NATIONAL GEOGRAPHIC LEARNING | CENGAGE Learning

Biology

Concepts and Applications | 9e

Starr
Evers
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Biology

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About the Cover Photo

Despite their awkward waddle on land, emperor penguins soar through the sea. Once they dive into the water, these animals are both graceful and unbelievably fast. Scientists have now discovered the secret to a swimming penguin's speed: A layer of air that stays between the water and their dense coat of feathers acts as a lubricant.

When an emperor penguin swims, it is slowed by the friction between its body and the water, keeping its maximum speed somewhere between four and nine feet per second. But in short bursts the penguin can double or even triple its speed by releasing air from its feathers in the form of tiny bubbles. The bubbles reduce the density and viscosity of the water around the penguin's body, cutting drag and enabling the bird to reach speeds that would otherwise be impossible—and that help the penguins avoid fast-moving predators such as leopard seals.

The key to this talent is in the penguin's feathers. Like other birds, emperors have the capacity to fluff their feathers and insulate their bodies with a layer of air. Unlike most birds, which have rows of feathers with bare skin between them, emperor penguins have a dense, uniform coat of feathers. And because the bases of their feathers include tiny filaments—just 20 microns in diameter, less than half the width of a thin human hair—air is trapped in a fine, downy mesh and released as microbubbles so tiny that they form a lubricating coat on the feather surface.

Though feathers are not an option for ships, technology may finally be catching up with biology. In 2010 a Dutch company started selling systems that lubricate the hulls of container ships with bubbles. Last year Mitsubishi announced that it had designed an air-lubrication system for supertankers. But so far no one has designed anything that can gun past a leopard seal and launch over a wall of sea ice. That's still proprietary technology.

Join photographer Paul Nicklen as he captures unique video of emperor penguins soaring through the sea and launching their bodies out of the water onto the ice at *http://ngm.nationalgeographic.com/2012/11/emperor-penguins/behind-the-scenes-video.*

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Ninth Edition
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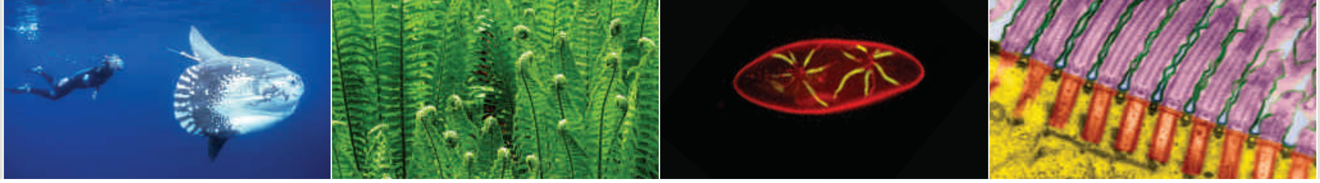
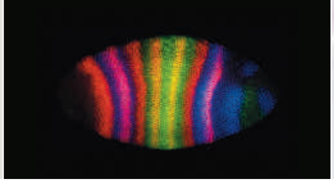
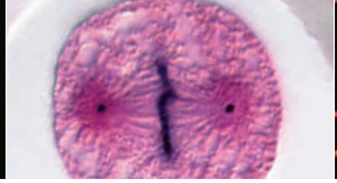
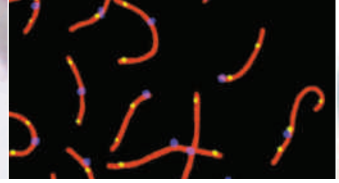
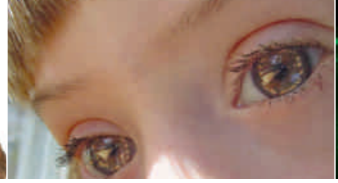
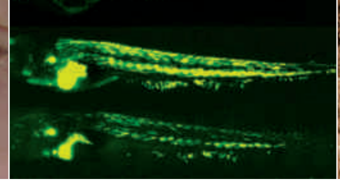


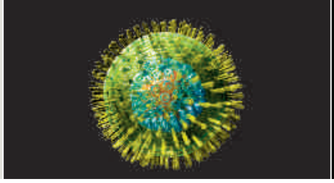
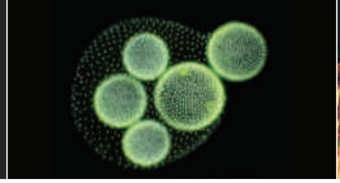
UNIT I PRINCIPLES OF CELLULAR LIFE



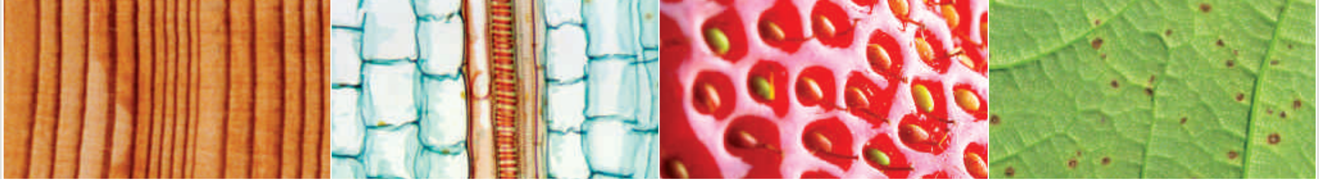









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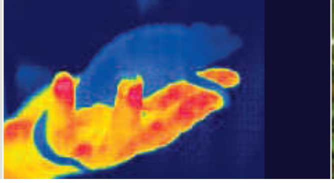
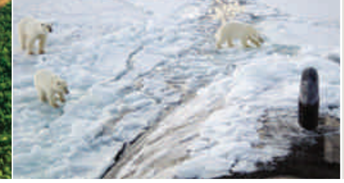








Preface

We wrote this book to provide an accessible and appealing introduction to the study of life. Most students who use it will not become biologists, but all can benefit from an enhanced understanding of biological processes. For example, knowing how cells and bodies work helps a person make informed decisions about nutrition, life-style, and medical care. Recognizing the breadth of biodiversity, the mechanisms by which it arises, and the ways in which species interact brings to light the threats posed by human-induced extinctions. Realizing how living and nonliving components of ecosystems interact makes it clear why human activities such as adding greenhouse gases to the atmosphere puts us and other species at risk.

