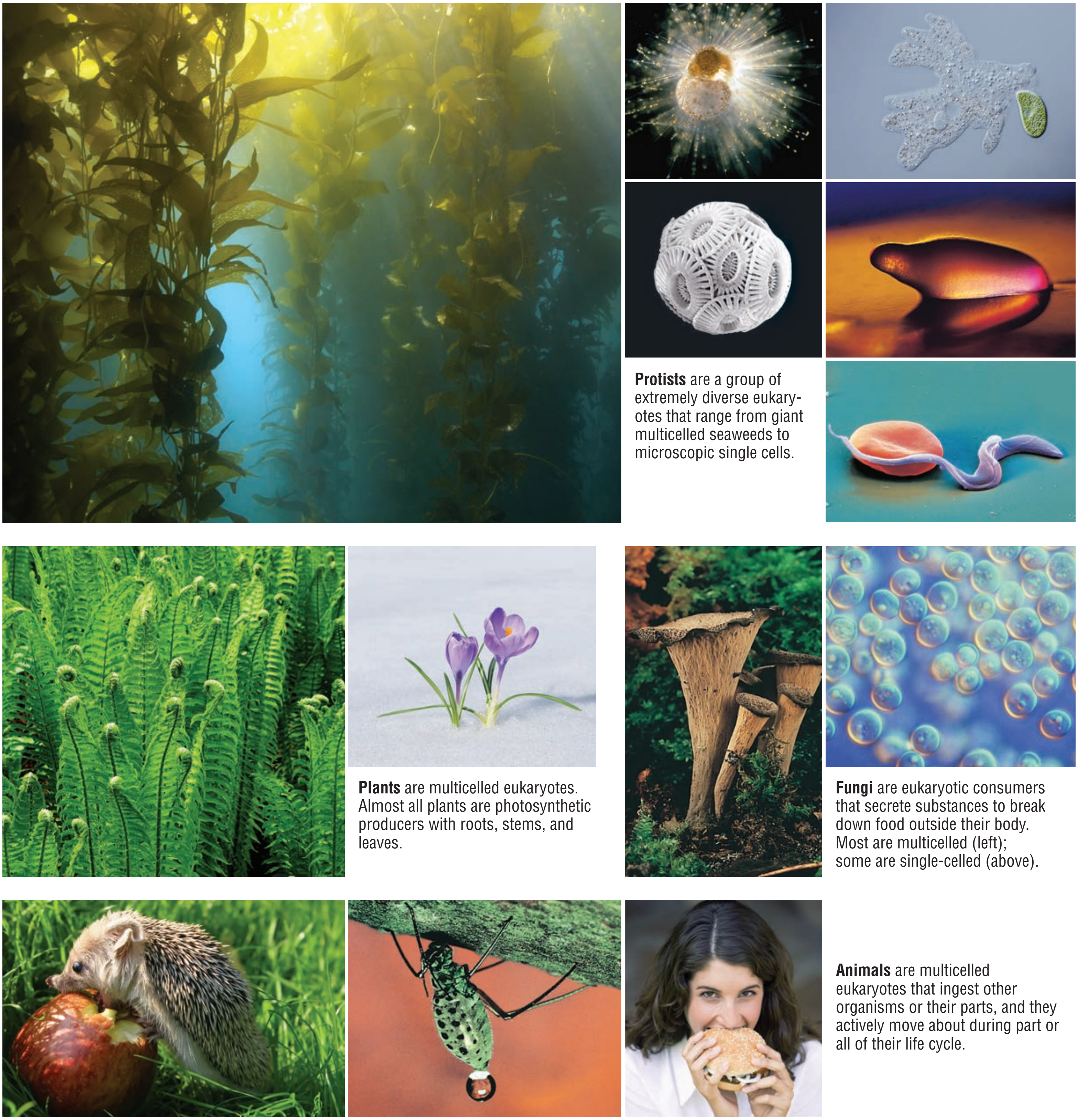
eukaryotes Organisms whose cells characteristically have a nucleus.

fungus Plural, fungi. A single-celled or multicelled eukaryotic consumer that breaks down material outside itself, then absorbs nutrients released from the breakdown.

plant A multicelled eukaryotic producer; most are photosynthetic and live on land.

prokaryotes Single-celled organisms with no nucleus.

protist Common term for a eukaryote that is not a fungus, plant, or animal.



Protists are a group of extremely diverse eukaryotes that range from giant multicelled seaweeds to microscopic single cells.

Plants are multicelled eukaryotes. Almost all plants are photosynthetic producers with roots, stems, and leaves.

Fungi are eukaryotic consumers that secrete substances to break down food outside their body. Most are multicelled (left); some are single-celled (above).

Animals are multicelled eukaryotes that ingest other organisms or their parts, and they actively move about during part or all of their life cycle.

Figure 1.6 A few representative eukaryotes.

Protists: Top left, worldswildlifewonders/Shutterstock.com; Top center, Courtesy of Allen W. H. Be & David A. Caron; Emiliania huxleyi. Photograph by Vita Pariente. Scanning electron micrograph taken on a Jeol T330A instrument at the Texas A & M University Electron Microscopy Center; Top right, Lebendkulturen.de/Shutterstock.com; Carolina Biological Supply Company; Oliver Meckes/Science Source; Center left, Jag_cz/Shutterstock.com; Center, Martin Ruegner/Radius Images/Getty Images; Edward S. Ross; Center right, London Scientific Films/Exactostock-1598/Superstock; Bottom left, Shironina/Shutterstock.com; Bottom center, Martin Zimmerman, Science, 1961, 133:73–79, © AAAS; Bottom right, Pixtal/Superstock.

	wild carrot	marijuana	apple	prickly rose	dog rose
domain	Eukarya	Eukarya	Eukarya	Eukarya	Eukarya
kingdom	Plantae	Plantae	Plantae	Plantae	Plantae
phylum	Magnoliophyta	Magnoliophyta	Magnoliophyta	Magnoliophyta	Magnoliophyta
class	Magnoliopsida	Magnoliopsida	Magnoliopsida	Magnoliopsida	Magnoliopsida
order	Apiales	Rosales	Rosales	Rosales	Rosales
family	Apiaceae	Cannabaceae	Rosaceae	Rosaceae	Rosaceae
genus	*Daucus*	*Cannabis*	*Malus*	*Rosa*	*Rosa*
species	*Daucus carota*	*Cannabis sativa*	*Malus domestica*	*Rosa acicularis*	*Rosa canina*

Figure 1.7 Taxonomic classification of five species that are related at different levels.

Each species has been assigned to ever more inclusive groups, or taxa: in this case, from genus to domain. Note the formal names of the taxa: the dog rose, for example, is a eukaryote (it belongs in the domain called Eukarya) and a plant (kingdom Plantae).

From the left, Joaquim Gaspar; Kym Kemp; Sylvie Bouchard/Shutterstock.com; Courtesy of Melissa S. Green, www.flickr.com/photos/henkimaa; Gordana Sarkotic.

FIGURE IT OUT: Which of the plants shown here are in the same order?

Answer: Marijuana, apple, prickly rose, and dog rose

Organizing Information about Species

A Rose by Any Other Name . . . When a new species is discovered, it is given a unique name. We started naming species thousands of years ago, but naming them in a consistent way did not become a priority until the eighteenth century. At the time, European explorers who were just discovering the scope of life's diversity started having more and more trouble communicating with one another because species often had multiple names. For example, the dog rose (a plant native to Europe, Africa, and Asia) was alternately known as briar rose, witch's briar, herb patience, sweet briar, wild briar, dog briar, dog berry, briar hip, eglantine gall, hep tree, hip fruit, hip rose, hip tree, hop fruit, and hogseed—and those are only the English names! Species often had multiple scientific names too, in Latin that was descriptive but often cumbersome. The scientific name of the dog rose was *Rosa sylvestris inodora seu canina* (odorless woodland dog rose), and also *Rosa sylvestris alba cum rubore, folio glabro* (pinkish white woodland rose with smooth leaves).

The Linnaean System Carl Linnaeus was an eighteenth-century naturalist who standardized a two-part naming system that we still use. By the Linnaean system, every species is given a unique two-part scientific name. The first part is the **genus** (plural, genera), which is defined as a group of species that share a unique set of inherited characteristics. The second part of a species name is called the specific epithet. Together, the genus name and the specific epithet designate one species. Thus, the dog rose now has one official name, *Rosa canina*, that is recognized worldwide.

genus Plural, genera. A group of species that share a unique set of inherited characteristics.

taxon Plural, taxa. A rank in the classification of life; consists of a group of organisms that share a unique set of traits.

taxonomy Practice of naming, describing, and classifying species.

trait An inherited characteristic of an organism or species.

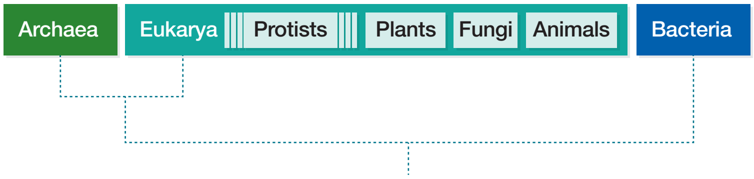


Figure 1.8 The big picture of life.

This diagram summarizes one hypothesis about how all life is connected by shared ancestry. Lines indicate evolutionary connections between the domains.

Taxonomy

Traits The practice of naming, describing, and classifying species is called **taxonomy**, and it is based on inherited characteristics, or **traits**. Individuals of the same species have the same set of traits, and that set of traits is unique to the species. For example, giraffes normally have very long necks, brown spots on white coats, and so on. These are morphological (structural) traits. Individuals of a species also share biochemical traits (they make and use the same molecules) and behavioral traits (they respond the same way to certain stimuli, as when hungry giraffes feed on tree leaves).

Taxa We can rank a species into ever more inclusive categories based on some subset of traits it shares with other species. Each rank, or **taxon** (plural, taxa), is a group of organisms that share a unique set of traits. Of the major taxa, species is the lowest. Each taxon above species—genus, family, order, class, phylum (plural, phyla), kingdom, and domain—consists of a group of the next lower taxon. For example, the dog rose is among several species in the genus *Rosa*; *Rosa* is among several genera in the family *Rosaceae*; and so on (**Figure 1.7**). Using this system, we can sort all life into a few categories (**Figure 1.8**).