Our quest to educate and edify is shared by the National Geographic Society, with whom we have partnered for this edition. You will see the fruits of this partnership throughout the text—in spectacular new photographs, informative illustrations, and text features that highlight the wide variety of work supported by the society.

FEATURES OF THIS EDITION

SETTING THE STAGE

Each chapter opens with a dramatic two-page photo spread. A brief Links to Earlier Concepts paragraph reminds students of relevant information that has been covered in previous chapters, and concise Key Concept statements summarize the current chapter's content. An eye-catching image that appears in icon form next to each key concept also occurs within a relevant section, as part of a visual message that threads through the chapter.

CONCEPT SPREADS

The content of every chapter is organized as a series of Concepts, each explored in a section that is two pages or less. A section's Concept is reflected in its title, which is posed as a question that the student should be able to answer after reading the text. Bulleted sentences in the Take Home Message summarize and reinforce the Concept and supporting information provided in the section.

PEOPLE MATTER

Our new People Matter feature illustrates the relevance of ongoing research, and also highlights the diversity of the modern scientific community. Individuals whose work is spotlighted in this feature include well-established scientists, young scientists who are just beginning their careers, and a few nonscientists; most are National Geographic Explorers or Grantees.

ON-PAGE GLOSSARY

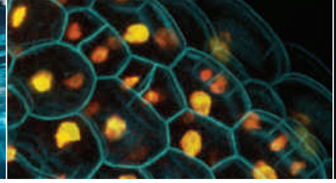
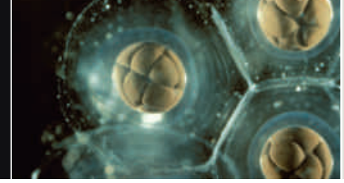
A new On-Page Glossary comprises boldface key terms introduced in each section. This section-by-section glossary offers definitions in alternate wording, and can also be used as a quick study aid. All glossary terms also appear in boldface in the Chapter Summary.

EMPHASIS ON RELEVANCE

Each chapter ends with an Application section that explains a current topic in light of the chapter content. For example, in Chapter 29, students use what they just learned about neural control to understand how sports-induced concussions permanently injure the brain—which is under intense study by scientific and athletic communities at this writing. Each Application also relates to a core interest of the National Geographic Society: Education, Conservation, Exploration, Get Involved, or Sustainability.

SELF-ASSESSMENT TOOLS

Many figure captions now include a Figure-It-Out Question and answer that allow students to quickly check their understanding of the illustration. At the end of each chapter, Self-Quiz and Critical Thinking Questions provide additional self-assessment material. A new chapter-end Data Analysis Activity sharpens analytical skills by asking the student to interpret data presented in graphic or tabular form. The data is related to the chapter material, and is from a published scientific study in most cases. For example, the Activity in Chapter 13 (Observing Patterns in Inherited Traits) asks the student to interpret data from an experiment revealing the suppressive effect of cystic fibrosis mutations on cellular uptake of *Salmonella* bacteria. This Activity continues the explanation of cystic fibrosis inheritance patterns begun in the chapter's Application section.



CHAPTER-SPECIFIC CHANGES This new edition contains 275 new photographs and almost 200 new or updated illustrations. In addition, the text of every chapter has been updated and revised for clarity. A page-by-page guide to new content and figures is available upon request, but we summarize the highlights here.

Chapter 1, Invitation to Biology
Renewed and updated emphasis on the relevance of new species discovery and the process of science; new features spotlight Smithsonian curator Kris Helgen and marine biologist Tierney Thys.

Chapter 2, Life's Chemical Basis
New graphics illustrate elements and radioactive decay; new feature spotlights volcanologist Ken Sims sampling radioisotopes in lava.

Chapter 3, Molecules of Life
New illustrations of carbon rings and tertiary structure; new feature spotlights discovery of carbohydrates in gas surrounding a sunlike star.

Chapter 4, Cell Structure
New photos illustrate surface-to-volume ratio, prokaryotes, biofilms, food vacuoles, chloroplasts, amyloplasts, basal bodies, and *E. coli* on food. New art illustrates plant cell walls, plasmodesmata, and cell junctions. Comparison of microscopy techniques updated using *Paramecium*. New features highlight electrical engineer Aydogan Ozcan's cell phone microscope, and astrobiologist Kevin Hand's work with NASA.

Chapter 5, Ground Rules of Metabolism
New photos illustrate potential energy, activation energy, energy transfer in redox reactions, turgor, phagocytosis, and alcohol abuse. Temperature-dependent enzyme activity now illustrated with polymerases. New feature highlights pressure-tolerant enzymes of deep sea amphipods. Expanded material on cofactors consolidated with ATP into new section. New activity requires interpretation of pH activity graphs of four enzymes from an extremophile archaean.

Chapter 6, Where It Starts—Photosynthesis
New photos illustrate phycobilins, and adaptations of C4 plants. New feature highlights conservation work of forester Willie Smits.