Determining Relative Relatedness

Comparing Traits It is easy to tell that humans and dog roses are different species because they appear very different. Distinguishing between species that are more closely related may be much more challenging (**Figure 1.9**). In addition, traits shared by members of a species often vary a bit among individuals, as eye color does among people. How do we decide whether similar-looking organisms belong to the same species? The short answer to that question is that we rely on whatever information is available. Early naturalists studied anatomy and distribution—essentially the only methods available at the time—so species were named and classified according to what they looked like and where they lived. Today's biologists are able to compare traits that the early naturalists did not even know about, including biochemical ones such as details of DNA molecules.

Figure 1.9 Four butterflies, two species: Which are which?

The top row shows two forms of the species *Heliconius melpomene*; the bottom row, two forms of *H. erato*.

H. melpomene and *H. erato* never crossbreed. Their alternate but similar patterns of coloration evolved as a shared warning signal to predatory birds that these butterflies taste terrible.

© 2006 Axel Meyer, "Repeating Patterns of Mimicry," *PLoS Biology* 4, no. 10 (2006), e341 doi:10.1371/journal.pbio.0040341. Used with permission.

Comparing DNA The information in a molecule of DNA changes a bit each time it passes from parents to offspring, and it has done so since life began. Over long periods of time, these tiny changes have added up to big differences between species such as humans and dog roses. Thus, differences in DNA are one way to measure relative relatedness: The fewer differences between species, the closer the relationship. For example, we know that the DNA of humans is more similar to chimpanzee DNA than it is to rose DNA, so we can assume that humans are more closely related to chimpanzees than to roses. There are similarities between the DNA of every living species, so all species are related in some way or another. Unraveling these relationships has become a major focus of biology.

Impact of New Information The discovery of new information sometimes changes the way we distinguish a particular species or how we group it with others.

For example, Linnaeus grouped plants by the number and arrangement of reproductive parts, a scheme that resulted in odd pairings such as castor-oil plants with pine trees. Having more information today, we place these plants in separate phyla.

The Biological Species Concept

Evolutionary biologist Ernst Mayr defined a species as one or more groups of individuals that potentially can interbreed, produce fertile offspring, and do not interbreed with other groups. This "biological species concept" is useful in many cases, but it is not universally applicable. For example, the biological species concept cannot help us classify organisms that have become extinct. It is also not useful for distinguishing species of prokaryotes, which reproduce in a completely different way than eukaryotes. We return to speciation and how it occurs in Chapter 13, but for now it is important to remember that a "species" is a convenient but artificial construct of the human mind.

TAKE-HOME MESSAGE 1.4

- Bacteria and archaea are prokaryotes, single-celled organisms whose DNA is not contained in a nucleus. Archaea are more closely related to eukaryotes than to bacteria.
- Eukaryotes are single-celled or multicelled organisms whose DNA is contained in a nucleus.
- Fungi are eukaryotic consumers that break down food externally. Some are single-celled.
- Plants are multicelled eukaryotic producers; most are photosynthetic and live on land.
- Animals are multicelled eukaryotic consumers that move about for at least part of their lives.
- Protists are eukaryotes that are not fungi, plants, or animals.
- We define and classify species based on shared traits. Each species is given a unique two-part name.
- The more traits that two species have in common, the closer is their relationship.

1.5 The Science of Nature

LEARNING OBJECTIVES

- Detail the process of making and testing a hypothesis.
- Explain how a control group is used in an experiment.
- Use a suitable example to explain variables.
- Give an example, real or hypothetical, of a cause-and-effect relationship.

Thinking about Thinking

Most of us assume that we do our own thinking, but do we, really? You might be surprised to find out how often we let others think for us. Consider how a school's job (which is to impart as much information as possible to students) meshes perfectly with a student's job (which is to acquire as much knowledge as possible from the school). In this rapid-fire transfer of information, it can be very easy to forget about the quality of what is being transferred. Any time you accept information without questioning it, you let someone else think for you.

Critical thinking is the deliberate process of judging the quality of information before accepting it. When you use critical thinking, you move beyond the content

critical thinking The act of evaluating information before accepting it.

data Factual information collected from experiments or observations of the natural world.

experiment Procedure designed to evaluate a prediction; typically yields data.

hypothesis A testable explanation for a natural phenomenon.

model Analogous system in an experiment; tested in place of another subject.

prediction Statement, based on a hypothesis, about a condition that should reasonably occur if the hypothesis is correct.

science Systematic study of the observable world.

variable In an experiment, a characteristic or event that differs among individuals or over time.

of new information to consider supporting evidence, bias, and alternative interpretations. This may sound complicated, but it just involves a bit of awareness. There are many ways to do it. For example, you might ask yourself some of the following questions while learning something new:

- What message am I being asked to accept?
- Is the message based on fact or opinion?
- Is there a different way to interpret the facts?
- What biases might the presenter have?
- How do my own biases influence the way I hear this message?

Questions like these are a way of being conscious about learning. They can help you decide whether to allow new information to guide your thoughts and actions.

Critical Thinking in Science

Making Hypotheses Critical thinking is an integral part of **science**, the systematic study of the observable world and how it works. A line of inquiry in biology typically begins with a researcher's curiosity about something observable in nature, say, an unusual decrease in the number of birds in a particular area. The researcher reads scientific articles about related observations before making a hypothesis. A **hypothesis** is a testable explanation for a natural phenomenon. An example of a hypothesis would be: The number of birds is decreasing because the number of bird-eating cats is increasing.

Making Predictions Researchers test hypotheses by evaluating predictions that flow from them. A **prediction** is a statement of some condition that should reasonably occur if the hypothesis is correct. Making predictions is often called the if–then process, in which the "if" part is the hypothesis, and the "then" part is the prediction: *If* the number of birds is decreasing because the number of bird-eating cats is increasing, *then* removing cats from the area should stop the decline in the bird population.

Experiments

Researchers evaluate predictions by carrying out systematic observations or experiments. An **experiment** is a procedure designed to show whether a prediction is true or false, and a typical one yields **data**—factual information such as measurements or counts. Experimental data that validate a prediction constitute evidence in support of the related hypothesis.

In an investigation of our hypothetical bird–cat relationship, the researcher may remove all cats from the area, then count the number of birds over a period of time. If the bird population increases, then the experimental data is evidence in support of the hypothesis.

Variables The bird–cat experiment, like many others, explores a cause-and-effect relationship using variables. A **variable** is an experimental factor that varies: a characteristic that differs among individuals, for example, or an event that differs over time. In this case, the researcher changes one variable (the number of cats) and monitors another (the number of birds).

Models Some important experiments have ethical or technical restrictions. Such experiments may be performed on a **model**, or analogous system. For example, experiments that jeopardize human health are both unethical and illegal, so treatments for human diseases are often tested on animal models.

Experimental and Control Groups Biological systems are complex because they typically involve many interdependent variables. It can be difficult or even impossible to study one variable separately from the rest. Thus, biology researchers often perform an experiment on two groups of individuals. An **experimental group** is a set of individuals that have a certain characteristic or receive a certain treatment. This group is tested side by side with a **control group**, which is identical to the experimental group except for one variable: the characteristic or treatment being tested. Any differences in experimental results between the two groups is likely to be an effect of changing the variable.

TABLE 1.2 The Scientific Method

1. **Observe** some aspect of nature.
2. **Make a hypothesis** (think of a testable explanation for your observation).
3. **Test the hypothesis:**
   a. Make a prediction based on the hypothesis (If . . . then).
   b. Evaluate the prediction by making systematic observations or performing experiments that yield data.
4. **Form a conclusion** (determine whether your data validate the prediction and support your hypothesis).
5. **Report** your work to the scientific community.

The Scientific Method

Forming a hypothesis based on observation, testing the hypothesis by evaluating predictions that flow from it, and making conclusions about the resulting data are collectively called the **scientific method** (Table 1.2). However, scientific research—particularly in biology—rarely proceeds in a direct, start-to-finish fashion as Table 1.2 might suggest. Researchers often describe their work as a nonlinear process of exploration. Experimental results are often unexpected, and predictions are often wrong. Research usually raises more questions than it answers, so changes in direction are common and there may be no end point. The unpredictability might be frustrating at times, but researchers typically say they enjoy their work because of the surprising twists and turns it takes.

Figure 1.10 Example of scientific research in the field of biology.

Tierney Thys travels the world's oceans to study the giant sunfish (mola). "When it comes to fishes, the mola really pushes the boundary of fish form," she says. "It seems a somewhat counterintuitive design for plying the waters of the open seas—a rather goofy design—and yet the more I learn about it, the more respect and admiration I have for it."

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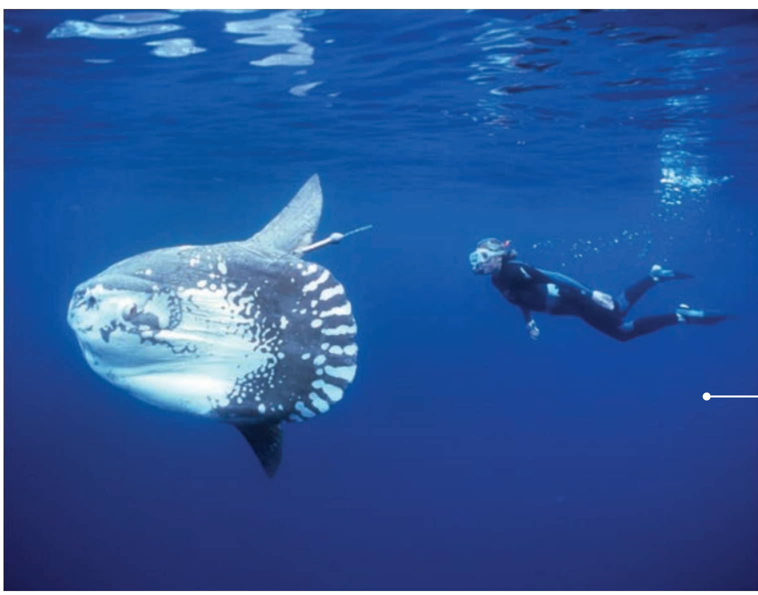


TABLE 1.3 A Few Research Specializations in Biology

Field	Focus
Astrobiology	Potential life elsewhere in the universe
Biogeography	Distribution of life on Earth
Bioinformatics	Development of tools to analyze data
Botany	Plant structure and processes
Cell biology	Cell structure and processes
Ecology	Interactions among organisms, and among organisms and their environment
Ethology	Animal behavior
Genetics	Inheritance
Marine biology	Life in saltwater environments
Medicine	Human health
Paleontology	Life in the ancient past
Structural biology	Architecture-dependent function of large biological molecules

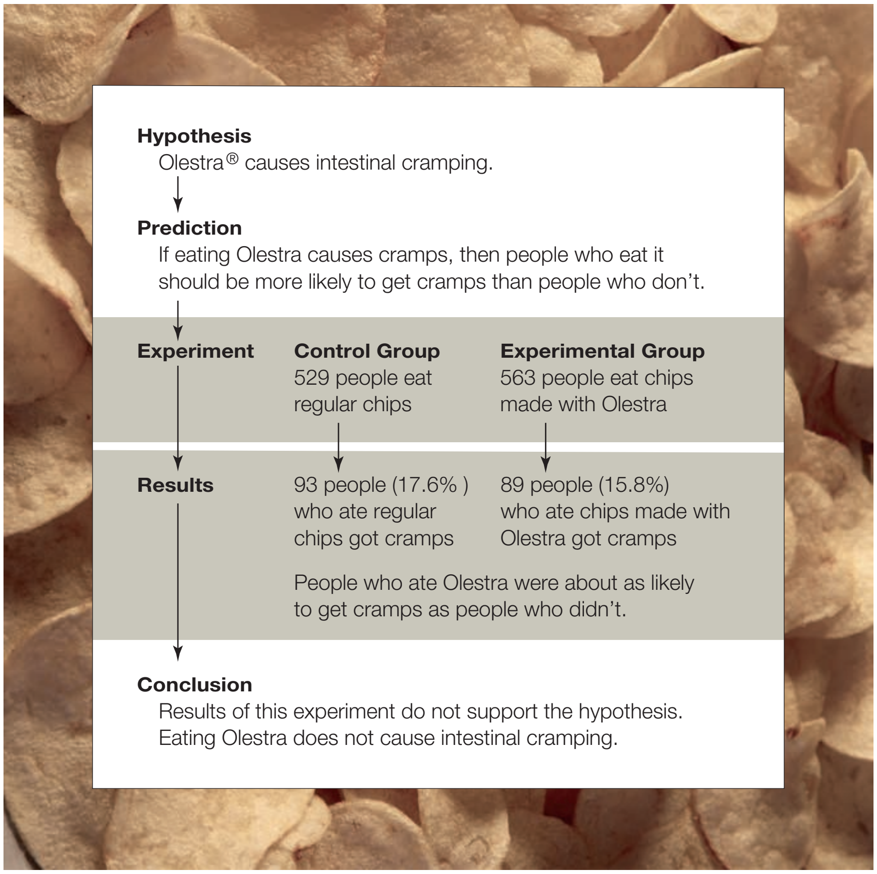


Figure 1.11 The steps in a scientific experiment to determine whether Olestra causes intestinal cramps.

A report of this study was published in the *Journal of the American Medical Association* in January 1998.

Source: *Journal of the American Medical Association* in January 1998; background, Superstock.

FIGURE IT OUT: What was the variable that the researchers changed?

Answer: The presence of Olestra in potato chips

Examples of Biology Experiments

Biology is the branch of science concerning past and present life, and it includes hundreds of research specializations (**Figure 1.10** and **Table 1.3**). To give you a sense of how biology research works, we summarize two published studies here.

Does Olestra® Cause Stomachaches? In 1996 the U.S. Food and Drug Administration (FDA) approved Olestra, a fat replacement manufactured from sugar and vegetable oil, as a food additive. Potato chips were the first Olestra-containing food product to be sold in the United States. Controversy about the chip additive soon raged. Many people complained of intestinal problems after eating the chips, and thought that the Olestra was at fault. Two years later, researchers at the Johns Hopkins University School of Medicine designed an experiment to test the hypothesis that Olestra causes cramps (**Figure 1.11**).

The researchers made the following prediction: If Olestra causes cramps, then people who eat Olestra are more likely to get cramps than people who do not eat it. To evaluate their prediction, they used a Chicago theater as a "laboratory." They asked 1,100 people between the ages of thirteen and thirty-eight to watch a movie and eat their fill of potato chips. Each person received an unmarked bag containing 13 ounces of chips. Some of the bags contained chips made with Olestra. In this experiment, the individuals who received Olestra-containing potato chips constituted the experimental group, and individuals who received regular chips were the control group.

A few days after the movie, the researchers contacted everyone and collected any reports of post-movie gastrointestinal problems. Of 563 people making up the experimental group, 89 (15.8 percent) reported having cramps. However, so did 93 of the 529 people (17.6 percent) making up the control group—who had eaten

control group A group of individuals identical to an experimental group except for the variable under investigation.

experimental group In an experiment, a group of individuals who have a certain characteristic or receive a certain treatment. Typically tested side by side with a control group.

scientific method Making hypotheses, evaluating predictions that flow from them, and forming conclusions based on the resulting data.

A. With wings folded, a resting peacock butterfly resembles a dead leaf, so it is appropriately camouflaged from predatory birds.

B. When a predatory bird approaches, a butterfly flicks its wings open and closed, revealing brilliant spots and producing hissing sounds.

C. Researchers tested whether the wing flicking and hissing of peacock butterflies affected predation by blue tits (a type of songbird).

Experimental Treatment	Number of Butterflies Eaten (of total)
Wing spots concealed	5 of 10 (50%)
Wings silenced	0 of 8 (0%)
Wing spots concealed and wings silenced	8 of 10 (80%)
No treatment	0 of 9 (0%)

D. Results of these experiments support only the hypothesis that peacock butterfly spots deter predatory birds.

Figure 1.12 Testing the defensive value of two peacock butterfly behaviors: wing-flicking and hissing.

Researchers concealed the spots of some butterflies, cut the sound-making part of the wings on others, and did both to a third group; then exposed each butterfly to a hungry blue tit for 30 minutes.

(A) Matt Rowlings, www.eurobutterflies.com; (B) Adrian Vallin/Stockholm University; (C) Antje Schulte; (D) *Proceedings of the Royal Society of London,* Series B (2005) 272: 1203–1207.

FIGURE IT OUT: What percentage of butterflies with spots concealed and wings cut survived the test?

Answer: 20 percent

the regular chips. People were about as likely to get cramps whether or not they ate chips made with Olestra. The data were not consistent with the prediction, so they did not support the hypothesis that eating Olestra causes cramps.

Why Do Butterflies Flick Their Wings and Hiss? The peacock butterfly is a winged insect named for the large, colorful spots on its wings (**Figure 1.12A**). In 2005, researchers reported the results of experiments investigating whether certain behaviors of peacock butterflies help the insects defend themselves from insect-eating birds. The study began with the observation that a resting peacock butterfly sits motionless, wings folded. The dark underside of the wings provides appropriate camouflage. However, when a predator approaches, the butterfly exposes its brilliant spots by repeatedly flicking its wings open and closed in a way that produces a hissing sound (**Figure 1.12B**). A colorful, moving, noisy insect is usually very attractive to insect-eating birds, so the researchers were curious about why the peacock butterfly moves and hisses only in the *presence* of predators. After they reviewed earlier studies, the scientists made two hypotheses that might explain the wing-flicking behavior:

- Hypothesis 1: Peacock butterflies flick their wings in the presence of a predator because exposing their brilliant wing spots reduces predation. (Peacock butterfly wing spots resemble owl eyes, and anything that looks like owl eyes is known to startle insect-eating birds.)
- Hypothesis 2: Peacock butterflies hiss in the presence of a predator because the sound reduces predation. (The sound may be an additional defense that startles insect-eating birds.)

The researchers used these hypotheses to make the following predictions:

- Prediction 1: If exposing brilliant wing spots by wing-flicking reduces predation, then peacock butterflies without wing spots should be more vulnerable to predation than butterflies with wing spots.
- Prediction 2: If the hissing sound produced during wing-flicking reduces predation, then silent peacock butterflies should be more vulnerable to predation than hissing butterflies.

Next came the experiments. The researchers used a black marker to conceal the wing spots of some butterflies. They cut the wings of other butterflies to disable the sound-making parts. A third group had both treatments: Their spots were concealed and their wings were silenced; and a fourth group had no treatments. Each butterfly was then put into a large cage with a hungry blue tit (a type of butterfly-eating bird, **Figure 1.12C**).

Figure 1.12D lists the results. All of the butterflies with unmodified wing spots survived, regardless of whether they could hiss. These results were consistent with the first hypothesis: By exposing brilliant spots, peacock butterfly wing-flicking behavior decreases predation by blue tits.

In contrast, a large proportion of butterflies with concealed spots got eaten, whether or not they could hiss. Experimental results were not consistent with the second hypothesis that peacock butterfly hissing reduces predation. Other questions raised by these results offer an example of how research often leads to more research: Do predatory birds other than blue tits respond differently to hissing? If not, does hissing reduce predation by other organisms (such as mice) that eat peacock butterflies? If hissing is unrelated to predation, what is its function? Several additional experiments would be necessary to address these questions.

TAKE-HOME MESSAGE 1.5

- Judging the quality of information before accepting it is an active process called critical thinking. Critical thinking is central to science.
- The field of biology consists of and relies upon the collection and analysis of scientific evidence.
- A hypothesis is a testable explanation for a natural phenomenon. Researchers test a hypothesis by systematically challenging it in a way that might reveal flaws.
- A hypothesis is tested by evaluating predictions that flow from it. A prediction is evaluated by experiments (or observations) that yield data. Data that validate a prediction are evidence in support of the related hypothesis; data that invalidate the prediction may be evidence that the hypothesis is flawed.
- Researchers can unravel cause-and-effect relationships in complex systems by changing one variable at a time.

1.6 Analyzing Experimental Results

LEARNING OBJECTIVES

- Use an example to explain why generalizing results from a subset can be problematic in research.
- Describe statistical significance.
- Explain the role of critical thinking in making science a self-correcting process.

Common pitfalls such as sampling error and bias can make research tricky. Standard practices for evaluating results help researchers draw valid, defensible conclusions from them.

Sampling Error

In a natural setting, researchers can rarely observe all individuals of a population or all instances of an event. For example, the biologists who explored the cloud forest

DIGGING INTO DATA

Peacock Butterfly Predator Defenses

The photographs below represent the experimental and control groups used in the peacock butterfly experiment discussed in Section 1.5. See if you can identify the experimental groups and match them up with the relevant control group(s). *Hint:* Identify which variable is being tested in each group (each variable has a control).

Adrian Vallin, Sven Jakobsson, Johan Lind and Christer Wiklund, *Proc. R. Soc. B* (2005: 272, 1203, 1207). Used with permission of The Royal Society and the author.

A. Wing spots concealed

B. Wing spots visible; wings silenced

C. Wing spots concealed; wings silenced

D. Wings painted but spots visible

E. Wings cut but not silenced

F. Wings painted, spots visible; wings cut, not silenced

Figure 1.13 In science, discovering an error is not always bad news.