Chapter 7, How Cells Release Chemical Energy
New photos illustrate alcoholic and lactate fermentation, mitochondria, and mitochondrial disease. Revised art shows aerobic respiration's third stage. New feature highlights Benjamin Rapoport's glucose-driven, implantable fuel cell.

Chapter 8, DNA Structure and Function
Chromosome and DNA artwork has been revised for consistency throughout unit; DNA replication art updated. New photos illustrate DNA, x-ray diffraction, and mutation. New section consolidates material on DNA damage and mutations. New Figure spotlights marine biologist Mariana Fuentes, who studies how global warming is impacting sex ratios in sea turtle populations. Sex determination figure removed (text content remains).

Chapter 9, From DNA to Protein
New feature highlights Jack Horner's discovery of *T. rex* collagen in an ancient fossil. Expanded material on the effects of mutation includes new micrograph of a sickled blood cell. Ricin essay expanded to include other RIPs along with new photos and illustrations. New activity requires interpretation of data on the effects of an engineered RIP on cancer cells.

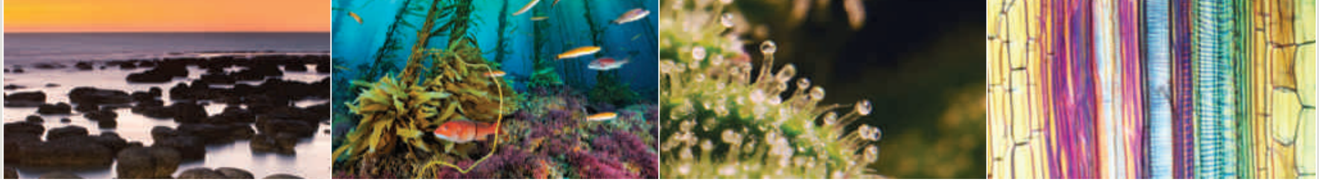
Chapter 10, Control of Gene Expression
New photos illustrate a polytene chromosome, *antennapedia* gene and mutation, X chromosome inactivation, *Arabidopisis* mutations, and breast cancer survivors; new feature details evolution of lactose tolerance. New section covers epigenetics; new activity requires analysis of retrospective data on an epigenetic effect.

Chapter 11, How Cells Reproduce
New photos illustrate mitosis, the mitotic spindle; new section details telomeres. New feature highlights behavioral ecologist Iain Couzin's hypothesis about collective behavior in metatstatic cells.

Chapter 12, Meiosis and Sexual Reproduction
New features highlight evolutionary biologist Maurine Neiman's work on the selective advantage of asexuality in the New Zealand mud snail, and asexuality in bdelloid rotifers. New photos illustrate crossovers and DNA repair during mitosis and meiosis.

Chapter 13, Observing Patterns in Inherited Traits
New figure illustrates how genotype gives rise to phenotype; new photos illustrate epistasis and continuous variation. Coverage of environmental effects on gene expression expanded and updated with new epigenetics research and new feature highlighting psychologist Gay Bradshaw's work on PTSD in elephants.

Chapter 14, Human Inheritance
New feature spotlights geneticist Nancy Wexler's work on Huntington's disease; new photo illustrates albinism.



Chapter 15, Biotechnology

Coverage of personal genetic testing updated with new medical applications, including photo of Angelina Jolie. New photos show recent examples of genetically modified animals. New "who's the daddy" critical thinking question offers students an opportunity to analyze a paternity test based on SNPs.

Chapter 16, Evidence of Evolution

Photos of analogous plants replaced with classic examples; new photo in morphological convergence section illustrates the difference. Photos of 19th century naturalists added to emphasize the process of science that led to natural selection theory. Expanded coverage of fossils includes how banded iron formations provide evidence of evolution of photosynthesis, and new feature spotlighting paleontologist Paul Sereno. New series of paleogeographic maps from Ron Blakey.

Chapter 17, Processes of Evolution

Added simple graphic to illustrate founder effect, and replaced hypothetical example in text with reduced diversity of ABO alleles in Native Americans. Consolidated and expanded material on antibiotic resistance into new Application section that covers overuse of antibiotics in livestock. New feature highlights evolutionary biologist Julia Day's work on speciation in African cichlids. New photos illustrate behavioral isolation in peacock spiders; new graphics illustrate stasis in coelacanths, and parsimony analysis. Added example of using cladistics to study viral evolution.

Chapter 18, Life's Origin and Early Evolution

Added information about earliest evidence of liquid water on Earth, a new contender for oldest fossil cells, and Robert Ballard's discovery of deep sea hydrothermal vents.

Chapter 19, Viruses, Bacteria, and Archaea

New feature about virologist Nathan Wolfe, increased coverage of viral recombination and of the roles of bacteria in human health and as decomposers.

Chapter 20, The Protists

New graphic illustrating primary and secondary endosymbiosis; added information about diatoms as a source of petroleum; new feature about Ken Banks, who created a text messaging system now used to track malaria outbreaks; coverage of choanoflagellates (the modern protists most closely related to animals) moved to this chapter.

Chapter 21, Plant Evolution

Updated life cycle graphics; improved photos of liverworts and horworts; new feature about Jeff Benca's studies of lycophytes, new coverage of seed banks as stores of plant diversity.

Chapter 22, Fungi

New graphics illustrating fungal phylogeny and a generalized fungal life cycle; new feature about DeeAnn Reeder, who studies white nose syndrome in bats; new coverage of fungi that infect insects and use of fungi in biotechnology and research; new coverage of the chytrid implicated in many amphibian declines.