Here, Kris Helgen holds a golden-mantled tree kangaroo he found during a 2005 expedition to the Foja Mountain cloud forest. Prior to this expedition, only one tiny population of this critically endangered species was known.

Bruce Beehler/Conservation International.

probability The chance that a particular outcome of an event will occur; depends on the total number of outcomes possible.

sampling error Difference between results obtained from a subset, and results obtained from the whole.

statistically significant Refers to a result that is statistically very unlikely to have occurred by chance alone.

you read about in Section 1.1 did not—and could not—survey every uninhabited part of the Foja Mountains. The cloud forest itself cloaks more than 2 million acres, so surveying all of it would be unrealistic.

When researchers cannot directly observe all individuals of a population or all instances of an event, they may test or survey a subset. Results from the sample are then used to make generalizations about the whole. However, subsets are not necessarily representative of the whole. Consider the golden-mantled tree kangaroo, an animal first discovered in 1993 on a single forested mountaintop in New Guinea. For more than a decade, the species was never seen outside of that area, which is getting smaller every year because of human activities. Then, in 2005, the New Guinea explorers discovered that the golden-mantled tree kangaroo also lives in the Foja Mountains cloud forest (**Figure 1.13**). Having a second home means this critically endangered animal has a better chance of avoiding extinction.

Sampling error is a difference between results obtained from a subset, and results from the whole (**Figure 1.14A**). Sampling error may be unavoidable, but knowing how it occurs helps scientists minimize it. For example, researchers often try to use large subsets for their studies, because sampling error can be a substantial problem with small ones (**Figure 1.14B**). To understand why this practice reduces the risk of sampling error, think about flipping a coin. There are two possible outcomes of each flip: The coin lands heads up, or it lands tails up. Thus, the chance that the coin will land heads up is one in two (1/2), or 50 percent. However, when you flip a coin repeatedly, it often lands heads up, or tails up, several times in a row. With just four flips, the proportion of times that the coin actually lands heads up may not even be close to 50 percent (an example of sampling error). With one thousand flips, however, the overall proportion of times the coin lands heads up is much more likely to approach 50 percent.

Statistical Significance

Probability is the measure, expressed as a percentage, of the chance that a particular outcome will occur. That chance depends on the total number of possible outcomes. In our coin-flipping example, there is a 50 percent probability that a flipped coin will land heads up. As another example, imagine 10 million people enter a lottery. Each person has the same chance of winning the lottery: 1 in 10 million, or (an extremely improbable) 0.00001 percent.

Analysis of experimental data often includes statistical calculations of probability. Say that you flip a coin four times, and it lands heads up three times. This result—3/4, or 75 percent—is very different from the expected 50 percent, so it is skewed by sampling error. If you flip the coin one hundred times, and it lands heads up 52 times, the result (52 percent) is much closer to the expected result.

A result that is highly unlikely to have occurred by chance alone is said to be **statistically significant**. In this context, the word "significant" does not refer to the result's importance. Rather, it means that a formal statistical analysis has shown a very low probability (usually 5 percent or less) of the result being inaccurate because of sampling error.

Bias

Like all humans, scientists are subjective by nature, so they risk designing experiments that would produce anticipated results. Consider the Olestra study detailed in Section 1.5. Other scientists criticized the study because it was funded by Procter & Gamble Co., the makers of Olestra. The conflict of interest was a potential source of bias toward a particular conclusion. The critics pointed out that the participants were chosen randomly, which means that the researchers did not pay attention to gender, age, weight, medical history, and so on. These additional variables may well have affected the results of the study.

The Importance of Feedback

Reporting research results in a standard way, such as in a peer-reviewed journal article, gives other scientists an opportunity to check experimental design, data, and conclusions. Why is this important? An open, curated exchange of information allows scientific research to advance by building on a solid foundation of previous discoveries.

Let's go back to our hypothetical bird–cat experiment. Imagine that the researcher's hypothesis (the bird population is declining because the bird-eating cat population is increasing) was not supported by the experimental results (the bird population continued to decline after cats were removed). The hypothesis may be flawed—but then again, it may not be. A negative result does not necessarily mean that a hypothesis is incorrect. For example, logical flaws in a prediction, or technical flaws in an experiment, can yield results that are unrelated to a hypothesis. Such flaws can be revealed during the peer-review process, or when other scientists read the published article.

Consider how the bird–cat researcher may have overlooked variables that were in play during the experiment. Perhaps the bird-eating capacity of cats varies, so that an undomesticated cat eats far more birds than a pet cat. Wild cats are more difficult to catch, so the researcher would likely have relocated mainly cats with the least effect on the bird population. A different experiment, one in which only the wild cats were relocated, may have yielded results in support of the hypothesis. If the bird–cat experiment had been submitted for publication in a scientific journal, other scientists would have probably pointed out this possibility.

Conclusions may be the most contentious part of research, because interpreting the meaning of results is a form of judgment. This point gets us back to the role of critical thinking in science. Researchers expect one another to exercise critical thinking, both in their own work and in evaluating the work of others. If a researcher does not test a hypothesis in a way that may reveal flaws, then others will, because exposing errors is just as useful as applauding insights. The scientific

A. Natalie chooses a random jelly bean from a jar. She is blindfolded, so she does not know that the jar contains 120 green and 280 black jelly beans.

The jar is hidden from Natalie's view before she removes her blindfold. She sees one green jelly bean in her hand and assumes that the jar must hold only green jelly beans (100 percent are green). This assumption is incorrect: 30 percent of the jelly beans in the jar are green, and 70 percent are black. The deviation is sampling error.

B. Still blindfolded, Natalie randomly picks out 50 jelly beans from the jar. She chooses 10 green and 40 black ones.

The larger sample leads Natalie to estimate that one-fifth of the jar's jelly beans are green (20 percent) and four-fifths are black (80 percent). The larger sample more closely approximates the jar's actual green-to-black ratio of 30 percent to 70 percent.

The more jelly beans that Natalie chooses, the closer her estimates will be to the actual ratio.

Figure 1.14 How sample size affects sampling error.

Gary Head.

community consists of critically thinking people trying to poke holes in one another's ideas. Their collective efforts make science a self-correcting endeavor.

TAKE-HOME MESSAGE 1.6

- If a subset under investigation is not representative of the whole, then the resulting data will be skewed by sampling error. The risk of sampling error is greatest with small subsets.
- Probability calculations can show whether a result is statistically significant (highly unlikely to have occurred by chance alone).
- Science is inherently a self-correcting process. Hypotheses are tested in ways that may reveal flaws; tests are designed to yield data that can be collected objectively; and results and conclusions are evaluated by a community of skeptics.

1.7 The Nature of Science

LEARNING OBJECTIVES

- Name the criteria that qualify a hypothesis for status as a scientific theory.
- Explain what happens to a theory when data arise that are inconsistent with it.
- Identify some areas of inquiry that science does not address.
- Discuss some ways to identify pseudoscience.

What Science Is

Theories You may hear people apply the word "theory" to a speculative idea, as in the phrase, "It's just a theory." This everyday usage of the word differs from the specific way it is used in science. Suppose a hypothesis stands after many years of systematic challenges. It is consistent with existing evidence, and researchers use it to make successful predictions about a wide range of other phenomena. A hypothesis that meets these criteria is called a **scientific theory** (Table 1.4). Theories are our most objective way of describing the natural world.

Consider the hypothesis that all matter consists of atoms and their tiny components, which are called subatomic particles. Researchers no longer spend time testing this hypothesis for the compelling reason that, since we started looking 200 years ago, no one has discovered matter that consists of anything else. Thus, the hypothesis—now atomic theory—has been incorporated into our general understanding of matter. This understanding underpins research in many fields, including biology.

Even though scientific theories have been thoroughly evaluated and scrutinized, scientists carefully avoid using the word "proven" to describe them. Instead, a theory is "accepted," along with the possibility—however remote it might be—that new data inconsistent with it might be found. Consider how, like other hypotheses, a theory can never be evaluated under every possible circumstance. For example, testing the validity of atomic theory under all circumstances would require analysis of the composition of all matter in the universe for all time—an impossible task even if someone wanted to try.

TABLE 1.4 Examples of Scientific Theories

Atomic theory	All matter consists of atoms and their smaller subatomic parts.
Big bang	In its first moment, our universe began rapidly expanding from an extremely hot, high-density state.
Cell theory	All organisms consist of one or more cells, the cell is the basic unit of life, and all cells arise from preexisting cells.
Evolution by natural selection	Environmental pressures drive change in the inherited traits of a population.
Plate tectonics	Earth's lithosphere (crust and upper mantle) is cracked into pieces that move in relation to one another.

Theories Can Be Revised What happens if someone discovers data that is inconsistent with a theory? By definition, a theory has been tested rigorously and repeatedly.

New results do not invalidate previous results, but the interpretation of what the results mean can change. Thus, new data inconsistent with a theory may trigger its revision. For example, atomic theory has been modified many times since it was proposed hundreds of years ago. If someone ever discovers matter that does not consist of atoms and subatomic particles, the theory would be revised to include the exception (all matter consists of atoms and subatomic particles except . . .). If many exceptions accumulate, the theory will be rewritten so it better accounts for the discrepancies.

The theory of evolution by natural selection, which holds that environmental pressures can drive change in the inherited traits of a population, still stands after more than a century of concerted testing. Natural selection is not the only mechanism by which evolution occurs, but it is by far the most studied. Few other scientific theories have withstood as much scrutiny.

Laws of Nature A scientific theory differs from a **law of nature**, which describes a natural phenomenon that always occurs under certain circumstances, but has an incomplete scientific explanation. Laws, unlike scientific theories, do not necessarily include mechanisms. The laws of thermodynamics, which describe energy, are examples. We understand how energy behaves, but not entirely why it behaves the way it does (Chapter 4 returns to energy).

What Is Not Science

Not everything that uses scientific vocabulary is actually science. Claims, arguments, or methods that are presented as science but do not follow scientific principles are called **pseudoscience** (*pseudo* means false).

Distinguishing pseudoscience from the real thing can be tricky, but your critical thinking skills will help (Table 1.5). Consider how a scientific hypothesis is a testable explanation for an observable aspect of nature. Pseudoscience, by contrast, can involve mysterious phenomena: "Earth appears older than it is because it came into existence that way," for example. If this claim were true, then it would be impossible to test because no measurement or observation could reveal Earth's true age. Claims that cannot be tested are not part of science.

In science, making a hypothesis is followed by a systematic challenge that may reveal its flaws. With pseudoscience, making a claim is often followed by a selective search for information that can be used to defend it. The information may be invented, unverified, or anecdotal. Science also progresses: When new data are inconsistent with a hypothesis, the hypothesis is revised. By contrast, pseudoscience tends to be static: Evidence inconsistent with a pseudoscientific claim is typically ignored, dismissed, or denied.

Pseudoscience is prevalent, and it is not harmless. Unlike science, it has no requirement for accuracy, truthfulness, or objectivity; communication typically consists of rhetoric intended to persuade the general public. Convincing people that false or misleading information is scientific jeopardizes our individual and collective welfare, for example by undermining public trust in safe and effective vaccines. Widespread vaccination programs all but eradicated dangerous diseases such as measles in the United States and western Europe, but these diseases are now making a comeback because many parents have been persuaded by pseudoscientific rhetoric to refuse vaccinations for their children (Chapter 23 returns to this topic). Measles in particular is extremely contagious, and the consequences of becoming infected can be extremely severe or fatal, especially for children.

TABLE 1.5 Using Critical Thinking to Identify Pseudoscience

Science	Pseudoscience
Does the concept concern an observable natural phenomenon?	
Involves only the observable, natural world.	May involve supernatural or mysterious phenomena.
Is the concept testable?	
Testable via predictions that flow from a hypothesis. Tests are designed to reveal flaws.	Untestable, or untestable in ways that might reveal flaws.
What is the evidence that supports the concept?	
Data collected from systematic observations or experiments.	Invented or unverified information, anecdotes, rhetoric, or the absence of scientific data.
How is inconsistent evidence addressed?	
Evidence inconsistent with a hypothesis prompts its revision.	Evidence inconsistent with a claim is ignored, dismissed, or denied.

law of nature A generalization describing a consistent natural phenomenon that has an incomplete scientific explanation.

pseudoscience Claims, arguments, or methods that are presented as science, but do not follow scientific principles.

scientific theory A hypothesis that stands after many years of systematic testing, is consistent with existing evidence, and is useful for making predictions about a wide range of phenomena.

Figure 1.15 Observing an aspect of nature.

Near a tent serving as a makeshift laboratory, herpetologist Paul Oliver records the call of a frog on the first expedition to New Guinea's Foja Mountains cloud forest in 2005.

Tim Laman/National Geographic Image Collection.

What Science Is Not

Science helps us to be objective because it is limited to observable aspects of nature (**Figure 1.15**). For example, science does not address philosophical questions such as "Why do I exist?" Answers to questions like this one can only come from within, as an integration of all the personal experiences and mental connections that shape our consciousness. This is not to say subjective answers have no value, because no human society can function for long unless its individuals share standards for making judgments, even if they are subjective. Moral, aesthetic, and philosophical standards vary from one society to the next, but all help people decide what is important and good. All give meaning to our lives.

Neither does science address the supernatural, or anything that is "beyond nature." Science does not assume or deny that supernatural phenomena occur, but scientists often cause controversy when they discover a natural explanation for something that was thought to have none. Such controversy arises when a society's moral standards are interwoven with its understanding of nature. Consider the idea that Earth orbits the sun. This model is generally accepted today, but it was not always so. Nicolaus Copernicus published a mathematical model for this idea in the early 1500s, when the prevailing belief system in Europe had Earth as the immovable center of the universe. In 1610, astronomer Galileo Galilei published evidence for this model, and was quickly convicted of heresy. He was forced to publicly recant his work, prohibited from communicating about it ever again, and spent the rest of his life under house arrest.

As Galileo's story illustrates, exploring a traditional view of the natural world from a scientific perspective may be misinterpreted as a violation of morality. As a group, scientists are no less moral than anyone else, but their work follows a particular set of principles that other professions do not require.

Why Science?

Science helps us communicate our experiences of the natural world without bias. As such, it may be as close as we can get to a universal language. We are fairly sure, for example, that gravity behaves the same way everywhere in the universe. Intelligent beings on a distant planet would likely understand it the same way we do. Thus, we might well use gravity or another scientific concept to communicate with them, or anyone, anywhere. The point of science, however, is not to communicate with aliens. It is to find common ground here on Earth.

TAKE-HOME MESSAGE 1.7

- Science is concerned only with testable ideas about observable aspects of nature.
- A scientific theory is a hypothesis that has been rigorously tested and is useful for making predictions about other phenomena.
- Pseudoscience is a claim, argument, or method that is presented as science but does not follow scientific practices.

SUMMARY

Section 1.1 We do not yet know all the **species** that live on Earth, in part because we have not yet explored all of its inhabited regions. Identifying new species is part of **biology**, the scientific study of life. Understanding the scope of life gives us perspective on where we fit into it.

Section 1.2 Biologists think about life at successive levels of organization. Interactions among components of each level give rise to complex properties that emerge at the next level.

All matter, living or not, consists of **atoms** and their subatomic components. Atoms bond together to form **molecules**, some of which are unique to life. The property of life emerges as molecules become organized into a **cell**. **Organisms** are individuals that consist of one or more cells. In many multicelled organisms, cells are organized as **tissues**, **organs**, and **organ systems**.

A **population** is a group of interbreeding individuals of a species in a given area; a **community** is all populations of all species in a given area. An **ecosystem** is a community interacting with its environment. Earth's largest ecosystem, the **biosphere**, includes all regions of the planet that hold life.

Section 1.3 Life has underlying unity in that all living things have similar characteristics. All organisms must acquire energy and **nutrients** to sustain themselves. **Producers** acquire energy and simple raw materials from the environment to make their own food, often by processes such as **photosynthesis**. **Consumers** acquire energy and nutrients by feeding on the tissues, wastes, or remains of other organisms. Nutrients cycle between producers and consumers.

All organisms sense and respond to change, making adjustments that keep conditions in their internal environment within tolerable ranges—a process called **homeostasis**. Information in an organism's **DNA** guides its **development**, **growth**, and **reproduction**. DNA is the basis of similarities and differences among organisms. The passage of DNA from parents to offspring is called **inheritance**.

Section 1.4 The many types of organisms that currently exist on Earth differ greatly in form and function. **Bacteria** and **archaea**, informally called the **prokaryotes**, are single-celled organisms whose DNA is not contained within a nucleus. Archaea are less related to bacteria than they are to **eukaryotes**: single-celled or multicelled organisms whose DNA is contained within a nucleus. **Protists**, **plants**, **fungi**, and **animals** are eukaryotes.

The practice of naming and classifying species is called **taxonomy**. Each species' name consists of two parts: the **genus** name and the specific epithet. We define and classify a species based on **traits** it shares with other species. The more traits that two species share, the closer is their evolutionary relationship. Shared traits can be used to rank species into ever more inclusive categories called **taxa**. Species, genus, family, order, class, phylum, kingdom, and domain are taxa.

Section 1.5 **Critical thinking**, the act of judging the quality of information as one learns, is an important part of **science**, the systematic study of the observable world. Generally, a researcher observes something in nature, forms a **hypothesis** (testable explanation) for it, then makes a **prediction** about what should occur if the hypothesis is correct. Researchers test hypotheses by evaluating predictions that flow from them, and they evaluate predictions by making systematic observations or performing experiments. A typical **experiment** explores a cause-and-effect relationship between **variables**, and it yields **data**. Data that validate a prediction are evidence in support of the related hypothesis.

Biological systems in particular are complex and typically influenced by many interacting variables, so researchers often perform an experiment on two groups of individuals. Any differences in results between the **experimental group** and the **control group** are presumed to be an effect of changing the variable. An experimental **model** may be used if working directly with a subject or event is not possible.

The **scientific method** includes making hypotheses, evaluating predictions that flow from them, and forming conclusions based on the resulting data. Research in the real world tends to be a nonlinear process of exploration.

Section 1.6 Standard practices for evaluating results minimize the possibility of error and the effects of bias in research. Researchers try to study large subsets in order to minimize **sampling error**, which occurs when a subset is not representative of the whole. They also use **probability** calculations to check whether their results are **statistically significant**. Results and conclusions are presented for evaluation to the scientific community, which consists of many critically thinking people systematically checking one another's work.

Section 1.7 Opinion and belief have value in human culture, but they are not part of science. Science addresses only testable ideas about observable aspects of the natural world. A **scientific theory** is a hypothesis that stands after years of systematic tests, and is useful for making predictions about other phenomena. A theory may be revised upon discovery of new data inconsistent with it.

SUMMARY (Continued)

A **law of nature** describes a consistent natural phenomenon but does not include an explanation for it.

Claims, arguments, or methods that are not scientific but presented as if they were are **pseudoscience**. Pseudoscientific rhetoric is prevalent, and unlike science, it has no requirement for accuracy, truthfulness, or objectivity. Convincing people that false or misleading information is scientific jeopardizes our welfare as individuals and as a society.

SELF-QUIZ

Answers in Appendix I

1. A species is a(n) _______ type of organism.
 a. unique c. multicelled
 b. new d. undiscovered

2. The smallest unit of matter is the _______ .
 a. atom c. cell
 b. molecule d. millimeter

3. The smallest unit of life is the _______ .
 a. atom c. cell
 b. molecule d. organism

4. All organisms must acquire _______ and _______ from the environment to maintain themselves, grow, and reproduce.
 a. heat; light c. nutrients; energy
 b. DNA; homeostasis d. producers; consumers

5. _______ is the transmission of DNA to offspring.
 a. Reproduction c. Homeostasis
 b. Development d. Inheritance

6. _______ is a process by which an organism produces offspring.
 a. Reproduction c. Homeostasis
 b. Development d. Inheritance

7. By sensing and responding to change, organisms keep conditions in their internal environment within ranges that cells can tolerate. This process is called _______ .
 a. reproduction c. homeostasis
 b. development d. inheritance

8. _______ move around for at least part of their life.
 a. Living organisms c. Species
 b. Animals d. Eukaryotes

9. A butterfly is a(n) _______ (choose all that apply).
 a. organism e. consumer
 b. domain f. producer
 c. species g. prokaryote
 d. eukaryote

10. A bacterium is _______ (choose all that apply).
 a. an organism c. an animal
 b. single-celled d. a eukaryote

11. Bacteria, Archaea, and Eukarya are three _______ .
 a. domains c. genera
 b. species d. families

12. A control group is _______ .
 a. a set of individuals that have a certain characteristic or receive a certain treatment
 b. the standard against which an experimental group is compared
 c. the experiment that gives conclusive results

13. Five randomly selected university students are found to be taller than 6 feet. The researchers concluded that the average height of a university student is greater than 6 feet. This result is likely to be skewed because of _______ .
 a. experimental error
 b. sampling error
 c. a subjective opinion