Chapter 23, Animals I: Major Invertebrate Groups

New graphic comparing body plans in acolomate, pseudocoelomate, and coelomate worms; new feature about David Gruber's studies of biofluorescence in cnidarians; added information about penis fencing in marine flatworms and regeneration in planarians, similarity between larvae of annelids and mollusks as evidence of shared ancestry.

Chapter 24, Animals II: The Chordates

Updated evolutionary tree diagrams for chordates showing monophyly of jawless fishes; dropped discussion of "craniates"; updated and revised discussion of primate subgroups and human evolution with new photos and graphics; new feature about paleontologists Meave and Louise Leakey; new discussion of health problems related to our bipedalism.

Chapter 25, Plant Tissues

Reorganized to consolidate growth patterns into a single section. Many new photos added to illustrate internal structure of stems, leaves, roots. Two new features highlight the work of plant biologist Mark Olson and plant ecologist Jon Keeley.

Chapter 26, Plant Nutrition and Transport

New feature highlights the work of agroecologist Jerry Glover. Many new photos and updated art pieces. Illustration of Casparian strip integrated with new micrograph.

Chapter 27, Plant Reproduction and Development

Updated material on bee pollination behavior and colony collapse. Expanded coverage of asexual reproduction includes seedless crops, and historical information on John Chapman and *Phylloxera*. Plant development heavily revised to reflect paradigm shifts driven by recent breakthroughs in research. Expanded material on hormones organized by section. New features highlight the work of ethnobotanist Grace Gobbo and entomologist Dino Martins. New photos illustrate UV-reflecting patterns in flowers, mammal and bird pollination, embryonic development, internal anatomy of eudicot seeds, ABA mutation, chloroplast tropism, abscission, hypersensitive response, honeybee pollination. New art shows apical dominance, ethylene production during fruit formation, stomata function, gibberellin function in seed germination, circadian cycles of gene expression.

Chapter 28, Animal Tissues and Organ Systems

New feature about Brenda Larison's investigation into the adaptive value of zebra stripes, new information about walrus blubber (a specialized adipose tissue); improved coverage of organ systems; added information about tissue regeneration in nonhuman animals to discussion of stem cells.

Chapter 29, Neural Control

Added a subsection about methods of studying the human brain. New feature highlights the work of Diana Reiss, who studies dolphin cognition. New coverage of concussions and traumatic brain injury.

Chapter 30, Sensory Perception

New graphic of neurons involved in olfaction; new information about loss of sweet receptors in cats and some other carnivores and about newly discovered taste receptor for fatty acids; new feature about Fernando Montealegre-Z's studies of insect hearing; new section about cochlear implants.

Chapter 31, Endocrine Control

New coverage of the roles of thyroid hormone in amphibian metamorphosis and of melatonin in seasonal coat color changes in arctic hares; updated coverage of phthalates as endocrine disrupters.

Chapter 32, Structural Support and Movement

New opening section about mechanisms of animal locomotion; new feature about Kakani Katija Young's investigation into how marine animals mix the seas; new information about muscles of an elephant's trunk and the composition of muscle fibers in loris limbs.

Chapter 33, Circulation

New graphic showing the structure of and relationship among blood vessels; improved description of and depiction of capillary exchange; added information about circulation in giraffes and about cardiocerebral resuscitation.

Chapter 34, Immunity

Added material on neutrophil nets, chronic inflammation, cytokine storm, public confidence as a factor in the success of vaccination programs. Updated material on HIV/AIDS treatment strategies. New photos illustrate T cell/APC interaction, skin as a surface barrier, neutrophil nets, IgM polymers, leukocytes populating a lymph node, cytotoxic T cells killing a cancer cell, contact allergy. New feature highlights biochemist Mark Merchant's work discovering and characterizing crocodilian antimicrobial peptides.

Chapter 35, Respiration

Added a photo of horseshoe crab hemolymph and information about modification of nostril position in vertebrates; updated information about first aid for choking. New feature about Cynthia Beall's study of humans who live at high altitude.

Chapter 36, Digestion and Human Nutrition

New graphic illustrates organs that contribute material to the small intestine; new table summarizes chemical digestion. New feature highlights the work of epidemiologist Christopher Golden, who studies the nutritional importance of bushmeat. New application about health effects of obesity.

Chapter 37, Maintaining the Internal Environment

New feature highlights biological anthropologist Cheryl Knott's use of urinalysis in studies of orangutans. New information about climate-related genetic adaptations in humans.

Chapter 38, Reproduction and Development

Major reorganization—the overview of development now precedes the discussion of humans. New feature highlights the work of zoologist Stewart Nicol, who studies sexual anatomy and behavior of echidnas. Improved depiction of the ovarian cycle.

Chapter 39, Animal Behavior

Added information about epigenetic effects on behavior. New feature highlights biologist Isabelle Charrier's work studying vocal recognition in animals. Improved discussion of parental care variation among animal groups.

Chapter 40, Population Ecology

New feature highlights the work of biologist Karen DeMatteo, who studies predator populations. Revised coverage of life history strategies.

Chapter 41, Community Ecology

New feature highlights population geneticist Nayuta Yamashita's study of resource partitioning in lemurs.

Chapter 42, Ecosystems

New feature highlights conservationist Jonathan Waterman's journey along the water-deprived Colorado River. Updated information about current level of atmospheric carbon dioxide; expanded discussion of the nitrogen cycle.

Chapter 43, The Biosphere

Improved general description of biomes. Added information about desert crust. New feature highlights biogeochemist Katey Walter Anthony's studies of arctic methane.

Chapter 44, Human Effects on the Biosphere

New feature about Paula Kahumbu's conservation efforts in Africa; sustainable uses of resources. Updated information about acid rain, ozone depletion.