14. Science addresses only that which is _______ .
 a. alive c. variable
 b. observable d. indisputable

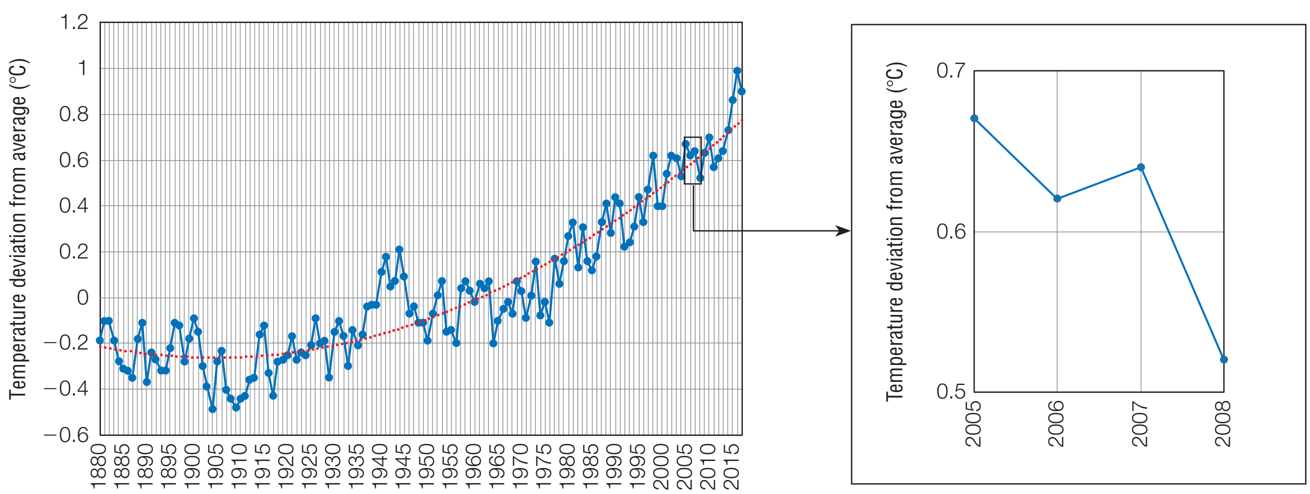
15. Match the terms with the most suitable description.

_____ life	a. if–then statement
_____ probability	b. unique type of organism
_____ species	c. emerges with cells
_____ data	d. testable explanation
_____ hypothesis	e. measure of chance
_____ prediction	f. makes its own food
_____ producer	g. experimental results

CRITICAL THINKING

1. Where would you look for a new species, and why would you look there?
2. A person is declared dead upon the irreversible ceasing of brain activity, blood circulation, and respiration. Only about 1 percent of a body's cells have to die for all of these things to happen. How can a person be dead when 99 percent of his or her cells are still alive?
3. We mentioned in Section 1.7 that critics pointed out flaws in the Olestra study. How would you redesign the experiment so these critics would have more confidence in the researchers' conclusion?
4. Consider the phenomenon called climate change, which refers to an ongoing change in weather patterns driven by an increase in average global temperatures. Temperatures of the atmosphere and ocean have been measured directly for about 200 years, and taken as a whole, these data show a dramatic rising trend (**Figure 1.16A**). Some skeptics have concluded that Earth's temperature is not rising because there are short periods of time in which the average global temperatures have not increased (**Figure 1.16B**). Why do climate scientists find the skeptics' reasoning problematic?
5. Explain the following statement: "The absence of evidence is not evidence of absence."
6. The MMR vaccine offers effective protection from three very dangerous diseases (measles, mumps, and rubella). In 1998, the journal *Lancet* published a scientific paper written by Andrew Wakefield and his colleagues about their study of twelve children with autism. The paper received a lot of media attention because it concluded that vaccination with MMR causes autism. Other groups failed to find such a link, and in 2004, the *Lancet* published a retraction of the conclusion by ten of the paper's twelve authors. Eventually, the *Lancet* retracted the entire paper because it turned out that Wakefield had faked his data. His motive was apparently financial: An attorney suing the MMR vaccine's manufacturer employed Wakefield specifically to find a link between the vaccine and autism. For decades, other groups have researched the subject intensively, and the (real) science is quite clear: MMR vaccination does not cause autism. The evidence that Wakefield falsified his data is also clear. However, public opinion continues to be swayed by pseudoscience that perpetuates Wakefield's fraud.

   Does the incident show that results of scientific studies cannot be trusted? Or does it confirm the usefulness of a scientific approach, because other scientists discovered and exposed the fraud?



A. The full set of data from 137 years shows an overall trend of rising temperatures. **B.** A selected subset of the data shows a different trend.

Figure 1.16 Cherry-picking climate change data.

Formal measurements of global atmospheric and oceanic surface temperatures have been taken every year since the 1800s. Both of these graphs show yearly temperature data as deviations from an average. Temperatures taken between 1951 and 1980 were used to calculate the average.

Data for the graphs is from NASA's Goddard Institute for Space Studies (GISS).

2

Molecules of Life

Properties of matter begin with its component atoms. The cubic structure of these tiny crystals is one property that arises from interactions among the two types of atoms that compose salt.

Francois Gohier/Science Source

CONCEPT CONNECTIONS

In this chapter, you will explore the first levels of life's organization as you encounter examples of how the same building blocks, arranged different ways, form different products (Section 1.2). New properties emerge at each level of organization. Electrons, which are components of atoms, carry energy among molecules in metabolic processes that harvest and store energy, especially photosynthesis (5.3) and respiration (6.2). The structure of lipids gives rise to their function as the foundation of cell membranes (3.3); the structure of proteins, to their function as active participants in metabolism (4.4). Cells use information encoded in the structure of DNA (7.3) to build other molecules (8.2–8.4). Mechanisms of homeostasis (1.3) introduced in this chapter will return again in the context of blood composition (22.9) and body temperature (20.5).

APPLICATION

2.1 A Big Fat Problem

The human body requires only about a tablespoon of fat each day to stay healthy, but most people in developed countries eat far more than that. The average American eats about 70 pounds of fat per year, which may be part of the reason why the average American is overweight. Being overweight increases one's risk for many chronic illnesses. However, the total quantity of fat in the diet may have less of an impact on health than the types of fats eaten.

Molecules that make up oils and other fats have three fatty acid tails, each a long chain of carbon atoms that can vary a bit in structure. Fats that have a certain arrangement of hydrogen atoms around those carbon chains are called *trans* fats. Small amounts of *trans* fats occur naturally in red meat and dairy products, but the main source of these fats in the American diet has been an artificial food product called partially hydrogenated vegetable oil (PHO). Hydrogenation is a manufacturing process that adds hydrogen atoms to oils in order to change them into solid fats, and it creates abundant *trans* fats.

In 1911, Procter & Gamble Co. introduced partially hydrogenated cottonseed oil as a substitute for the more expensive solid animal fats they had been using to make candles and soaps. The demand for candles then began to wane as more households in the United States became wired for electricity, and P&G looked for another way to sell its proprietary fat. PHO looks a lot like lard, so the company began aggressively marketing it as a revolutionary new food: a solid cooking fat with a long shelf life, mild flavor, and lower cost than lard or butter.

By the mid-1950s, PHO had become a major part of the American diet. It was a preferred ingredient for home cooking, and also for preparing a huge variety of manufactured and restaurant foods: French fries, chicken nuggets, and other fried items; as well as margarines, microwave popcorn, cake mixes and frostings, cookies, crackers, peanut butter, pie crusts, pizza dough, and so on. For decades, it was considered to be healthier than animal fats because it was made from plants, but we have known otherwise since 1990. More than any other fat, *trans* fats negatively affect blood cholesterol levels and the function of arteries and veins. The effects of such changes are quite serious. Eating as little as 2 grams per day (about 0.4 teaspoon) of PHO measurably increases one's risk of atherosclerosis (hardening of the arteries), heart attack, and diabetes. A small serving of French fries prepared in it contains about 5 grams of *trans* fats.

A ruling by the U.S. Food and Drug Administration (FDA) now prohibits restaurants and food manufacturers from using PHO in their products. However, manufactured foods prepared before June 2018 may contain PHOs, and they can still be sold until 2020. If you want to avoid these foods, check the ingredients list on the package for partially hydrogenated oils (**Figure 2.1**). Note that PHO-containing products may be marked "0g Trans Fat" even if a single serving contains up to half a gram.

All organisms consist of the same kinds of molecules, but small differences in the way those molecules are put together can have big effects. With this concept, we introduce you to the chemistry of life. This is your chemistry, and it makes you far more than the sum of your body's molecules.

Figure 2.1 Partially hydrogenated vegetable oils in packaged foods.

Prepared foods manufactured before July 2018 may contain partially hydrogenated vegetable oils, which have a high content of unhealthy *trans* fats. A food package may be labelled "0g *Trans* Fat" if a single serving contains less than half a gram. Check the ingredients list for partially hydrogenated oils.

Top, Yellow Cat/Shutterstock.com

DISCUSSION QUESTIONS

1. Fat is an important nutrient for humans. What roles might it play in the body?
2. *Trans* fats were banned from foods decades after scientists discovered them to be dangerous for health. Why do you think it took so long?
3. French fries cooked in partially hydrogenated safflower are much crispier and lighter than those cooked in regular safflower oil. If you were at a restaurant that offered a choice, which fries would you order and why?

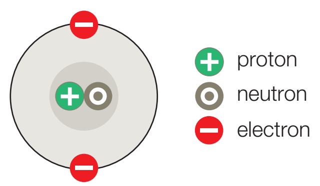


Figure 2.2 Atoms.

Atoms consist of electrons moving around a nucleus of protons and neutrons. Models such as this one do not show what atoms look like. Electrons move in defined, three-dimensional spaces about 10,000 times bigger than the nucleus.

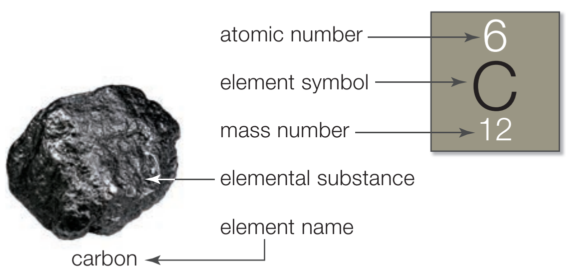


Figure 2.3 Example of an element: carbon.

Left, Theodore Gray/Visuals Unlimited, Inc.

2.2 Atoms

LEARNING OBJECTIVES

- Use an example to explain why we say that an atom is the smallest unit of a substance.
- Explain the difference between an atom and an element.
- Describe radioactive decay.
- Use the concept of vacancies to explain the chemical activity of atoms.

Atomic Structure

You learned in Chapter 1 that an atom is the smallest unit of matter. To understand what that means, you need to know about subatomic particles—the particles that make up atoms: protons, neutrons, and electrons (Figure 2.2). **Protons** (p^+) are positively charged (charge is an electrical property in which opposite charges attract, and like charges repel). One or more protons occupy the central core, or **nucleus**, of every atom. Most atoms also have uncharged **neutrons** in their nucleus. Negatively charged **electrons** (e^-) move at high speed around the nucleus.

Different atoms can have different numbers of subatomic particles, but most have about the same number of electrons as protons. The negative charge of an electron is the same magnitude as the positive charge of a proton, so the two charges cancel one another. Thus, an atom with exactly the same number of electrons and protons carries no charge.

Elements

All atoms have protons. The number of protons in an atom's nucleus is called the **atomic number**, and it defines the atom as a particular element. **Elements** are pure substances, each consisting only of atoms with the same number of protons in their nucleus. For example, the element carbon has an atomic number of 6 (Figure 2.3). All atoms with six protons in their nucleus are carbon atoms, no matter how many electrons or neutrons they have. Elemental carbon (the substance) consists only of carbon atoms, and all of those atoms have six protons. We know of 118 elements, and each is represented by a symbol that is an abbreviation of its name (see Appendix II). Carbon's symbol, C, is from *carbo*, the Latin word for coal, which is mostly carbon.

Isotopes

All atoms of an element have the same number of protons, but they can differ in the number of other subatomic particles. For example, one carbon atom may have six neutrons, and another may have seven. We call these two carbon atoms

atomic number Number of protons in the atomic nucleus; defines the element.

electron Negatively charged subatomic particle; in an atom, moves at high speed around the nucleus.

element A pure substance that consists only of atoms with the same number of protons.

isotopes Forms of an element that differ in the number of neutrons.

mass number Of an isotope, the total number of protons and neutrons in the atomic nucleus.

neutron Uncharged subatomic particle that occurs in the atomic nucleus.

nucleus Of an atom, core that is occupied by protons and (in most atoms) neutrons.

proton Positively charged subatomic particle that occurs in the nucleus of all atoms.

radioactive decay Process in which atoms of a radioisotope emit energy and subatomic particles when their nucleus spontaneously breaks up.

radioisotope An isotope with an unstable nucleus.

tracer A substance that can be traced via its detectable component.

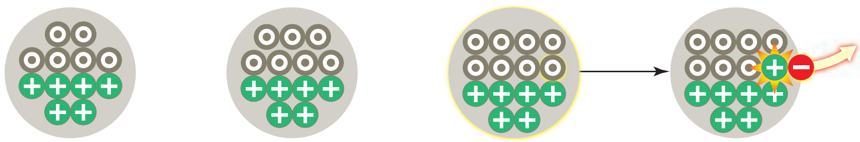


Figure 2.4 Isotopes of carbon.

A–C show protons and neutrons in the nuclei of three naturally occurring isotopes of carbon: carbon 12 (^{12}C), carbon 13 (^{13}C), and carbon 14 (^{14}C).

Carbon 14 is a radioisotope, and it decays into nitrogen 14 (^{14}N) when one of its neutrons spontaneously splits into a proton and an electron (**D**). The electron is emitted as radiation.

isotopes. **Isotopes** are atoms of the same element that have different numbers of neutrons. The total number of neutrons and protons in the nucleus of an isotope is its **mass number**. Mass number is written as a superscript to the left of the element's symbol. The most common isotope of carbon has six protons and six neutrons, so it is ^{12}C, which is pronounced carbon 12 (**Figure 2.4**). The other naturally occurring carbon isotopes are ^{13}C (six protons, seven neutrons), and ^{14}C (six protons, eight neutrons).

Radioisotopes Carbon 14 is an example of a **radioisotope**, or radioactive isotope. Atoms of a radioisotope have an unstable nucleus that breaks up spontaneously. As a nucleus breaks up, it emits radiation (subatomic particles, energy, or both), a process called **radioactive decay**. The atomic nucleus cannot be altered by heat or any other ordinary means, so radioactive decay is unaffected by external factors such as temperature, pressure, or whether the atoms are part of molecules.

Each radioisotope decays at a predictable rate into predictable products. For example, when carbon 14 decays, we know that one of its six neutrons splits into a proton and an electron (**Figure 2.4C,D**). The proton remains in the nucleus, and the electron is emitted as radiation. The nucleus lost a neutron and gained a proton, so it now has seven of each. All atoms with seven protons are nitrogen atoms. Thus, an atom of ^{14}C (6 protons, 8 neutrons) decays into an atom of ^{14}N (7 protons, 7 neutrons). The rate of this decay has been measured, so we know that about half of the atoms in any sample of ^{14}C will be ^{14}N atoms after 5,730 years. Radioisotope decay is so predictable that researchers can estimate the age of a rock or fossil by measuring its isotope content (Section 12.4 returns to this topic).

Tracers The chemical behavior of an atom arises from the number of protons and electrons it has. Neutrons have little effect on chemistry, so all isotopes of an element generally have the same chemical properties—and all are interchangeable in a biological system. Researchers take advantage of the interchangeability when they use radioactive tracers to study biological processes. A **tracer** is any substance with a detectable component such as a radioisotope. When delivered into a biological system such as a cell or a body, a radioactive tracer may be followed by detecting the radiation emitted during decay (**Figure 2.5**).

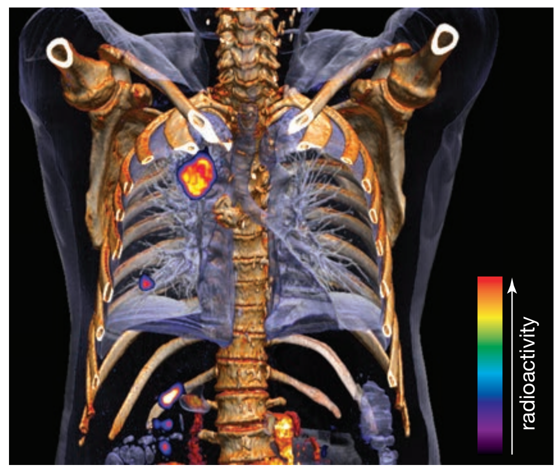


Figure 2.5 A medical application for radioisotopes.

A procedure called PET (short for positron-emission tomography) helps us "see" cellular activity inside a living body.

A radioactive tracer was injected into this lung cancer patient. Inside the patient's body, cancer cells took up more of the tracer than normal cells. A PET scanner detected radioactive decay wherever the tracer was, then translated that data into a digital image. A large tumor in the lung and several smaller tumors are visible.

Source: © Siemens 1996–2019, https://www.siemens.com/press/en/presspicture/2013/healthcare/imaging-therapy-systems/him201310002-01.htm?content[]=HIM&content[]=HCIM

Why Electrons Matter

The more we learn about electrons, the weirder they seem. Consider that an electron has mass but no size, and its position in space is described as more of a smudge than a point. It carries energy, but only in incremental amounts: An electron can gain energy only by absorbing the amount needed to boost it to a higher energy level; likewise, it loses energy only by emitting the difference between two energy levels (these concepts will be important to remember when you learn how cells harvest and release energy).

The Atomic Apartment Building Imagine that an atom is a multilevel apartment building, with the nucleus in the basement. Each "floor" of the building corresponds to a certain energy level, and each has a certain number of "rooms" available for rent. Up to two electrons can occupy each room. Pairs of electrons populate rooms from the ground floor up (lowest to highest energy level). The farther an electron is from the nucleus in the basement, the more energy it has. An electron can move to a room on a higher floor if an energy input gives it a boost, but it quickly emits the extra energy and moves back down.

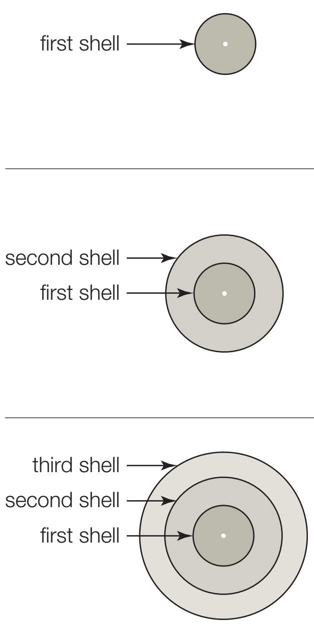
Shell Models A **shell model** is a conceptual diagram of how electrons populate an atom, with successive "shells" corresponding to successively higher energy levels (**Figure 2.6**). Each shell includes all of the rooms on one floor (one energy level) of our atomic apartment building.

We draw a shell model of an atom by filling it with electrons (represented as balls or dots) from the innermost shell out, until there are as many electrons as the atom has protons. There is only one room on the first floor—the lowest energy level—and it fills up first. In hydrogen, the simplest element, a single electron occupies that room (**Figure 2.6A**). Helium, with two protons, has two electrons that fill the room—and the first shell. In larger atoms, more electrons rent the second-floor rooms (**Figure 2.6B**). When the second floor fills, more electrons rent third-floor rooms (**Figure 2.6C**), and so on.

Vacancies When an atom's outermost shell is filled with electrons, we say that it has no vacancies. Atoms with no vacancies are in their most stable state. When an atom's outermost shell has room for another electron, it has a vacancy. Atoms with

Figure 2.6 Shell models.

Each circle (shell) represents one energy level. To make these models, we fill the shells with electrons from the innermost shell out, until there are as many electrons as the atom has protons. The number of protons in each model is indicated.



A. The first shell corresponds to the first energy level, and it can hold up to 2 electrons. Hydrogen has 1 proton, so it has 1 electron and one vacancy. A helium atom has 2 protons, 2 electrons, and no vacancies.

B. The second shell corresponds to the second energy level, and it can hold up to 8 electrons. Carbon has 6 electrons, so its first shell is full. Its second shell has 4 electrons and four vacancies. Oxygen has 8 electrons and two vacancies. Neon has 10 electrons and no vacancies.

C. The third shell corresponds to the third energy level, and it can hold up to 8 electrons. A sodium atom has 11 electrons, so its first two shells are full and the third shell has 1 electron. Thus, sodium has seven vacancies. Chlorine has 17 electrons and one vacancy. Argon has 18 electrons and no vacancies.