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Acknowledgments

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—Lisa Starr, Chris Evers, and Cecie Starr 2013

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Maury Wrightson
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Lan Xu
South Dakota State University

Poksyn ("Grace") Yoon
Johnson and Wales University

Muriel Zimmermann
Chaffey College

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

1 INVITATION TO BIOLOGY

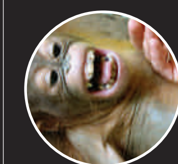
Links to Earlier Concepts

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—contributes to that understanding.

KEY CONCEPTS

THE SCIENCE OF NATURE

We can understand life by studying it at many levels, starting with atoms that are components of all matter, and extending to interactions of organisms with their environment.



LIFE'S UNITY

All living things require ongoing inputs of energy and raw materials; all sense and respond to change; and all have DNA that guides their functioning.

LIFE'S DIVERSITY

Observable characteristics vary tremendously among organisms. Various classification systems help us keep track of the differences.

THE NATURE OF SCIENCE

Carefully designing experiments helps researchers unravel cause-and-effect relationships in complex natural systems.

LIMITATIONS OF SCIENCE

Science addresses only testable ideas about observable events and processes. It does not address anything untestable, such as beliefs and opinions.

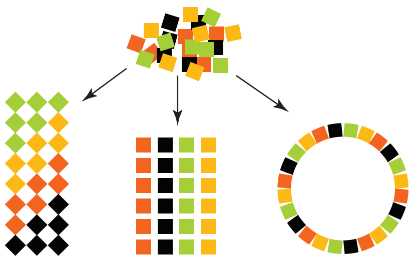
Photograph by Tim Laman/National Geographic Creative.

1.1 HOW DO LIVING THINGS DIFFER FROM NONLIVING THINGS?

LIFE IS MORE THAN THE SUM OF ITS PARTS

Biology is the study of life, past and present. What, exactly, is the property we call "life"? We may never actually come up with a good 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 only identifying properties that differentiate living from nonliving things.

Complex properties, including life, often emerge from the interactions of much simpler parts. To understand why, take a look at this drawing:



The property of "roundness" emerges when the parts are organized one way, but not other ways. Characteristics of a system that do not appear in any of the system's components are called **emergent properties**. The idea that structures with emergent properties can be assembled from the same basic building blocks is a recurring theme in our world, and also in biology.

LIFE'S ORGANIZATION

Through the work of biologists, we are beginning to understand an overall pattern in the way life is organized. We can look at life in successive levels of organization, with new emergent properties appearing at each level (**FIGURE 1.1**).

Life's organization starts with interactions between atoms. **Atoms** are fundamental building blocks of all substances 1. Atoms join as **molecules** 2. There are no atoms unique to living things, but there are unique molecules. In today's world, only living things make the "molecules of life," which are lipids, proteins, DNA, RNA, and complex carbohydrates. The emergent property of "life" appears at the next level, when many molecules of life become organized as a cell 3. A **cell** is the smallest unit of life. Cells survive and reproduce themselves using energy, raw materials, and information in their DNA.

Some cells live and reproduce independently. Others do so as part of a multicelled organism. An **organism** is an individual that consists of one or more cells. A poppy plant is an example of a multicelled organism 7.

In most multicelled organisms, cells are organized as tissues 4. A **tissue** consists of specific types of cells organized in a particular pattern. The arrangement

1 atom
Atoms are fundamental units of all substances, living or not. This image shows a model of a single atom.

2 molecule
Atoms join other atoms in molecules. This is a model of a water molecule. The molecules special to life are much larger and more complex than water.

3 cell
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.

4 tissue
Organized array of cells that interact in a collective task. This is epidermal tissue on the outer surface of a flower petal.

5 organ
Structural unit of interacting tissues. Flowers are the reproductive organs of many plants.

FIGURE 1.1 {Animated} An overall pattern in the way life is organized. New emergent properties appear at each successive level.

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6 organ system
A set of interacting organs. The shoot system of this poppy plant includes its aboveground parts: leaves, flowers, and stems.

7 multicelled organism
Individual that consists of more than one cell. Cells of this California poppy plant are part of its two organ systems: aboveground shoots and belowground roots.

8 population
Group of single-celled or multicelled individuals of a species in a given area. This population of California poppy plants is in California's Antelope Valley Poppy Reserve.

9 community
All populations of all species in a specified area. These plants are part of a community called the Antelope Valley Poppy Reserve.

10 ecosystem
A community interacting with its physical environment through the transfer of energy and materials. Sunlight and water sustain the community in the Antelope Valley.

11 biosphere
The sum of all ecosystems: every region of Earth's waters, crust, and atmosphere in which organisms live. No ecosystem in the biosphere is truly isolated from any other.

allows the cells to collectively perform a special function such as protection from injury (dermal tissue), movement (muscle tissue), and so on.

An **organ** is an organized array of tissues that collectively carry out a particular task or set of tasks 5. For example, a flower is an organ of reproduction in plants; a heart, an organ that pumps blood in animals. An **organ system** is a set of organs and tissues that interact to keep the individual's body working properly 6. Examples of organ systems include the aboveground parts of a plant (the shoot system), and the heart and blood vessels of an animal (the circulatory system).

A **population** is a group of individuals of the same type, or species, living in a given area 8. An example would be all of the California poppies that are living in California's Antelope Valley Poppy Reserve. At the next level, a **community** consists of all populations of all species in a given area. The Antelope Valley Reserve community includes California poppies and all other organisms—plants, animals, microorganisms, and so on—living in the reserve 9. Communities may be large or small, depending on the area defined.

The next level of organization is the **ecosystem**, which is a community interacting with its environment 10. The most inclusive level, the **biosphere**, encompasses all regions of Earth's crust, waters, and atmosphere in which organisms live 11.

atom Fundamental building block of all matter.
biology The scientific study of life.
biosphere All regions of Earth where organisms live.
cell Smallest unit of life.
community All populations of all species in a given area.
ecosystem A community interacting with its environment.
emergent property A characteristic of a system that does not appear in any of the system's component parts.
molecule An association of two or more atoms.
organ In multicelled organisms, a grouping of tissues engaged in a collective task.
organism Individual that consists of one or more cells.
organ system In multicelled organisms, set of organs engaged in a collective task that keeps the body functioning properly.
population Group of interbreeding individuals of the same species that live in a given area.
tissue In multicelled organisms, specialized cells organized in a pattern that allows them to perform a collective function.

TAKE-HOME MESSAGE 1.1

Biologists study life by thinking about it at different levels of organization, with new emergent properties appearing at each successive level.

All things, living or not, consist of the same building blocks: atoms. Atoms join as molecules.

The unique properties of life emerge as certain kinds of molecules become organized into cells.

Higher levels of life's organization include multicelled organisms, populations, communities, ecosystems, and the biosphere.

CREDITS: (1) 6: Lady Bird Johnson Wildflower Center; 7: Michael Szoenyi/Science Source; 8: Photographers Choice RF/SuperStock; 9: © Sergei Krupnov, www.flickr.com/photos/7969319@N03; 10: © Mark Koberg Photography; 11: NASA.

1.2 HOW ARE ALL LIVING THINGS ALIKE?

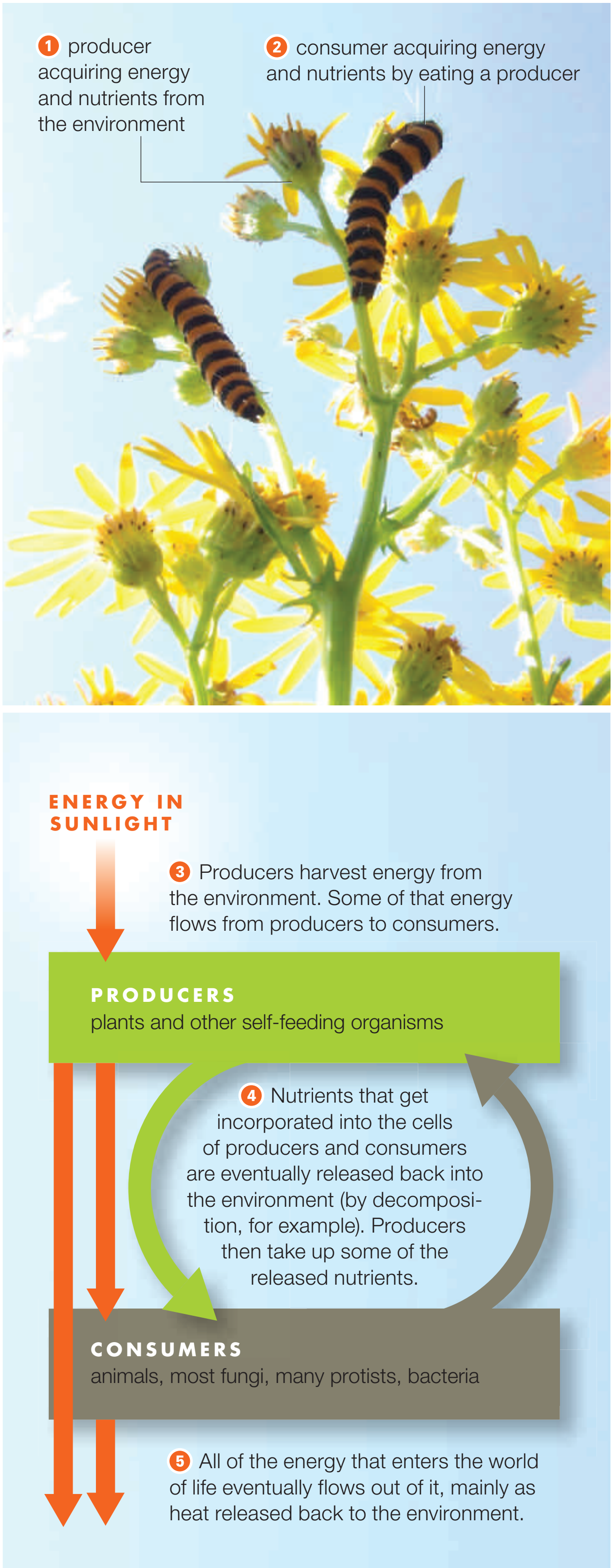

FIGURE 1.2 **{Animated}** The one-way flow of energy and cycling of materials through the world of life.

Even though we cannot precisely define "life," we can intuitively understand what it means because all living things share a set of key features. All require ongoing inputs of energy and raw materials; all sense and respond to change; and all pass DNA to offspring (**TABLE 1.1**).

TABLE 1.1

Three Key Features of Living Things

Requirement for energy and nutrients	Ongoing inputs of energy and nutrients sustain life.
Homeostasis	Each living thing has the capacity to sense and respond to change.
Use of DNA as hereditary material	DNA is passed to offspring during reproduction.

ORGANISMS REQUIRE ENERGY AND NUTRIENTS

Not all living things eat, but all require energy and nutrients on an ongoing basis. Both are essential to maintain the functioning of individual organisms and the organization of life. A **nutrient** is a substance that an organism needs for growth and survival but cannot make for itself.

Organisms spend a lot of time acquiring energy and nutrients (**FIGURE 1.2**). 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 categories: producers and consumers. **Producers** make their own food using energy and simple raw materials they get from nonbiological sources 1. Plants are producers that use the energy of sunlight to make sugars from water and carbon dioxide (a gas in air), a process called **photosynthesis**. By contrast, **consumers** cannot make their own food. They get 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. The leftovers from consumers' meals end up in the environment, where they serve as nutrients for producers. Said another way, nutrients cycle between producers and consumers.

Unlike nutrients, energy is not cycled. It flows through the world of life in one direction: from the environment 3, through organisms 4, and back 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 (we return to this topic in Chapter 5).

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ORGANISMS SENSE AND RESPOND TO CHANGE

An organism cannot survive for very long in a changing environment unless it adapts to the changes. Thus, every living thing has the ability to sense and respond to change both inside and outside of itself (**FIGURE 1.3**). For example, after you eat, the sugars from your meal enter your bloodstream. The added sugars set in motion a series of events that causes cells throughout the body to take up sugar faster, so the sugar level in your blood quickly falls. This response keeps your blood sugar level within a certain range, which in turn helps keep your cells alive and your body functioning.

The fluid portion of your blood is a component of your internal environment, which is all of the body fluids outside of cells. Unless that internal environment is kept within certain ranges of temperature and other conditions, your body cells will die. By sensing and adjusting to change, you and all other organisms keep conditions in the internal environment within a range that favors survival. **Homeostasis** is the name for this process, and it is one of the defining features of life.

ORGANISMS USE DNA

With little variation, the same types of molecules perform the same basic functions in every organism. For example, information in an organism's **DNA** (deoxyribonucleic acid) guides ongoing functions that sustain the individual through its lifetime. Such functions include **development**: the process by which the first cell of a new individual gives rise to a multicelled adult; **growth**: increases in cell number, size, and volume; and **reproduction**: processes by which individuals produce offspring.

consumer Organism that gets energy and nutrients by feeding on tissues, wastes, or remains of other organisms.
development Multistep process by which the first cell of a new multicelled organism gives rise to an adult.
DNA Deoxyribonucleic acid; carries hereditary information that guides development and other activities.
growth In multicelled species, an increase in the number, size, and volume of cells.
homeostasis Process in which an organism keeps its internal conditions within tolerable ranges by sensing and responding to change.
inheritance Transmission of DNA to offspring.
nutrient Substance that an organism needs for growth and survival but cannot make for itself.
photosynthesis Process by which producers use light energy to make sugars from carbon dioxide and water.
producer Organism that makes its own food using energy and nonbiological raw materials from the environment.
reproduction Processes by which parents produce offspring.

FIGURE 1.3 Living things sense and respond to their environment. This baby orangutan is laughing in response to being tickled. Apes and humans make different sounds when being tickled, but the airflow patterns are so similar that we can say apes really do laugh.

Individuals of every natural population are alike in certain aspects of their body form and behavior because their DNA is very similar: Orangutans look like orangutans and not like caterpillars because they inherited orangutan DNA, which differs from caterpillar DNA in the information it carries. **Inheritance** refers to the transmission of DNA to offspring. All organisms inherit their DNA from one or two parents.

DNA is the basis of similarities in form and function among organisms. However, the details of DNA molecules differ, and herein lies the source of life's diversity. Small variations in the details of DNA's structure give rise to differences among individuals, and also among types of organisms. As you will see in later chapters, these differences are the raw material of evolutionary processes.

TAKE-HOME MESSAGE 1.2

Continual inputs of energy and the cycling of materials maintain life's complex organization.

Organisms sense and respond to change inside and outside themselves. They make adjustments that keep conditions in their internal environment within a range that favors cell survival, a process called homeostasis.

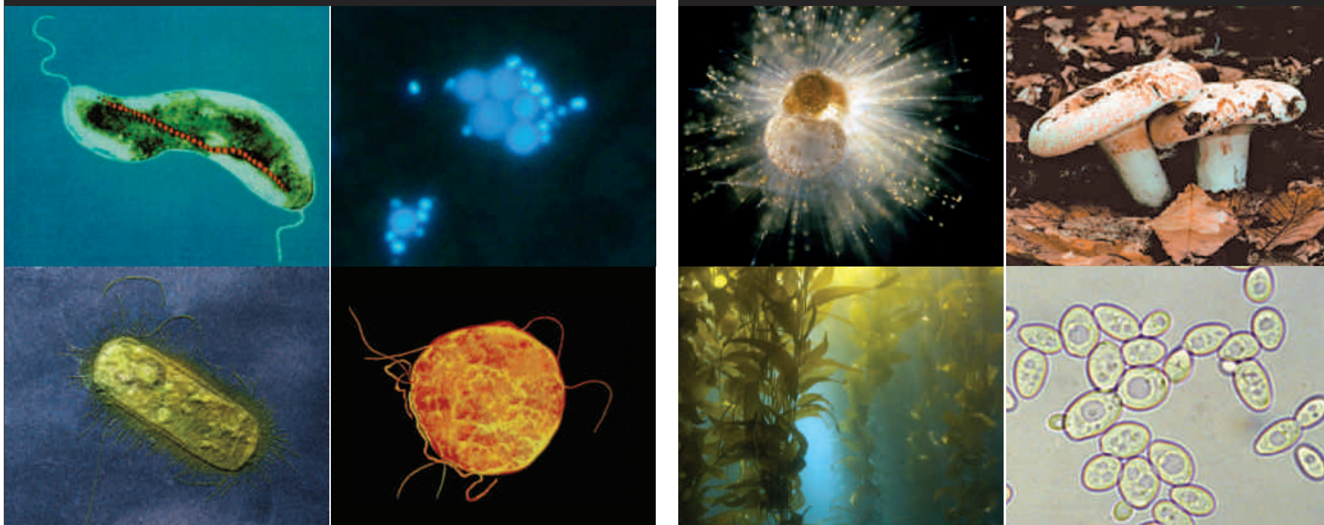
All organisms use information in the DNA they inherited from their parent or parents to develop, grow, and reproduce. DNA is the basis of similarities and differences in form and function among organisms.

CREDIT: (3) © Dr. Marina Davila Ross, University of Portsmouth.

1.3 HOW ARE LIVING THINGS DIFFERENT?

A Prokaryotes are single-celled, and have no nucleus. As a group, they are the most diverse organisms.

B Eukaryotes consist of cells that have a nucleus. Eukaryotic cells are typically larger and more complex than prokaryotes.



bacteria are the most numerous organisms on Earth. Top, this bacterium has a row of iron crystals that functions like a tiny compass; bottom, a resident of human intestines.

archaea resemble bacteria, but they are more closely related to eukaryotes. Top: two types from a hydrothermal vent on the seafloor. Bottom, a type that grows in sulfur hot springs.

protists are a group of extremely diverse eukaryotes that range from microscopic single cells (top) to giant multicelled seaweeds (bottom).

fungi are eukaryotic consumers that secrete substances to break down food outside their body. Most are multicelled (top), but some are single-celled (bottom).

FIGURE 1.4 A few representatives of life's diversity: **A** some prokaryotes; **B** some eukaryotes.

Living things differ tremendously in their observable characteristics. Various classification schemes help us organize what we understand about the scope of this variation, which we call Earth's **biodiversity**.

For example, organisms can be grouped on the basis of whether they have a **nucleus**, which is a sac with two membranes that encloses and protects a cell's DNA. **Bacteria** (singular, bacterium) and **archaea** (singular, archaeon) are organisms whose DNA is *not* contained within a nucleus. All bacteria and archaea are single-celled, which means each organism consists of one cell (**FIGURE 1.4A**). Collectively, these organisms are the most diverse representatives of life. Different kinds are producers or consumers in nearly all regions of Earth. Some inhabit such extreme environments as frozen desert rocks, boiling sulfurous lakes, and nuclear reactor waste. The first cells on Earth may have faced similarly hostile environments.

Traditionally, organisms without a nucleus have been called **prokaryotes**, but this designation is now used only informally. This is because, despite the similar appearance of bacteria and archaea, the two types of cells are less related to one another than we once thought. 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 (**FIGURE 1.4B**). Eukaryotic cells are typically larger and more complex than bacteria or archaea.

Structurally, **protists** are the simplest eukaryotes, but as a group they vary dramatically, from single-celled consumers to giant, multicelled producers.

animal Multicelled consumer that develops through a series of stages and moves about during part or all of its life.
archaea Group of single-celled organisms that lack a nucleus but are more closely related to eukaryotes than to bacteria.
bacteria The most diverse and well-known group of single-celled organisms that lack a nucleus.
biodiversity Scope of variation among living organisms.
eukaryote Organism whose cells characteristically have a nucleus.
fungus Single-celled or multicelled eukaryotic consumer that breaks down material outside itself, then absorbs nutrients released from the breakdown.
nucleus Sac that encloses a cell's DNA; has two membranes.
plant A multicelled, typically photosynthetic producer.
prokaryote Single-celled organism without a nucleus.
protist Member of a diverse group of simple eukaryotes.

CREDITS: (4A) top left, Dr. Richard Frankel; top right, © Dr. Harald Huber, Dr. Michael Hohn, Prof. Dr. K.O. Stetter, University of Regensburg, Germany; bottom left, © Biophoto Associates/Science Source; bottom right, Dr. Terry Beveridge, Visuals Unlimited Inc.; (4B) Protists: top, Courtesy of Allen W. H. Bé and David A. Caron; bottom, © worldswildlifewonders/Shutterstock.com; Fungi: top, © JupiterImages; bottom, Visuals Unlimited/Masterfile.

plants are multicelled eukaryotes. Most are photosynthetic, and have roots, stems, and leaves.

animals are multicelled eukaryotes that ingest tissues or juices of other organisms. All actively move about during at least part of their life.

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

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

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

TAKE-HOME MESSAGE 1.3

Organisms differ in their details; they show tremendous variation in observable characteristics, or traits.

We can divide Earth's biodiversity into broad groups based on traits such as having a nucleus or being multicellular.

PEOPLE MATTER

National Geographic Explorer
KRISTOFER HELGEN

Kristofer Helgen discovers new animals. Deep in a New Guinea rain forest. High on an Andean mountainside. Resting in a museum's specimen drawer. "Conventional wisdom would have it that we know all the mammals of the world," he notes. "In fact, we know so little. Unique species, profoundly different from anything ever discovered, are out there waiting to be found." His own efforts prove this. Helgen himself has discovered approximately 100 new species of mammals previously unknown to science. "Since I was three years old, I've been transfixed by animals," he recalls. "Even then, my excitement revolved around figuring out how many different kinds there were."

Helgen's search plunges him into the wild on almost every continent. Yet about three times as many new finds are made within the walls of museums. "An expert can go into any large natural history museum and identify kinds of animals no one knew existed," he explains. When only a few specimens of a species exist, and reside in museums scattered across the globe, sheer logistics often prevent researchers from connecting the dots and pinpointing a new find. "Collections build up over centuries," he says, "It's virtually impossible to fully interpret that wealth of material. Every day brings surprises." As Curator of Mammals for the Smithsonian Institution's National Museum of Natural History, he oversees not only the collection's use as an invaluable research resource, but also its continued expansion through exploration.

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