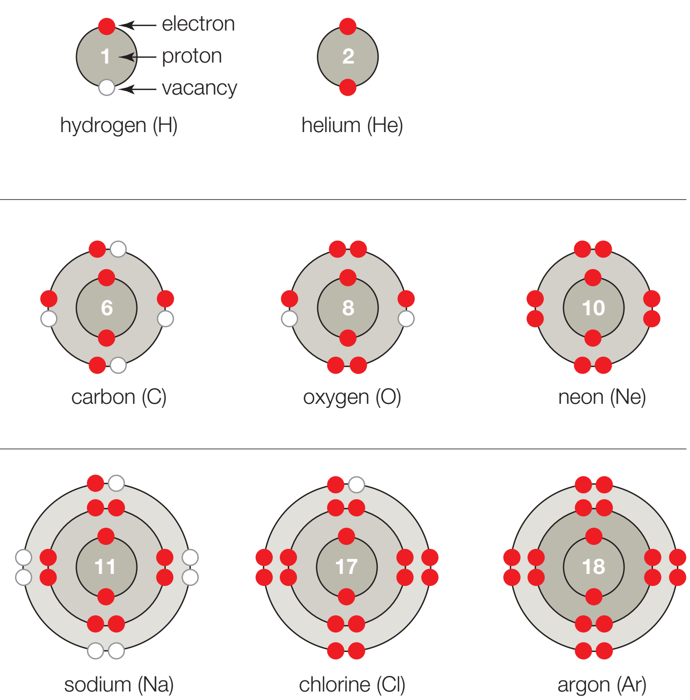


FIGURE IT OUT: Which of these models have unpaired electrons in their outer shell?

Answer: Hydrogen, carbon, oxygen, sodium, and chlorine

Top and bottom photos, Kazunori Nagashima/ The Image Bank/Getty Images

vacancies tend to get rid of them: In other words, they are chemically active.

Consider the element neon (Ne). Neon has 10 protons; with 10 electrons, its outer (third) shell is full—it has no vacancies. Atoms of this element do not interact with other atoms. By contrast, the element sodium has 11 protons; with 11 electrons, a sodium atom's outer (third) shell has one electron and seven vacancies. We can predict that these atoms are chemically active.

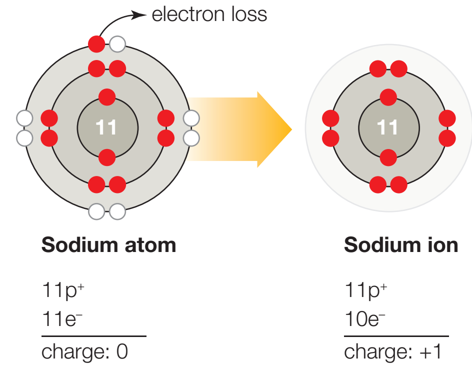
Free Radicals A sodium atom with 11 electrons is not just active, it is extremely active. Why? This atom has a lone electron in its outer shell, but electrons really like to be in pairs when they populate atoms. Atoms that have unpaired electrons are called **free radicals**. With a few exceptions, free radicals are very unstable, easily forcing electrons upon other atoms or ripping electrons away from them. Such interactions damage organic molecules such as DNA, which is why free radicals can be dangerous to life.

Ions A sodium atom with 11 electrons will quickly rid itself of its unpaired electron. When that happens, its second shell—which is full of electrons—becomes its outermost, and no vacancies remain. This is the most stable state of a sodium atom, which is why the vast majority of sodium atoms on Earth have 11 protons and 10 electrons. Atoms like this one, with an unequal number of protons and electrons, are ions. **Ions** are atoms or molecules that carry a net (or overall) charge. Sodium ions have more protons than electrons, so they are positively charged (**Figure 2.7A**). Note how an ion's charge is indicated by a superscript to the right of the element symbol: Na^+, for example, is the designation for a sodium ion.

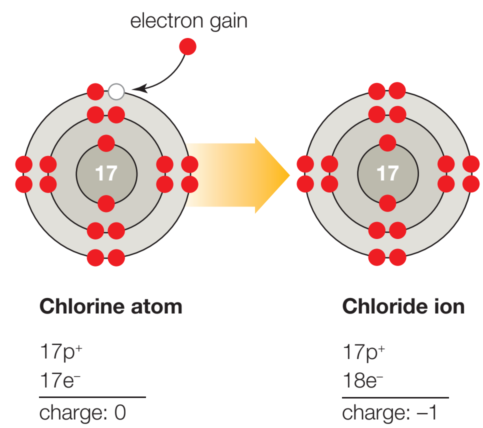
Atoms of other elements accept electrons and become negatively charged. Chlorine is an example. A chlorine atom has 17 protons; with 17 electrons, its outer shell has seven electrons and one vacancy. This atom has one unpaired electron, so it is a free radical. An uncharged chlorine atom can easily fill its vacancy by pulling an electron off of another atom. When that happens, the chlorine atom has more electrons than protons, so it is negatively charged (**Figure 2.7B**). This ion is called chloride (Cl^-).

TAKE-HOME MESSAGE 2.2

- All matter consists of atoms, tiny particles that in turn consist of electrons moving around a nucleus of protons and neutrons. The number of protons in an atom (the atomic number) defines the element.
- Isotopes are atoms of an element that have different numbers of neutrons. The number of neutrons in an atom is its mass number.
- Unstable nuclei of radioisotopes emit radiation as they spontaneously break apart (decay). Radioisotopes decay at a predictable rate to form predictable products.
- When an atom's outer shell is not full of electrons, it has a vacancy. Atoms with vacancies are chemically active.
- Atoms with unpaired electrons—free radicals—can destroy biological molecules, so they are dangerous to life.
- An atom that has a different number of protons and electrons carries a net charge, so it is an ion.



A. A sodium atom (Na) becomes a positively charged sodium ion (Na^+) when it loses the single electron in its third shell. The atom's full second shell is now its outermost, so it has no vacancies.



B. A chlorine atom (Cl) becomes a negatively charged chloride ion (Cl^-) when it gains an electron and fills the vacancy in its third, outermost shell.

Figure 2.7 Ion formation.

Superscripts designate charge. Protons (p^+) carry a positive charge; electrons (e^-) carry a negative charge.

FIGURE IT OUT: Does a chloride ion have an unpaired electron?

Answer: No

free radical An atom with an unpaired electron. Extreme chemical reactivity makes free radicals dangerous to life.

ion An atom or molecule that carries a net charge.

shell model Conceptual diagram of electron distribution in an atom.

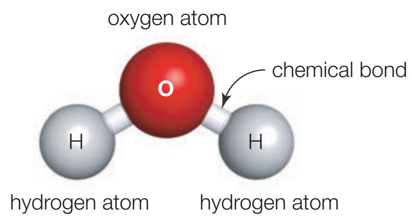
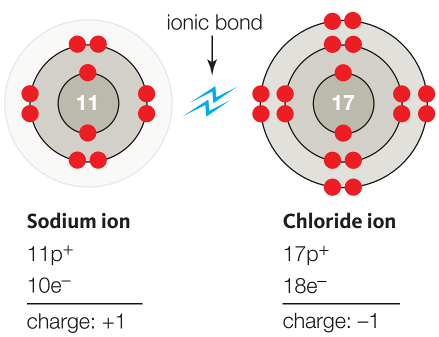
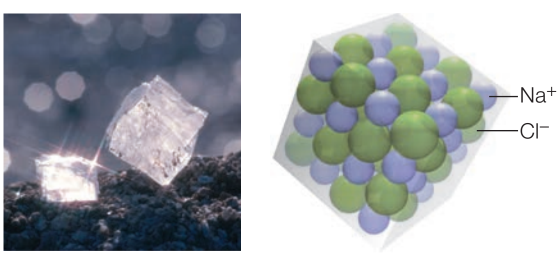


Figure 2.8 Chemical bonds make atoms into molecules.

Chemical bonds hold atoms together in a particular arrangement that defines the type of molecule. This is a model of a water molecule. Every water molecule consists of two hydrogen atoms bonded to the same oxygen atom.



A. The strong mutual attraction of opposite charges holds a sodium ion and a chloride ion together in an ionic bond.



B. Tiny crystals of sodium chloride (left) compose table salt. Each crystal consists of many sodium and chloride ions locked together in a cubic lattice by ionic bonds (right).

Figure 2.9 Ionic bonds in table salt (NaCl).

Bottom left, Francois Gohier/Science Source.

2.3 Chemical Bonds

LEARNING OBJECTIVES

- Describe a chemical bond.
- Explain polarity in terms of ionic bonds and covalent bonds.
- Write the structural formula for a molecule of water.

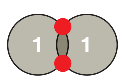
A **chemical bond** is a strong attractive force that arises between two atoms, and the interaction unites the atoms into a molecule. Each molecule consists of atoms held together in a particular number and arrangement by chemical bonds. Consider the molecules that make up water. A water molecule has three atoms: two hydrogen atoms bonded to the same oxygen atom (**Figure 2.8**). Every water molecule has the identical configuration, whether it is part of an ocean, floating in space, making up vapor in your lungs, and so on. A water molecule is an example of a **compound**—a molecule that consists of two or more elements. Other molecules have atoms of one element only.

The term "bond" applies to a continuous range of atomic interactions. However, we can categorize most bonds into distinct types based on their properties. In this book, we discuss two kinds of chemical bonds: ionic and covalent.

Ionic Bonds

An **ionic bond** is a strong mutual attraction between ions of opposite charge. For example, a molecule of sodium chloride (NaCl) consists of a sodium ion and a chloride ion held together by an ionic bond (**Figure 2.9A**). Molecules of sodium chloride make up the substance we know as table salt. Each crystal of salt is a tiny lattice of sodium and chloride ions interacting in ionic bonds (**Figure 2.9B**).

Covalent Bonds



Some atoms can fill their vacancies by sharing electrons with other atoms, an interaction called a **covalent bond** (left). Covalent bonds can be stronger than ionic bonds, but they are not always so.

Table 2.1 shows some of the different ways we represent covalent bonds. In structural formulas, a line between two atoms represents a single covalent bond. For example, a covalent bond links two atoms in molecular hydrogen, so the structural formula of this molecule is H—H. Multiple covalent bonds may form between two atoms when they share multiple pairs of electrons. For example, two atoms sharing two pairs of electrons are connected by two covalent bonds, which are represented by a double line between the atoms. A double bond links the two oxygen atoms in molecular oxygen (O═O). Three lines indicate a triple bond, in which two atoms share three pairs of electrons. A triple covalent bond links the two nitrogen atoms in molecular nitrogen (N≡N).

A structural formula consists of letters connected by lines. By contrast, a structural model is a three-dimensional representation of atoms and bonds. Double and triple bonds are not distinguished from single bonds in structural models. All covalent bonds are shown as one stick connecting two balls, which represent atoms. We use a common color-coding scheme to distinguish elements in structural models: