The King's Academy
Mrs. Carruthers

AP BIOLOGY

SYLLABUS
DESCRIPTION OF DESIRED PERFORMANCE
LETTER OF INTENT
SUMMER READING AND ASSIGNMENTS

As you probably already know, success in an Advanced Placement course requires a huge commitment by you as a student. AP Biology is no exception, so before you begin your summer reading and assignments, I want to make sure that you are aware of the degree of dedication and commitment that this course requires.

Please read the course syllabus that begins on page 2 in order to get a feel for the course content, goals, and elements. The syllabus will also give you an idea about the kind of teaching and learning you can expect in the class.

Next, please read *Appendix A: Preparing Students for Success in AP Biology* beginning on page 6. This section includes a description of desired performance – it gives you an idea of what you should know and be able to do for high achievement in an AP Biology course.

If after reading the syllabus and description of desired performance, you are still interested in taking AP Biology, print the letter of intent on page 18. Please read the letter and discuss it with your parent(s) or guardian before signing it. You will turn the signed letter in, along with your summer assignments, on the first day of school in August.

You can find the directions for your summer reading and assignments on page 19.

The King’s Academy
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AP BIOLOGY
SYLLABUS

COURSE OVERVIEW:

This AP Biology course is designed to be the equivalent of a two-semester college introductory biology course usually taken by biology majors during their first year. The course covers those topics regularly covered in a college biology course for majors. The textbook used is equivalent to the kind of textbook used by college biology majors and the kinds of labs done are equivalent to those done by college students.

This course is designed to be taken by students after successful completion of a first course in high school biology and one in high school chemistry. It aims to provide students with the conceptual framework, factual knowledge, and analytical skills necessary to deal critically with the rapidly changing science of biology.

The revised AP Biology course addresses the challenge of balancing breadth of content coverage with depth of understanding by shifting from a traditional “content coverage” model of instruction to one that focuses on enduring, conceptual understandings and the content that supports them. This approach will enable students to spend less time on factual recall and more time on inquiry-based learning of essential concepts, and will help them develop the reasoning skills necessary to engage in the science practices used throughout their study of AP Biology.

To foster this deeper level of learning, the breadth of content coverage in AP Biology is defined in a way that distinguishes content essential to support the enduring understandings from the many examples or applications that can overburden the course. Specific illustrative examples are provided that help students achieve deeper understanding.

Students who take an AP Biology course designed using this curriculum framework as its foundation, will also develop advanced inquiry and reasoning skills, such as designing a plan for collecting data, analyzing data, applying mathematical routines, and connecting concepts in and across domains. The result will be readiness for the study of advanced topics in subsequent college courses.

COURSE OBJECTIVES:

The key concepts and related content that define the revised AP Biology course and exam are organized around a few underlying principles called the big ideas, which encompass the core scientific principles, theories, and processes governing living organisms and biological systems. Each of the big ideas embody enduring understandings which are the core concepts that students should retain. Each enduring understanding includes the essential knowledge necessary to support it.

Science practices enable students to establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena. Because content, inquiry, and reasoning are equally important in AP Biology, competency in the science practices that follow the concept outline of this framework is expected of AP Biology students.

THE CONCEPT OUTLINE:

Big Idea 1: The process of evolution drives the diversity and unity of life.
Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce, and to maintain dynamic homeostasis.
Big Idea 3: Living systems store, retrieve, transmit, and respond to information essential to life processes.
Big Idea 4: Biological systems interact, and these systems and their interactions possess complex properties.

SCIENCE PRACTICES OUTLINE:

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
Science Practice 2: The student can use mathematics appropriately.
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.
Science Practice 4: The student can plan and implement data collection strategies appropriate to a particular scientific question.
Science Practice 5: The student can perform data analysis and evaluation of evidence.
Science Practice 6: The student can work with scientific explanations and theories.
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

EXAM INFORMATION:

The AP Biology Exam consists of two sections: multiple choice and free response. The multiple choice section consists of 63 multiple choice questions and 6 numerical grid-in questions that require the integration of science and mathematical skills. The free response section consists of 2 multi-part questions, 1 of which connects to the lab experience, and 6 single-part questions. Both sections include questions that assess students' understanding of the big ideas, enduring understandings, essential knowledge, and the ways in which this understanding can be applied through the science practices. These may include questions on the following:

• the use of modeling to explain biological principles;
• the use of mathematical processes to explain concepts;
• the making of predictions and the justification of phenomena;
• the implementation of experimental design; and
• the manipulation and interpretation of data.

The exam is 3 hours long and includes both a 90-minute multiple choice and numerical grid-in section and a 90-minute free-response section that begins with a mandatory 10-minute reading period. The multiple-choice section accounts for half of the student's exam grade, and the free-response section accounts for the other half.

COURSE TEXTS:

Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, and Robert B. Jackson. AP Edition Biology, 9th Edition (San Francisco: Pearson Benjamin Cummings, 2011).

The College Board. AP Biology Investigative Labs: An Inquiry- Based Approach (USA: The College Board, 2012).

COURSE DESCRIPTION:

Organization:

A summer assignment sheet is provided before students leave school for the summer. This summer assignment consists of mandatory reading assignments and chapter tests which must be completed upon the start of the school year. It also consists of homework assignments for each chapter covered in the summer reading.

At the beginning of the school year a schedule for the course is provided. Weekly reading assignment, lab, test, and exam schedules are included. Students are responsible for keeping up with reading assignments and being prepared for class discussions, labs, tests and exams. Class will be a combination of lecture, coverage of discussion questions, laboratory work, and answering student questions. Periodically, additional homework assignments will be required.

Lab Component:

Students work either individually or in pairs to prepare and complete each hands-on lab. Students complete labs from the *AP Biology Investigative Labs: An Inquiry-Based Approach Lab Manual*. In addition to performing pre-designed labs, students are frequently required to design their own experiments and carry them out whenever possible. Pre-lab and post-lab discussions are an important aspect of the lab component. All labs are graded. Students complete tables and graphs, answer questions, and submit their lab manual for grading.

Classwork/Homework:

Homework for each chapter covered includes the following exercises:
- reading guide (30 points)
- self quiz found at the end of each chapter in the textbook, also found on-line* (10 points)
- practice test found on-line* (10 points)

On-line exercises must be emailed to the teacher by the due date and the reading guide must be hand written and turned in during class. All homework assignments are worth 50 daily points (see above for individual points for each exercise).

Tests

Chapter tests will be a combination of objective and short answer essay questions and will be given weekly, on Fridays, whenever possible. All weekly tests are worth 20 test points. After grading, all test questions are discussed for additional reinforcement of concepts and unification with the four big ideas and enduring understandings as described in the course objectives.

Comprehensive Unit Exams

At the end of each unit, students take a comprehensive exam over materials covered since the start of the course. Each exam is formatted in a similar fashion to the actual *AP Biology* exam and is scored using the scoring formula and standards used on the *AP* exam. Each exam is worth 100 test points. One of the comprehensive unit exams is used as the first semester exam. After grading, all unit exam questions are reviewed, again for reinforcement of concepts and unification with the four big ideas and enduring understandings as described in the course objectives.

Final Practice Exam

Approximately one week prior to the scheduled date of the *AP Biology* exam, students come to school on a Saturday and take a practice exam. This exam is designed, timed and scored like an actual *AP Biology* exam. Students complete a topical analysis of their exam to get an idea of areas they need to review and focus on prior to the actual exam.

Student Evaluation

Homework assignments, lab reports, tests, and unit exams are used to evaluate student's learning.

Appendix A: Preparing Students for Success in AP Biology

In order to provide teachers with the information they need to incorporate the science practices and required course concepts into the AP Biology classroom, this section includes a description of **desired performance** (what students should know and be able to do) for high achievement in an introductory college-level biology course (which is comparable to an AP Biology course). This includes information on the following:

- How students should be able to appropriately demonstrate the concepts and skills.
- How students can develop the desired performance level, if they haven't already.

Big Idea 1: The process of evolution explains the diversity and unity of life.

Students need to understand the central position that evolution plays in the discipline of biology and the enduring understandings that support big idea 1. Differences in performance levels are distinguished by the student's ability to demonstrate his or her depth of understanding of concepts related to evolution. The student also must demonstrate his or her ability to apply different science practices in articulating understanding of these concepts.

What should students be able to do to demonstrate high achievement with the concepts and skills related to big idea 1?

Students should be able to do the following:

a) Apply mathematical methods to data from a real or simulated population and predict what will happen to the population in the future based on the Hardy-Weinberg equilibrium model (e.g., genetic drift, bottleneck, migration, chi-square statistical analysis) and justify the prediction.

b) Evaluate and connect evidence provided by data sets from many scientific disciplines (e.g., morphology, biochemistry, geology, biogeography, physics) and explain how the data support the modern concept of biological evolution.

c) Construct, refine, revise, and/or justify mathematical models, diagrams, or simulations that represent processes of biological evolution and use the representations to predict future trends of a population; representations include complex cladograms and phylogenetic trees based on morphological features, amino acid/genetic sequence data, and geological timelines.

d) Explain and justify conserved core processes and features that support common ancestry within and across domains of life.

e) Construct and/or use phylogenetic representations to pose or answer scientific questions about the relatedness of a group of organisms.

f) Explain how the different lines of data (morphological, biochemical, genetic) support the concept of a common ancestry within a phylogenetic domain and for all life.

g) Describe speciation in an isolated population and make a prediction about speciation based on changes in gene frequency, change in environment, natural selection, and/or genetic drift. Description may include comparison of environments of the original and isolated populations, speed of reproductive isolation, how new species arise, why Archaea and Bacteria challenge definition of species, and factors that change Hardy-Weinberg frequencies.

h) Evaluate data from a real or simulated population to explain how types of selection (e.g., bottleneck effect, hybrid sterility, reproductive isolating mechanisms) might affect the population in the future.

i) Evaluate and explain several examples of scientific evidence that support the claim that evolution is an ongoing process (e.g., antibiotic resistance, pesticide resistance, antiviral resistance).

j) Pose scientific questions about the origin of life on Earth and describe the scientific evidence that supports the proposed key events in the origin of life, including the abiotic synthesis of small organic molecules; assembly of monomers into complex polymers; formation of protobionts; and the origin of self-replicating, catalytic molecules.

k) Describe several models about the origins of life on Earth (e.g., Oparin-Haldane organic "soup" model, solid reactive surface model), explain reasons for revisions of hypotheses based on new scientific evidence from different disciplines (e.g., "RNA World," early atmosphere neither reducing nor oxidizing, origin of life in deep-sea vents, submerged volcanoes), and explain limitations of the various models, such as laboratory conditions simulating conditions on primitive Earth.

l) Evaluate data from a variety of sources (e.g., Internet, government, universities, public interest groups) with respect to objectivity and accuracy with response to questions about the origin of life on Earth.

How can students develop this level of performance if they haven't already?

Students can begin by doing the following:

a) Connecting evolutionary changes in a population over time to a change(s) in the environment by describing 2–3 examples (e.g., peppered moth, sickle cell anemia, DDT resistance in insects, introduction of nonnative species, introduction of predator, cataclysmic event).

b) Describing several sources of evidence from multiple scientific disciplines that support biological evolution (e.g., fossil records, morphological features, DNA and/or protein sequences, radioactive dating, distribution, or extant and extinct species).

c) Applying mathematical models (e.g., Hardy-Weinberg formula) to convert a data set from a table of numbers reflecting a change in the genetic makeup of a population over time and explaining the cause(s) and effect(s) of this change, such as natural selection, genetic drift, changes in population size, migration, mutations, and nonrandom mating.

d) Describing a limited set of given conserved features and core processes shared within and between domains of life (e.g., DNA as the genetic material, a shared genetic code, common metabolic pathways, number of limbs, etc.) as evidence of common ancestry.

e) Explaining how a phylogenetic representation reflects ancestral differences and similarities.

f) Describing how given data support the concept of a common ancestry within and between phylogenetic domains and for all life.

g) Analyzing data related to questions of speciation and extinction throughout Earth's history. Analysis may include (1) identifying patterns of speciation and/or extinction, (2) determining rates of speciation and/or extinction, and (3) connecting changes in gene frequency to speciation.

h) Justifying the selection of data that address questions related to reproductive isolation and speciation (e.g., pre- and post-zygotic and allopatric and sympatric isolation).

i) Describing a model that represents evolution within a population and providing evidence to support the description (e.g., evolution due to genetic variation, such as antibiotic resistance, structure, or process, such as the brain, immune system, or linkage of a given population to common ancestors, through genetic, physiological, and morphological data).

j) Evaluating scientific hypotheses about the origin of life on Earth (e.g., organic "soup" model, solid surface, pangenic) and predicting how a hypothesis would be revised in light of new evidence (e.g., "RNA World" hypothesis, new ideas about reducing atmosphere).

k) Evaluating scientific questions based on hypotheses about the origin of life on Earth, such as what constitutes a scientific hypothesis versus other hypotheses or beliefs.

Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce, and to maintain dynamic homeostasis. All organisms require free energy and matter to maintain order, grow, and reproduce. Different organisms employ various strategies to capture, use, and store free energy and exchange matter with the environment. Students need to understand the importance of matter exchange and free energy flow in maintaining life. Differences in achievement levels are distinguished by the student's depth of understanding of the interrelatedness of the processes, structure-function relationships, and the roles these processes play within biological systems. The student also must demonstrate his or her ability to apply different science practices in articulating understanding of these concepts.

What should students be able to do to demonstrate high achievement with the concepts and skills related to big idea 2?

Students should be able to do the following:

a) Calculate surface area-to-volume ratios for a variety of cell shapes (e.g., spherical, cuboidal, squamous, columnar) and predict, based on ratios, which cell(s) procures nutrients or eliminates wastes faster.

b) Justify the selection of data to explain how cells absorb or eliminate molecules that various organisms acquire as necessary building blocks or eliminate as wastes.

c) Create a visual representation (e.g., graph or diagram) to make predictions about the exchange of molecules between an organism and its environment, the use of these molecules (e.g., CHNOPS and incorporation into carbohydrates, proteins, lipids, nucleic acids, ATP for energy storage, enzymes, membrane structure, genetic information, etc.), and consequences to the organism if these molecules cannot be obtained.

d) Pose scientific questions about how surface area-to-volume ratios influence the movement of nutrients and wastes into and out of cells.

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e) Pose scientific questions about what mechanisms and structural features allow organisms to capture, store, and use free energy (e.g., autotrophs versus heterotrophs, photosynthesis, chemosynthesis, anaerobic versus aerobic respiration).

f) Create a visual representation to describe the structure of cell membranes and how membrane structure leads to the establishment of electrochemical gradients and the formation of ATP.

g) Describe the interdependency of photosynthesis and cellular respiration (e.g., that the products of photosynthesis are the reactants for cellular respiration and vice versa).

h) Use representations and models to pose scientific questions about the properties of cell membranes and selective permeability based on molecular structure.

i) Provided with electrochemical properties of several different molecules, make predictions about the permeability of the membrane to the molecule(s) and describe several methods of transport (e.g., diffusion, facilitated diffusion, osmosis, active transport, exocytosis, endocytosis) across the membrane.

j) Explain how several internal membrane-bound organelles and other structural features (e.g., ER, ribosomes) work together to provide a specific function for the cell (e.g., synthesis of protein for export) and contribute to efficiency (e.g., increasing surface area for reactions, localization of processes).

k) Evaluate data that describe the effect(s) of changes in concentrations of key molecules on negative or positive regulatory systems (e.g., operons in gene regulation, temperature regulation in animals, plant responses to water limitations, oxytocin levels in childbirth).

l) Provided with a visual representation with multiple components, explain with justification or make predictions of how alterations of the components in a negative or positive regulatory system can result in deleterious consequences to the organism (e.g., change in blood glucose levels, decreased ADH level and diabetes insipidus, Graves' disease and hyperthyroidism).

m) Justify the selection of the kind of data needed to pose scientific questions about the regulatory mechanism(s) that organisms use to respond to changes in their external environments (e.g., photoperiodism and phototropism in plants, hibernation in animals, circadian rhythms, shivering and sweating in humans).

n) Analyze data to identify possible patterns and relationships between a biotic or abiotic factor and a biological system, identify and explain any anomalies in the pattern or relationship, and predict consequences of a change in a biotic or abiotic factor(s) to the system.

o) Connect differences in the environment with the evolution of homeostatic mechanisms and describe how these mechanisms reflect both common ancestry and divergence due to adaptations.

p) Create representations and models to describe essential aspects of nonspecific and specific immune response systems in plants, invertebrates, and vertebrates (e.g., chemical responses in plants, cell-mediated and humoral responses in mammals).

q) Connect concepts in and across domains to describe how timing and coordination of specific events are necessary for normal development in an organism, describe how these events are regulated by multiple mechanisms (e.g., homeotic genes, environmental factors, embryonic induction, role of microRNAs), and predict consequences in alterations in mechanisms necessary for normal development (e.g., genetic mutation, mutations of transcription factors).

r) Justify claims with evidence to show that timing and coordination of several events are necessary for normal development in an organism, and that these events are regulated by multiple mechanisms (e.g., homeotic genes in developmental patterns and sequences, embryonic induction in timing of developmental events).

s) Analyze data to support the claim that responses to information and communication of information can affect natural selection (e.g., changes in light source and phototropism, seasonal behavior in animals and reproduction, visual and auditory signals and species recognition, mutualistic relationships).

How can students develop this level of performance if they haven't already?

Students can begin by doing the following:

a) Calculating simple surface area-to-volume ratios for cubic and round cells and explaining how this impacts procurement of nutrients and elimination of wastes.

b) Identifying several (more than 4) chemical elements and molecules that function as key building blocks (e.g., C, N, H_2O, sugars, lipids, proteins) or are eliminated as wastes.

c) Predicting 1–2 consequences to organisms, populations, and ecosystems if sufficient free energy is not available (e.g., death, changes in population size, changes to number and size of trophic levels in ecosystems).

d) Describing 2–3 different strategies that organisms employ to obtain free energy for cell processes (e.g., different metabolic rates, physiological changes, variations in reproductive and offspring-rearing strategies).

e) Refining or revising a visual representation to more accurately depict the light-dependent and light-independent (i.e., Calvin cycle) reactions of photosynthesis and the dependency of the processes in the capture and storage of free energy.

f) Provided with a visual representation of the fluid mosaic model of the cell membrane, identifying the molecular components and describing how each component is directly related to the selective permeability of that membrane (e.g., transport proteins, lipid bilayer).

g) Explaining how the phospholipid bilayer of the cell membrane is a barrier to the diffusion of polar molecules across it.

h) Using representations and models to describe how eukaryotic cells use internal membranes that partition the cell into several specialized regions (e.g., mitochondria, Golgi, ER), and how cell structure of eukaryotes differs from cell structure of prokaryotes.

i) Provided with an example of a simple positive feedback loop, making predictions about how the mechanism amplifies activities and processes in organisms based on scientific models (e.g., lactation in mammals, progression of labor in childbirth, ripening of fruit, blood clotting).

j) Describing an example of a simple negative regulatory system and how an organism uses the mechanism to respond to an environmental change (e.g., temperature regulation in animals, plant responses to water limitation, blood glucose level).

k) Connecting the use of negative feedback and maintaining the internal environment in response to changing external conditions and consequences if dynamic homeostasis is not maintained.

l) Justifying, based on scientific evidence, the statement that homeostatic mechanisms reflect continuity due to common ancestry and/or divergence due to adaptation in different environments (e.g., mechanisms for obtaining nutrients and eliminating wastes) in several different phyla or species, using appropriate examples.

m) Refining representations and models to describe an example of a nonspecific immune defense system in plants and animals (e.g., chemical responses, cellular responses).

n) Using a visual representation (e.g., graph or diagram) to make predictions about the sequence of steps in the development of an organism.

o) Designing a plan for collecting data to support the claim that the timing and coordination of physiological events in an organism of choice involve regulation (e.g., phototropism in plants, circadian rhythms, jet lag in humans).

p) Describing 2–3 examples of how a cooperative behavior benefits both the individual and the population (e.g., mutualistic relationships, niche partitioning) that involves timing and coordination of activities/events.

Big Idea 3: Living systems store, retrieve, transmit, and respond to information essential to life processes. Genetic information provides for continuity of life, and this information is passed from parent to offspring. Random changes in information allow for evolution, with natural selection acting upon the products of genetic information, i.e. phenotypes. Understanding how cells code, decode, and regulate expression of genetic information is essential to knowing how biological systems from cells to communities of organisms operate, communicate, respond to the environment, and evolve. Differences in achievement levels are distinguished by the student's depth of understanding of these concepts and processes. The student also must demonstrate his or her ability to apply different science practices in articulating understanding of these concepts.

What should students be able to do to demonstrate high achievement with the concepts and skills related to big idea 3?

Students should be able to do the following:

a) Predict which features of DNA and RNA were necessary to allow the identification of DNA as the genetic material and justify how these features enable information to be replicated, stored, and expressed.

b) Using at least two commonly used technologies, describe how humans manipulate heritable information and possible consequences.

c) Justify the effects of a change in the cell cycle mitosis and/or meiosis will have on chromosome structure, gamete viability, genetic diversity, and evolution.

d) Predict possible effects that alterations in the normal process of meiosis will have on the phenotypes of offspring compared to the normal situation and connect the outcomes to issues surrounding human genetic diseases.

e) Apply mathematical routines to determine Mendelian patterns of inheritance provided by data sets, and, using appropriate examples, explain at the chromosome, cellular, and offspring (organism) levels why certain traits do or do not follow Mendel's model of inheritance.

f) Justify how various modes of gene regulation (positive and negative) can explain the differences seen at the cellular, organismal, and population level. Predict how changes in regulation will affect cellular functions.

g) Using appropriate examples, predict how changes in signal transduction pathways will affect specific cellular processes and responses for both bacteria and eukaryotes.

h) Predict how various types of change in a DNA sequence can alter a phenotype, and describe several using real-world examples.

i) Justify how various molecular, cellular, and organismal processes in bacteria and eukaryotes increase genetic variation in a population and allow for natural selection.

j) Using specific examples, justify how the life cycles of DNA and RNA viruses can contribute to rapid evolution of both the virus and the host.

k) Justify how the mechanics of cell-to-cell communication support common lines of evolutionary descent. Pose scientific questions that test the justification rationale.

l) Using appropriate examples from plants, animals, and bacteria, justify how the features of cell-to-cell contact and the use of chemical signals allow communication over short and long distances.

m) Construct a model that illustrates how chemical signals can alter cellular responses. Predict the effects of changes in the signal pathway on cellular responses using appropriate examples.

n) Justify how changes in internal or external clues affect the behavior of individuals and their interactions within a population and between related individuals.

o) Describe how the animal nervous system's biochemical, physiological, and structural components work together to respond to internal and/or external stimuli. Describe how changes within nerve cells and the nervous system produce responses to the stimuli.

How can students develop this level of performance if they haven't already?

Students can begin by doing the following:

a) Explaining how the structural features of DNA and RNA allow heritable information to be replicated, stored, expressed, and transmitted to future generations.

b) Explaining how the steps in the cell cycle allow transmission of heritable information between generations and contribute to genetic diversity.

c) Identifying mathematical evidence that supports the roles of chromosomes and fertilization in the passage of traits from parent to offspring.

d) Justifying whether a given data set supports Mendelian inheritance.

e) Using appropriate examples, explaining how gene regulation allows for cell specialization and efficient cell function.

f) Using an appropriate example, describing a signal transduction pathway mechanism that affects protein expression.

g) Describing the basic processes by which a change in a DNA sequence results in a change in a peptide sequence.

h) Describing two processes that increase genetic variation and explaining how genetic variation allows for natural selection within a population.

i) Describing several mechanisms that result in increased genetic variation and rapid evolution of viruses.

j) Proposing scientific questions that address if there are shared mechanisms for cell-to-cell communication across evolutionary lines.

k) Describing how both plants and animals use cell-to-cell communication for cellular processes using an appropriate example from each.

l) Explaining key features of models that illustrate how changes in a signal pathway can alter cellular responses.

m) Describing how behavior is modified in response to external and internal cues for both animals and plants using appropriate examples from each.

n) Describing how the nervous system detects external and internal stimuli and transmits signals along and between nerve cells.

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Big Idea 4: Biological systems interact, and these systems and their interactions possess complex properties. All biological systems are composed of parts that interact with one another and the environment, and these interactions result in characteristics not found in the individual parts alone. Interactions, including competition and cooperation, play important roles in the activities of biological systems. From the molecular level to the ecosystem level, biological systems exhibit properties of biocomplexity and diversity; these properties provide robustness that enables greater resiliency and flexibility to tolerate and respond to changes in the environment. Understanding biotic and abiotic interactions, including competition, and cooperation within and between biological components and systems, is necessary to comprehend the beauty and complexity of biology. Differences in achievement levels are distinguished by a student's depth of understanding of these interactions and their effects on individual organisms, populations, and ecosystems. The student also must demonstrate his or her ability to apply different science practices in articulating understanding of these concepts.

What should students be able to do to demonstrate high achievement with the concepts and skills related to big idea 4?

Students should be able to do the following:

a) Justify how structure imparts function for key biological molecules (DNA, RNA, lipids, carbohydrates, proteins, ATP) and cell organelles (nucleus, Golgi, ER, mitochondria, plasma membrane chloroplasts, vacuoles) and describe how they interact in key biological processes.

b) Predict how changes in internal and environmental stimuli will affect gene expression and the development of specialized cells, tissues, and organs based on a given developmental model or representation.

c) Pose scientific questions that address how interactions between constituent parts of a biological system (cells, tissue, organs) provide essential biological activities.

d) Pose scientific questions and apply mathematical routines to analyze interactions among community components.

e) Predict the effect of a change in one of the components on the interactions within the community and matter and energy flow.

f) Analyze data showing how changes in enzyme structure, substrate concentration, and environmental conditions (pH, temperature, salinity, etc.) affect enzymatic activity. Predict the effects when one of the parameters is further changed.

g) Use representations and models to describe and analyze how cooperative interactions at the cellular, organismal, or system level increase efficiency and fitness of the organism.

h) Analyze data to develop and refine qualitative and quantitative models for species and population, abundance, densities, distribution, and interactions and predict the effect(s) of human activity on the biological system.

i) Using appropriate examples, justify why molecular variation in genes, basic cellular building blocks, and macromolecules provides a wider range of metabolic and cellular functions and explain how these variations affect fitness and evolution.

j) Use evidence to justify the claim that phenotype is a product of both genetics and environment, explain the mechanism(s) that operates to affect the change, and predict how a change in environment can alter a phenotype.

k) Analyze evidence to develop models and predictions as to the effect that changes in the level of variation within populations and species diversity will have on fitness and system stability.

How can students develop this level of performance if they haven't already?

Students can begin by doing the following:

a) Describing the basic structure and functions of key biological polymers (DNA, RNA, lipids, carbohydrates, proteins) and cell organelles (nucleus, Golgi, ER, mitochondria, chloroplast, vacuoles, plasma membrane).

b) Describing in general terms how cells specialize and become tissue and organs.

c) Explaining how interactions between constituent parts of a biological system (cells, tissues, organs) provide essential biological activities.

d) Refining models showing organism interaction and matter and energy flow in a biological system and predicting the effects of a change in one of the components.

e) Analyzing data showing how changes in structure and concentrations affect enzymatic activity

g) Identifying patterns that show cooperative interactions at the cellular, organismal, or system level that increase efficiency and fitness of the organism.

Dear Student and Parent,

I am looking forward to having you in my Advanced Placement Biology class during the 2017/2018 school year. In order to work together toward your success, I want to make you aware of the degree of dedication and commitment this course requires.

The student that is most successful in AP Biology is the student who is self-motivated and is willing to teach them self through reading the textbook and outside references. Due to the volume of material, we cannot cover all the information together in class. Our time together needs to focus on labs and discussion of the more difficult concepts. If students are not keeping up by teaching themselves the basics, they certainly will not benefit from the instruction they receive in class. Good attendance is also critical. Students that are frequently absent or who repeatedly miss class for activities or sports will fall behind quickly. Please note that I am available for extra help outside of class. Students are encouraged to come in for extra help at the first sign of a struggle, as the curriculum is extremely integrated and unified.

The AP exam has a set date by the College Board, which cannot be changed. I plan our course schedule to ensure that students will finish the curriculum and be prepared to take the exam by the scheduled exam date. Please understand that I cannot change our course schedule because some students are falling behind. It is the student's responsibility to keep up with the schedule. Again, extra help is available, if necessary, to keep up.

All AP Biology students are committed to take a practice exam on a Saturday approximately one week before the scheduled College Board exam. Since the 2018 AP Biology exam is scheduled for Monday, May 14, 2018, the practice exam will be given on Saturday, May 5, 2018. This advanced notice should avoid any scheduling conflicts with personal matters. Please note that the 2018 Junior-Senior Formal is also tentatively scheduled for the same date, however, the practice exam will be over by noon so students should have plenty of time to get ready for this special event.

Parents, please be aware that students frequently complain about the amount of work and the pace we need to maintain. In all fairness, please also be aware, that I must teach the class at a college level because that is what the course is all about. Remember, students that successfully pass the AP Biology exam may receive, from many colleges and universities, credit for two semesters of introductory biology with lab. Students taking the exam will also receive an honor's point added to their grade point average.

Students and Parents, please have an in depth discussion about the commitment involved in this course so that we can all have a successful year. I am praying that you have a successful year and that you will never ceased to be amazed at God's incredible design as you learn more and more about the intricate details of life.

Sincerely,

Mrs. Cherri Carruthers

I have read and understand the above letter:

______________________________	______________________________	______________
Student's signature	Parent's signature	date

AP BIOLOGY

Summer Reading and Assignments

Welcome to the world of AP Biology. In preparation for AP Biology next school year, you will need to **<u>COMPLETE</u>** some work independently over the summer. When you return to school in August, we will spend a day, two at the most, discussing this information. You should find that much of the information is review from Chemistry.

THE TEXBOOK NEEDED TO COMPLETE THIS ASSIGNMENT MUST BE PICKED UP FROM MRS. CARRUTHERS (107-02) BEFORE LEAVING SCHOOL FOR THE SUMMER!!!

Chapters to be covered independently during the summer include:
Chapter 1 – Exploring Life
Chapter 2 – The Chemical Context of Life
Chapter 3 – Water and the Fitness of the Environment
Chapter 4 – Carbon and the Molecular Diversity of Life

Online, beginning on p.20, you will find the following supplements for each assigned chapter in your textbook:

- an outline of notes
- a power point presentation
- the reading guide you need to print and complete
- the test you need to print and complete

<u>MANDATORY</u> assignment for each chapter includes the following:
- read each chapter in the textbook: Campbell's <u>Biology, AP Edition, 9th edition</u>
- print and complete the reading guide provided online for each chapter
- print and complete the test provided online for each chapter (these tests are **<u>NOT</u>** open-book tests and should be completed within a 50-minute time period - be sure to write the SHORT ANSWERS in complete sentences if applicable)

EACH TEST WILL COUNT AS A TEST GRADE AND EACH READING GUIDE WILL COUNT AS A DAILY GRADE TOWARD YOUR FIRST QUARTER GRADE.

To help foster a deeper level of learning and to help develop advanced inquiry and reasoning skills, such as designing a plan for collecting data, analyzing data, applying mathematical routines, and connecting concepts in and across domains, read the following:
- Goals of the Laboratory Investigations – p.513
- Appendix B: Constructing Line Graphs – p.532
Print and complete the online assignment associated with Appendix B: Constructing Line Graphs located on p.527

All work and tests are due the first day of school. There will be **<u>NO EXCUSE</u>** for incomplete work**!!!!!!!**
If you do not have the work completed by the first day of class, you will be withdrawn from the course.

If you have any questions regarding this assignment or if you have any questions regarding the content that this assignment covers, contact me by email at <u>C.Carruthers@tka.net</u>. I will get back to you as soon as possible.

Chapter 1

Introduction: Themes in the Study of Life

Lecture Outline

Overview: Inquiring About Life

- Organisms are adapted to the environments they live in.
- These adaptations are the result of **evolution**, the fundamental organizing principle of biology and the core theme of this book.
- Posing questions about the living world and seeking science-based answers are the central activities of **biology**, the scientific study of life.
- Biologists ask a wide variety of ambitious questions.
    - They may ask how a single cell becomes a tree or a dog, how the human mind works, or how the living things in a forest interact.
- Biologists can help answer questions that affect our lives in practical ways.
- What is life?
    - The phenomenon of life defies a simple, one-sentence definition.
    - We recognize life by what living things do.

Concept 1.1 The themes of this book make connections across different areas of biology.

- Eight unifying themes will help you organize and make sense of biological information.

Theme 1: New properties emerge at each level in the biological hierarchy.

- Each level of biological organization has emergent properties.
- Biological organization is based on a hierarchy of structural levels, each building on the levels below.
    - At the lowest level are atoms that are ordered into complex biological molecules.
    - Biological molecules are organized into structures called organelles, the components of cells.
    - Cells are the fundamental unit of structure and function of living things.
- Some organisms consist of a single cell; others are multicellular aggregates of specialized cells.
- Whether multicellular or unicellular, all organisms must accomplish the same functions: uptake and processing of nutrients, excretion of wastes, response to environmental stimuli, and reproduction.
- Multicellular organisms exhibit three major structural levels above the cell: Similar cells are grouped into tissues, several tissues coordinate to form organs, and several organs form an organ system.
- For example, to coordinate locomotory movements, sensory information travels from sense organs to the brain, where nervous tissues composed of billions of interconnected neurons—supported by connective tissue—coordinate signals that travel via other neurons to the individual muscle cells.

- Organisms make up populations, localized groups of organisms belonging to the same species.
  - Populations of several species in the same area combine to form a biological community.
  - Populations interact with their physical environment to form an ecosystem.
  - The biosphere consists of all the environments on Earth that are inhabited by life.
- As we move from the molecular level to the biosphere, novel emergent properties arise at each level, properties that are not present at the preceding level.
  - **Emergent properties** are created by new arrangements and interactions of parts as complexity increases.
  - For example, photosynthesis can take place only when molecules are arranged in a specific way in an intact chloroplast.
  - If a serious head injury disrupts the intricate architecture of a human brain, the mind may cease to function properly even though all of the brain tissues are still present.
  - The cycling of chemical elements at the ecosystem level depends on a network of diverse organisms interacting with each other and with the soil, water, and air.
- Emergent properties are not unique to life: a set of bicycle parts won't take you anywhere, but if they are arranged in a certain way, you can pedal to your chosen destination on a working bicycle.
  - Compared to such nonliving examples, however, the unrivaled complexity of biological systems makes the emergent properties of life especially challenging to study.

Reductionism is a powerful strategy in biology.

- Reductionism is the approach of reducing complex systems to simpler components that are more manageable to study.
  - Biologists must balance the reductionist strategy with the larger-scale, holistic objective of understanding the emergent properties of life—how all the parts of biological systems are functionally integrated.
- Biologists are beginning to complement reductionism with new strategies for studying whole systems.
  - The ultimate goal of **systems biology** is to model the dynamic behavior of whole biological systems based on a study of the interactions among the system's parts.
  - Successful models allow biologists to predict how a change in one or more variables will affect other components as well as the whole system.
- The systems approach enables scientists to pose new kinds of questions.
  - How might a drug that lowers blood pressure affect the functions of organs throughout the human body?
  - How might increasing a crop's water supply affect processes in the plants, such as the storage of molecules essential for human nutrition?
  - How might a gradual increase in atmospheric carbon dioxide alter ecosystems and the entire biosphere?
- The ultimate aim of systems biology is to answer large-scale questions like the last one.
- Scientists investigating ecosystems pioneered the systems approach in the 1960s with elaborate models diagramming the interactions of species and nonliving components in ecosystems such as salt marshes.
- Systems biology is now becoming increasingly important in cellular and molecular biology.

Theme 2: Organisms interact with other organisms and the physical environment.

- Each organism interacts with its environment, which includes both other organisms and physical factors.
- Both organism and environment are affected by the interactions between them.
  - A plant takes up water and minerals from the soil through its roots, and its roots help form soil by breaking up rocks.
  - On a global scale, plants and other photosynthetic organisms have generated all the oxygen in the air.
- A tree also interacts with other organisms, such as soil microorganisms associated with its roots, insects that live in the tree, and animals that eat its leaves and fruit.
- Interactions between organisms ultimately result in the cycling of nutrients in ecosystems.
  - The minerals acquired by a tree are eventually returned to the soil by organisms that decompose leaf litter, dead roots, and other organic debris.
  - The minerals are then available to be taken up by plants again.
- Humans also interact with our environment, sometimes with drastic consequences.
  - Since the Industrial Revolution in the 1800s, the burning of fossil fuels (coal, oil, and gas) has been increasing at an ever-accelerating pace.
  - This releases gaseous compounds into the atmosphere, including huge amounts of carbon dioxide (CO_2).
- About half the human-generated CO_2 stays in the atmosphere, absorbing heat from the sun and acting like a reflective blanket over the planet that prevents heat from radiating into outer space.
  - Scientists estimate the average temperature of the planet has risen 1°C since 1900 due to this “greenhouse effect,” and they project a possible additional 5°C to 10°C increase in parts of the Arctic over the course of the 21st century.
- This global warming, a major aspect of **global climate change**, has already had dire effects on life forms and their habitats all over planet Earth.
  - Polar bears have lost much of the ice platform from which they hunt, some small rodents and plant species have shifted their ranges to higher altitudes, bird populations have altered their migration schedules, and in several ecosystems, predator populations have declined as their prey has disappeared.
- Only time will reveal the consequences of these and other changes. Scientists predict that even if we stopped burning fossil fuels today, it would take several centuries to return to pre-industrial CO_2 levels.
- We must learn all we can about the effects of global climate change on the Earth and its populations.

Theme 3: Life requires energy transfer and transformation.

- The input of energy from the sun makes life possible: a fundamental characteristic of living organisms is their use of energy to carry out life’s activities.
- Living organisms often transform one form of energy to another.
  - Chlorophyll molecules within the tree’s leaves harness the energy of sunlight and use it to drive photosynthesis, converting water and carbon dioxide to sugar and oxygen.
  - The chemical energy in sugar is then passed along by plants and other photosynthetic organisms (producers) to consumers.
  - Consumers are organisms, such as animals, that feed on producers and other consumers.
- An animal’s muscle cells use sugar as fuel to power movements, converting chemical energy to kinetic energy, the energy of motion.

- The cells in a leaf use sugar to drive the process of cell division during leaf growth, transforming stored chemical energy into cellular work.

- In every energy transformation, some energy is converted to thermal energy, which dissipates to the surroundings as heat.
- While chemical nutrients recycle within an ecosystem, energy flows through an ecosystem, usually entering as light and exiting as heat.

Theme 4: Structure and function are correlated at all levels of biological organization.

- Form fits function; how a device works is correlated with its structure.
  - Applied to biology, this theme is a guide to the anatomy of life at all its structural levels.
  - For example, the thin, flat shape of a leaf maximizes the amount of sunlight that can be captured by its chloroplasts.

Theme 5: Cells are an organism's basic units of structure and function.

- The cell is the lowest level of structure that can perform all the activities of life.
- The activities of organisms are all based on cell activities.
- Understanding how cells work is a major research focus of modern biology.
- All cells share certain characteristics.
  - Every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings.
  - Every cell uses DNA as its genetic information.
- There are two basic types of cells: prokaryotic cells and eukaryotic cells.
  - The cells of the two groups of microorganisms called bacteria and archaea are prokaryotic.
  - All other forms of life have more complex eukaryotic cells.
- A **eukaryotic cell** is subdivided by internal membranes into various membrane-enclosed organelles.
  - In most eukaryotic cells, the largest organelle is the nucleus, which contains the cell's DNA as chromosomes.
  - The other organelles are located in the cytoplasm, the entire region between the nucleus and the outer membrane of the cell.
- **Prokaryotic cells** are much simpler and smaller than eukaryotic cells.
  - In a prokaryotic cell, DNA is not separated from the cytoplasm in a nucleus.
  - There are no membrane-enclosed organelles in the cytoplasm.
- Whether an organism has prokaryotic or eukaryotic cells, its properties depend on the structure and function of its cells.

Theme 6: The continuity of life is based on heritable information in the form of DNA.

- The division of cells to form new cells is the foundation for all reproduction and for the growth and repair of multicellular organisms.
- Inside the dividing cells is deoxyribonucleic acid, or **DNA**, the heritable material that directs the cell's activities.
- DNA is the substance of **genes**, the units of inheritance that transmit information from parents to offspring.
- DNA in human cells is organized into chromosomes.

- Each chromosome has one very long DNA molecule, with hundreds or thousands of genes arranged along its length.
- The genes encode the information necessary to build other molecules in the cell, including the proteins that are responsible for carrying out most of the work of a cell.

- The DNA of chromosomes replicates as a cell prepares to divide.
  - Each of the two cellular offspring inherits a complete set of genes with information identical to that of the parent cell.
- Each of us began life as a single cell stocked with DNA inherited from our parents.
  - Replication of that DNA with each round of cell division transmitted copies of those genes to our trillions of cells.
- In each cell, the genes along the length of DNA molecules encode the information for building the cell's other molecules.
  - DNA is a central database that directs the development and maintenance of the entire organism.
- Each DNA molecule is made up of two long chains, called strands, arranged in a double helix.
  - Each chain is made up of four kinds of nucleotides called A, G, C, and T.
- We can think of nucleotides as a four-letter alphabet of inheritance.
  - Specific sequential arrangements of these four nucleotide letters encode the precise information in genes, which are typically hundreds or thousands of nucleotides long.
- DNA provides the blueprints for making proteins, and proteins serve as the tools that actually build and maintain the cell and carry out its activities.
  - For instance, the information carried in a bacterial gene may specify a certain protein in a bacterial cell membrane, while the information in a human gene may denote a protein hormone that stimulates growth.
  - Other human proteins include proteins in a muscle cell that drive contraction and the defensive proteins called antibodies.
  - Enzymes, which catalyze (speed up) specific chemical reactions, are mostly proteins and are crucial to all cells.
- DNA controls protein production indirectly, using a related kind of molecule called RNA as an intermediary.
  - The sequence of nucleotides along a gene is transcribed into RNA, which is then translated into a specific protein with a unique shape and function.
  - This entire process, by which the information in a gene is converted into a cellular product, is called **gene expression**.
- In translating genes to proteins, all forms of life employ essentially the same genetic code.
  - A particular sequence of nucleotides says the same thing to one organism as it says to another.
- Recently, scientists have discovered whole new classes of RNA that are not translated into protein.
  - Some RNA molecules regulate the functioning of protein-coding genes.

The library of genetic instructions that an organism inherits is called its genome.

- The chromosomes of each human cell contain about 3 billion nucleotides, including genes coding for about 75,000 kinds of proteins, each with a specific function.
- The entire sequence of nucleotides in the human genome is now known.
  - Scientists have also learned the genome sequences of many other organisms, including bacteria, archaea, fungi, plants, and animals.

- The sequencing of the human genome was a major scientific and technological achievement.
  - The challenge now is to learn how the activities of the proteins encoded by DNA are coordinated in cells and organisms.
- Systems biology is now becoming increasingly important in cellular and molecular biology, driven in part by the deluge of data from the sequencing of genomes and the growing catalog of known protein functions.
- Rather than investigating a single gene at a time, researchers have shifted to studying whole sets of genes of a species as well as comparing genomes between species—an approach called **genomics**.
- Three key research developments have led to the increased importance of systems biology:
  1. **High-throughput technology.** Systems biology depends on methods that can analyze biological materials very quickly and produce enormous amounts of data. An example is the automatic DNA-sequencing machines used by the Human Genome Project.
  2. **Bioinformatics.** The huge databases from high-throughput methods require the use of computational tools to store, organize, and analyze the huge volume of data.
  3. **Interdisciplinary research teams.** Systems biology teams may include engineers, medical scientists, physicists, chemists, mathematicians, and computer scientists as well as biologists.

Theme 7: Feedback mechanisms regulate biological systems.

- Chemical processes within cells are accelerated, or catalyzed, by specialized protein molecules called enzymes.
- Each type of enzyme catalyzes a specific chemical reaction.
  - In many cases, reactions are linked into chemical pathways, with each step having its own enzyme.
- How does a cell coordinate its various chemical pathways?
  - Many biological processes are self-regulating: The output or product of a process regulates that same process.
- In **negative feedback**, the accumulation of an end product of a process slows down that process.
  - For example, the cell's breakdown of sugar generates chemical energy in the form of a substance called ATP.
  - When a cell makes more ATP than it can use, the excess ATP "feeds back" and inhibits an enzyme near the beginning of the pathway
- Though less common, some biological processes are regulated by **positive feedback**, in which an end product *speeds up* its own production.
  - The clotting of blood in response to injury is an example.
  - When a blood vessel is damaged, structures in the blood called platelets begin to aggregate at the site.
  - Positive feedback occurs as chemicals released by the platelets attract *more* platelets.
  - The platelet pileup then initiates a complex process that seals the wound with a clot.
- Feedback is common to life at all levels, from the molecular level to the biosphere.
- Regulation via feedback is an example of the integration that makes living systems much more than the sum of their parts.

Theme 8: Evolution is the overarching theme of biology.

- Life has been evolving on Earth for billions of years, resulting in a vast diversity of past and present organisms.

- At the same time, living things share certain features.
- The scientific explanation for this unity and diversity—and for the suitability of organisms for their environments—is evolution: the idea that the organisms living on Earth today are the modified descendants of common ancestors.
  - In other words, scientists can explain traits shared by two organisms with the idea that they have descended from a common ancestor, and scientists can account for differences with the idea that heritable changes have occurred along the way.

Concept 1.2 The Core Theme: Evolution accounts for the unity and diversity of life.

- Evolutionary biologist Theodosius Dobzhansky said, "Nothing in biology makes sense except in the light of evolution."

Living things show both diversity and unity.

- Life is enormously diverse.
  - Biologists have identified and named about 1.8 million species.
  - These species include 100,000 fungi, 290,000 plants, 52,000 vertebrates, and 1,000,000 insects, as well as myriad single-celled organisms.
- Thousands of newly identified species are added each year.
  - Estimates of the total species count range from 10 million to over 100 million.
- In the face of this complexity, humans are inclined to categorize diverse items into a smaller number of groups.
  - Taxonomy is the branch of biology that names and classifies species into a hierarchical order.
- Historically, scientists have classified the diversity of life forms into kingdoms and finer groupings.
- New research methods, including comparisons of DNA among organisms, have led to an ongoing reevaluation of the number and boundaries of living kingdoms.
  - Various classification schemes have proposed anywhere from six kingdoms to dozens of kingdoms.
- This debate has brought about the recognition that there are three even higher levels of classification: the domains Bacteria, Archaea, and Eukarya.
- The first two domains, **domain Bacteria** and **domain Archaea**, consist of prokaryotes.
  - Most prokaryotes are single-celled and microscopic.
- All the eukaryotes are now grouped in **domain Eukarya**.
- Domain Eukarya includes the three kingdoms of multicellular eukaryotes, Plantae, Fungi, and Animalia, distinguished partly by their modes of nutrition.
  - Most plants produce their own sugars and other food molecules by photosynthesis.
  - Most fungi absorb dissolved nutrients from their surroundings. Many fungi decompose dead organisms and organic wastes (such as leaf litter and animal feces) and absorb nutrients from these sources.
  - Animals obtain food by ingesting other organisms.
- Neither animals, plants, nor fungi are as numerous or diverse as the single-celled eukaryotes we call protists.

- Once placed in a single kingdom, biologists now realize that protists do not form a single natural group of species.
- Some protist groups are more closely related to multicellular eukaryotes such as animals and fungi than they are to each other.
- The recent taxonomic trend has been to split the protists into several groups.

- Underlying the diversity of life is a striking unity, especially at the molecular and cellular levels of organization.
  - The universal genetic language of DNA unites prokaryotes and eukaryotes.
  - Among the eukaryotes, unity is evident in many details of cell structure.
- How do scientists account for life's dual nature of unity and diversity?
  - The process of evolution explains both the similarities and differences among living things.
- The history of life is the saga of a changing Earth, billions of years old, inhabited by an evolving cast of living forms.
- Charles Robert Darwin brought evolution into focus in 1859 when he presented two main points in one of the most important and influential books ever written, *On the Origin of Species by Means of Natural Selection.*
- Darwin's first point was that contemporary species arose from a succession of ancestors through "descent with modification."
  - This phrase captured the duality of life's unity and diversity: unity in the kinship among species that descended from common ancestors and diversity in the modifications that evolved as species branched from their common ancestors.
- Darwin's second point was a proposed mechanism for descent with modification: natural selection.
- Darwin started with three observations from nature.
  - Individuals in a population of any species vary in many heritable traits.
  - A population can potentially produce far more offspring than the environment can support; therefore, competition is inevitable.
  - Species generally are suited to, or adapted to, their environments.
- Darwin made inferences from these observations to arrive at his theory of evolution.
  - Individuals with inherited traits that are best suited to the local environment will produce more healthy, fertile offspring than less well-suited individuals.
  - Over many generations, heritable traits that enhance survival and reproductive success will tend to increase in frequency among a population's individuals.
  - Evolution occurs as the unequal reproductive success of individuals ultimately leads to adaptation to their environment, as long as the environment remains unchanged.
- Darwin called this mechanism of evolutionary adaptation **natural selection** because the natural environment "selects" for the propagation of certain traits among naturally occurring variant traits in the population.
- The unity of mammalian limb anatomy reflects inheritance of that structure from a common ancestor—the "prototype" mammal from which all other mammals descended.
  - The diversity of mammalian forelimbs results from modification by natural selection operating over millions of generations in different environmental contexts.
  - Fossils and other evidence corroborate anatomical unity in supporting this view of mammalian descent from a common ancestor.

- Natural selection, by its cumulative effects over vast spans of time, can produce new species from ancestral species.
    - For example, a population fragmented into several isolated populations in different environments may gradually diversify into many species as each population adapts over many generations to different environmental problems.
- Fourteen species of finches found on the Galápagos Islands diversified after an ancestral finch species reached the archipelago from the West Indies.
    - Each species adapted to exploit different food sources on different islands.
- Researchers use anatomical and geographic data and more recently DNA sequence comparisons to sort out the relationships among the finch species.
    - Biologists' diagrams of evolutionary relationships generally take a treelike form.
- Just as individuals have a family tree, each species is one twig of a branching tree of life.
    - Similar species like the Galápagos finches share a relatively recent common ancestor.
    - Finches share a more distant ancestor with all other birds.
    - The common ancestor of all vertebrates is even more ancient.
- If life is traced back far enough, all living things have a common ancestor.
    - All of life is connected through its long evolutionary history.

Concept 1.3 In studying nature, scientists make observations and then form and test hypotheses.

- The word *science* is derived from a Latin verb meaning "to know."
- **Science** is a way of knowing—an approach to understanding the natural world.
- At the heart of science is **inquiry**, asking questions about nature and focusing on specific questions that can be answered.
- As scientists, biologists attempt to understand how natural phenomena work using a process of inquiry that includes making observations, forming logical hypotheses, and testing them.
    - The process is necessarily repetitive: in testing a hypothesis, more observations are made that may force outright rejection of the hypothesis or revision and further testing.
    - This process allows biologists to get closer to their best estimation of the laws governing nature.

Scientists plan careful observations.

- Biologists describe natural structures and processes as accurately as possible through careful observation and analysis of data.
    - The observations are often valuable in their own right.
    - For example, a series of detailed observations have built our understanding of cell structure, and are currently expanding our databases of genomes of diverse species.
- Recorded observations are called **data**, items of information on which scientific inquiry is based.
- *Data* can be qualitative or quantitative.
    - *Qualitative data* may be in the form of recorded descriptions.
    - For example, Jane Goodall has spent decades recording qualitative data in the form of her observations of chimpanzee behavior during field research in Tanzania.
    - Jane Goodal has also collected volumes of *quantitative data,* which are generally recorded as measurements.

Observations can lead to important conclusions based on inductive reasoning.

- Through **induction**, scientists derive generalizations based on a large number of specific observations.
- Observations and inductive reasoning stimulate scientists to seek natural causes and explanations for those observations.
- In science, inquiry usually involves proposing and testing of hypotheses.
  - In science, a **hypothesis** is a tentative answer to a well-framed question.
  - It is usually a rational accounting for a set of observations, based on the available data and guided by inductive reasoning.
  - A scientific hypothesis leads to predictions that can be tested by recording additional observations or by performing experiments.

A type of logic called deduction is built into hypothesis-based science.

- In **deductive reasoning**, logic flows from the general to the specific.
  - From general premises, scientists extrapolate to a specific result that should be expected if the premises are true.
- In hypothesis-based science, deduction usually takes the form of predictions about what scientists should expect if a particular hypothesis is correct.
  - Scientists test the hypothesis by performing the experiment to see whether or not the results are as predicted.
  - Deductive logic takes the form *"If… then…"*
- Scientific hypotheses must be *testable*.
  - There must be some way to check the validity of the idea.
- Scientific hypotheses must be *falsifiable*.
  - There must be some observation or experiment that could reveal if a hypothesis is actually *not* true.
- The ideal in hypothesis-based science is to frame two or more alternative hypotheses and design experiments to falsify them.
- No amount of experimental testing can *prove* a hypothesis, because it is impossible to test *all* alternative hypotheses.
  - A hypothesis gains support by surviving various tests that could falsify it; testing falsifies alternative hypotheses.
- Not all hypotheses meet the criteria of science.
  - Because science requires natural explanations for natural phenomena, it can neither support nor falsify hypotheses that angels, ghosts, or spirits, whether benevolent or evil, cause storms, rainbows, illnesses, and cures.
  - Such supernatural explanations are simply outside the bounds of science, as are religious matters, which are issues of personal faith.

We can explore the scientific method.

- There is an idealized process of inquiry called the *scientific method*.
  - Very few scientific inquiries adhere rigidly to the sequence of steps prescribed by the textbook scientific method.

- We will consider a case study of scientific research that begins with a set of observations and inductive generalizations.
- Many poisonous animals have warning coloration that signals danger to potential predators.
  - Imposter species mimic poisonous species, although they are harmless.
  - What is the function of such mimicry? What advantage does it give the mimic?
- In 1862, Henry Bates proposed that mimics benefit when predators mistake them for harmful species.
  - This deception may lower the mimic's risk of predation.
- In 2001, David and Karin Pfennig of the University of North Carolina, together with undergraduate William Harcombe, designed a set of field experiments to test Bates' mimicry hypothesis.
- In North and South Carolina, a venomous snake called the eastern coral snake has warning coloration: alternating rings of red, yellow (or white), and black coloration.
  - Predators avoid coral snakes.
  - It is unlikely that predators learn to avoid coral snakes because a strike is usually lethal.
  - Natural selection may have favored an instinctive recognition and avoidance of the warning coloration of the coral snake.
- The nonpoisonous scarlet kingsnake mimics the ringed coloration of the coral snake.
- Both kingsnakes and coral snake live in North and South Carolina, but the kingsnake's range also extends into areas that have no coral snakes.
- The geographic distribution of these two species allowed the Pfennigs and Harcombe to test a key prediction of the mimicry hypothesis.
  - Mimicry should protect the kingsnake from predators, but *only* in regions where coral snakes live.
  - Predators in areas with no coral snakes should attack kingsnakes more frequently than predators in areas where coral snakes are present.
- To test the mimicry hypothesis, Harcombe made hundreds of artificial snakes.
  - The *experimental group* had the red, black, and white ring pattern of kingsnakes.
  - The *control group* had plain brown coloring.
- Equal numbers of both types of artificial snakes were placed at field sites, including areas without coral snakes.
- After four weeks, the scientists retrieved the fake snakes and counted bite or claw marks made by foxes, coyotes, raccoons, and black bears.
- The data fit the predictions of the mimicry hypothesis: The ringed snakes were attacked by predators less frequently than the brown snakes *only* in the geographic range of the coral snakes.
- The snake mimicry experiment provides an example of how scientists design experiments to test the effect of one variable by canceling out the effects of unwanted variables.
  - The design is called a **controlled experiment**.
  - An experimental group (artificial kingsnakes) is compared with a control group (brown artificial snakes).
  - The experimental and control groups differ only in the one factor the experiment is designed to test—the effect of the snake's coloration on the behavior of predators.
  - The artificial brown snakes allowed the scientists to rule out such variables as predator density and temperature as possible determinants of the number of predator attacks.

- A common misconception is that the term *controlled experiment* means that scientists control the experimental environment to keep everything constant except the one variable being tested.
  - Researchers usually "control" unwanted variables, not by *eliminating* them, but by *canceling* their effects using control groups.
- Another hallmark of science is that the observations and experimental results must be repeatable.
- Observations that can't be verified may be interesting or even entertaining, but they cannot count as evidence in scientific inquiry.
  - The scientists who investigated snake mimicry in the Carolinas obtained similar data when they repeated their experiments with different species of coral snakes and kingsnakes in Arizona.
  - *You* should be able to obtain similar results if you were to repeat the snake experiments.
- The everyday use of the term *theory* implies an untested speculation; *theory* has a very different meaning in science.
- A scientific **theory** is much broader in scope than a hypothesis.
  - *This* is a hypothesis: "Mimicking poisonous snakes is an adaptation that protects nonpoisonous snakes from predators."
  - *This* is a theory: "Evolutionary adaptations evolve by natural selection."
- A theory is general enough to generate many new, specific hypotheses that can be tested.
- Compared to any one hypothesis, a theory is generally supported by a much more massive body of evidence.
  - The theories that become widely adopted in science (such as the theory of adaptation by natural selection) explain many observations and are supported by a great deal of evidence.
- In spite of the body of evidence supporting a widely accepted theory, scientists may have to modify or reject theories when new evidence is found.
  - For example, the theory of biological diversity that lumped bacteria and archaea together as a kingdom of prokaryotes was abandoned when new methods for comparing cells and molecules allowed testing of hypothetical relationships between organisms based on the theory.
- If there is "truth" in science, it is conditional, based on the preponderance of available evidence.

Concept 1.4 Science benefits from a cooperative approach and diverse viewpoints

- Science is an intensely social activity.
  - Most scientists work in teams, which often include graduate and undergraduate students.
  - To succeed in science, it helps to be a good communicator.
  - Research results have no impact until shared with a community of peers through seminars, publications, and websites.
- Both cooperation and competition characterize scientific culture.
- Scientists attempt to confirm each other's observations and may repeat experiments.
  - If experimental results are unable to be repeated by scientific colleagues, this may reflect some underlying weakness in the original claim, which will then have to be revised.
- In a sense, science polices itself.
  - Integrity and adherence to honesty and high professional standards when reporting results are central to the scientific endeavor.
  - After all, the validity of experimental data is key to designing further lines of inquiry.

- Scientists may be very competitive when focusing on the same research question.
    - Some scientists enjoy the challenge of being first with an important discovery or key experiment, while others derive more satisfaction from cooperating with fellow scientists working on the same problem.
- Scientists also cooperate by sharing data about **model organisms**—organisms that are easy to grow in the lab and lend themselves to the study of particular questions.
    - Because all organisms are evolutionarily related, lessons learned from a model organism are often applicable to a much wider group.
    - For example, genetic studies of the fruit fly *Drosophila melanogaster* have taught us a lot about how genes work in other species, including humans.
    - Some other popular model organisms are the mustard plant *Arabidopsis thaliana*, the soil worm *Caenorhabditis elegans*, the zebrafish *Danio rerio*, the mouse *Mus musculus*, and the bacterium *Escherichia coli*.
- Some philosophers of science argue that scientists are so influenced by cultural and political values that science is no more objective than other ways of "knowing nature."
- At the other extreme are those who view scientific theories as natural laws, not human interpretations of nature.
    - The reality of science is somewhere in between.
    - The cultural milieu affects scientific fashion, but the need to replicate observations and hypothesis testing distinguishes science from other fields.

Both science and technology are functions of society.

- Although both science and technology employ similar inquiry patterns, their basic goals differ.
    - The goal of science is to understand natural phenomena.
    - In contrast, **technology** *applies* scientific knowledge for some specific purpose.
- Biologists and other scientists often speak of "discoveries," while engineers and other technologists more often speak of "inventions."
    - Scientists benefit from inventions as they put new technology to work in their research.
    - Science and technology are thus interdependent.
- The discovery of the structure of DNA by Watson and Crick sparked an explosion of scientific activity.
    - Many technologies of DNA engineering are transforming applied fields, including medicine, agriculture, and forensics.
- The direction that technology takes depends less on science than on the needs of humans and the values of society.
    - Debates about technology focus more on "*Should* we do it?" than on "*Can* we do it?"
- With advances in technology come difficult choices, informed as much by politics, economics, and cultural values as by science.
- Scientists should educate politicians, bureaucrats, corporate leaders, and voters about how science works and about the potential benefits and hazards of specific technologies.

Diverse viewpoints have value in science.

- Science gains much from embracing a diversity of backgrounds and viewpoints among its practitioners.
- Science in the U.S. and Europe has, until recently, been carried out primarily by men.

- Over the past 50 years, changing attitudes about career choices have increased the proportion of women in biology and some other sciences.
- The pace has been slow, and women and many racial and ethnic groups are still underrepresented in many scientific professions.

LECTURE PRESENTATIONS
For CAMPBELL BIOLOGY, NINTH EDITION
Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson

Chapter 1

Introduction: Themes in the Study of Life

Lectures by
Erin Barley
Kathleen Fitzpatrick

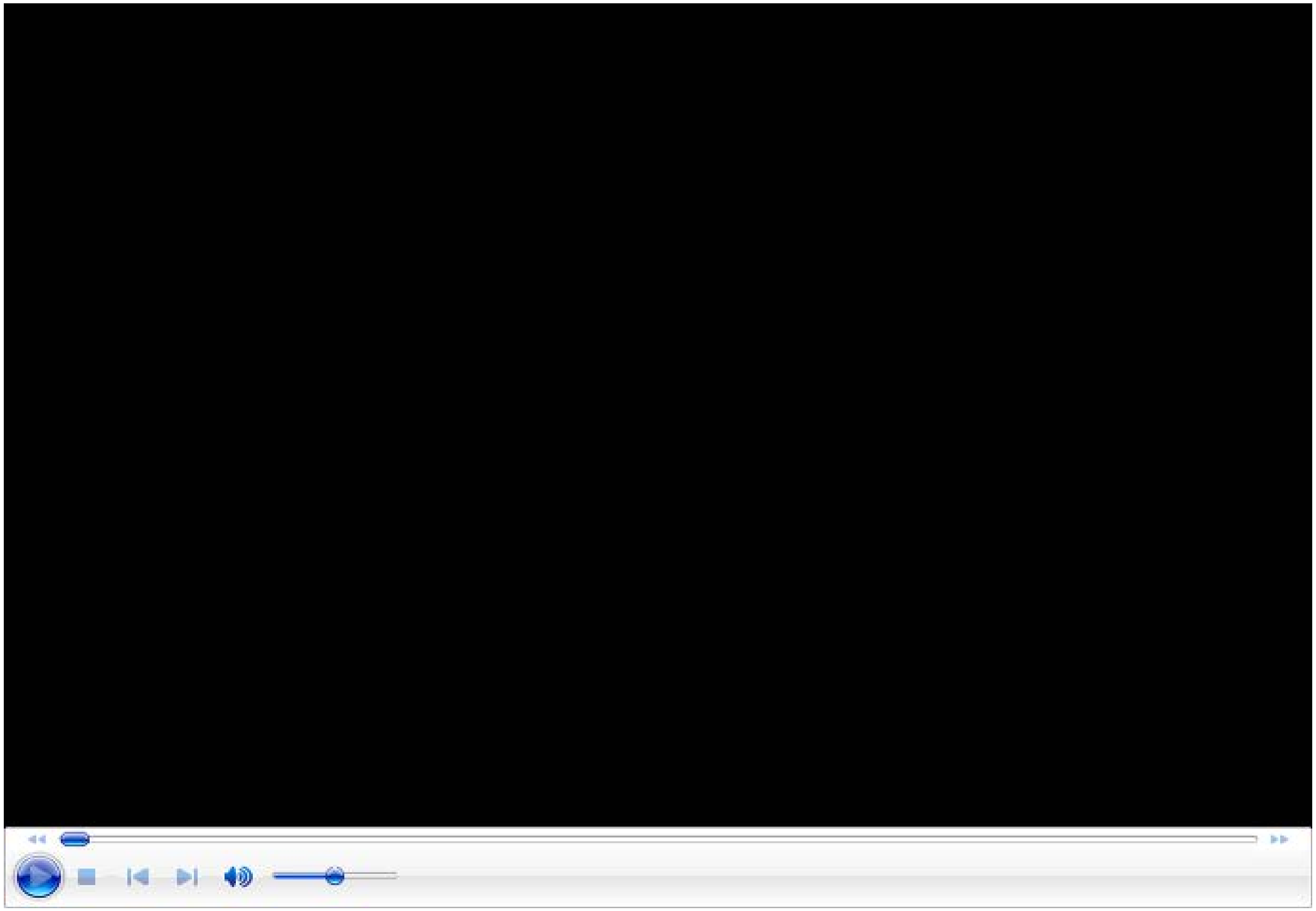
Overview: Inquiring About Life

- An organism's adaptations to its environment are the result of evolution
  - For example, the ghost plant is adapted to conserving water; this helps it to survive in the crevices of rock walls
- **Evolution** is the process of change that has transformed life on Earth

Figure 1.1

Figure 1.2

- **Biology** is the scientific study of life
- Biologists ask questions such as
  - How does a single cell develop into an organism?
  - How does the human mind work?
  - How do living things interact in communities?
- Life defies a simple, one-sentence definition
- Life is recognized by what living things do



Video: Seahorse Camouflage

Figure 1.3

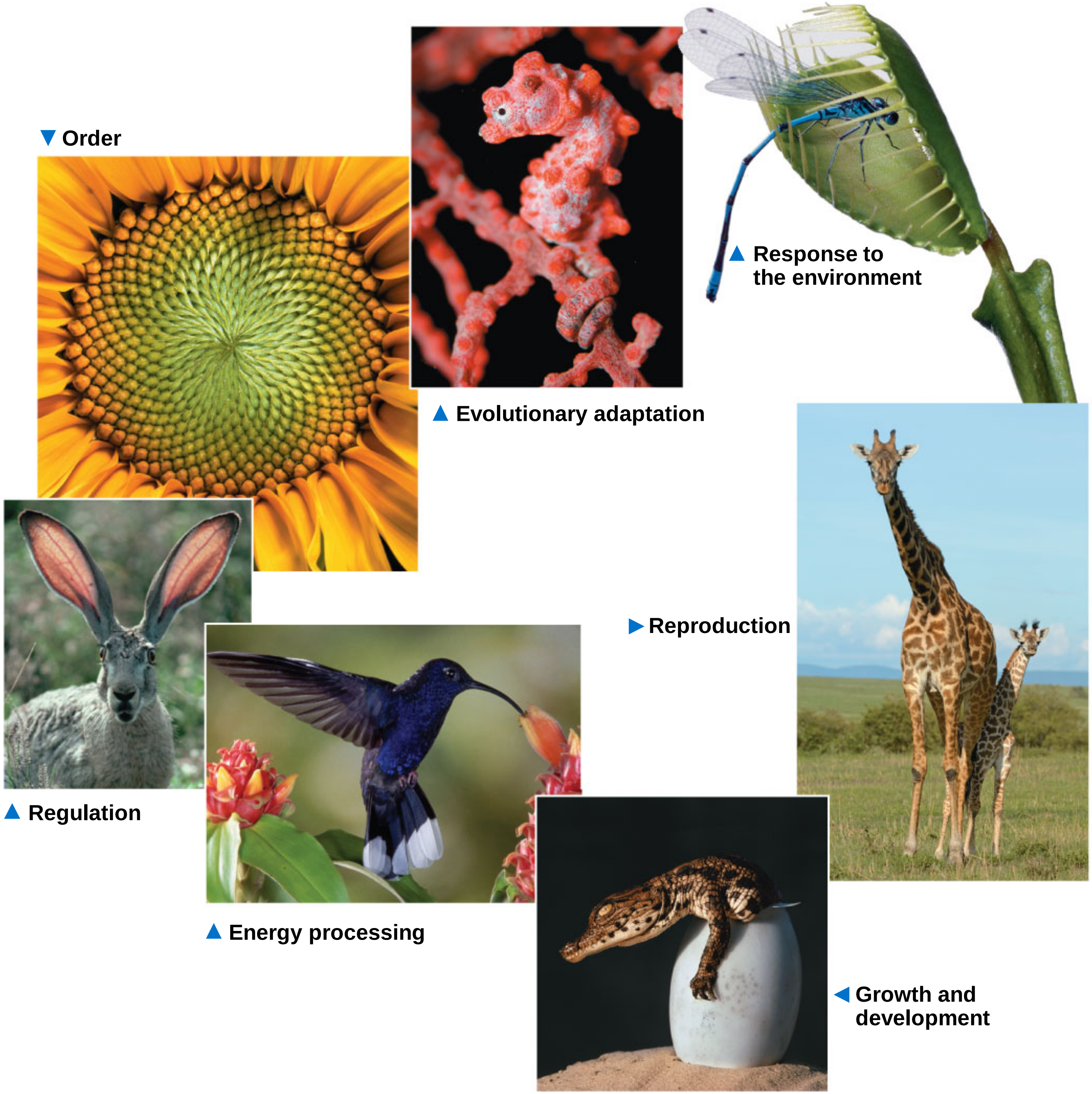

Order
Evolutionary adaptation
Response to the environment
Reproduction
Regulation
Energy processing
Growth and development

Figure 1.3a

Evolutionary adaptation

Figure 1.3b

Response to the environment

Figure 1.3c

Reproduction

Figure 1.3d

Growth and development

Figure 1.3e

Energy processing

Figure 1.3f

Regulation

Figure 1.3g

Order

Concept 1.1: The themes of this book make connections across different areas of biology

- Biology consists of more than memorizing factual details
- Themes help to organize biological information

Theme: New Properties Emerge at Each Level in the Biological Hierarchy

- Life can be studied at different levels, from molecules to the entire living planet
- The study of life can be divided into different levels of biological organization

Figure 1.4

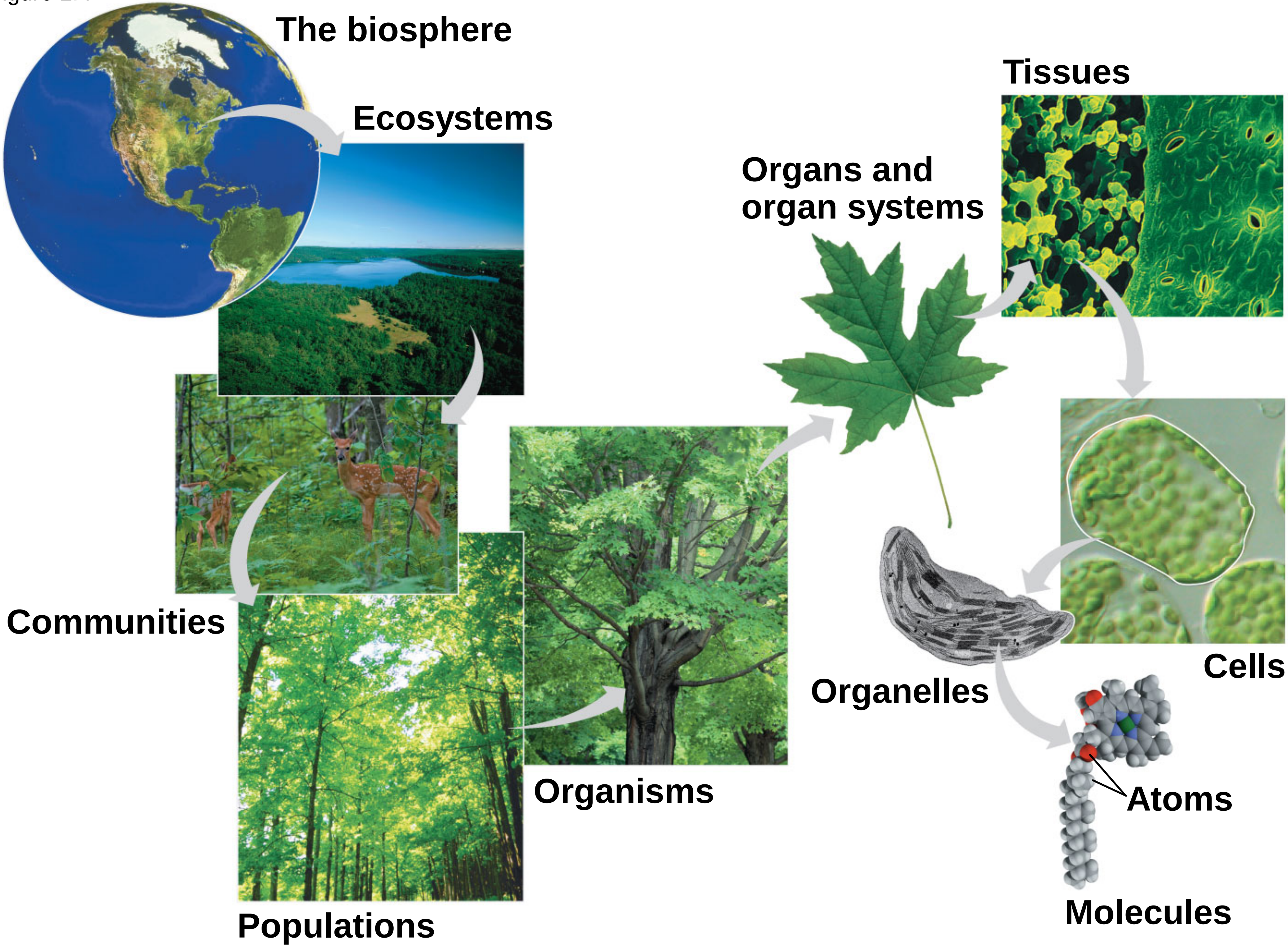

The biosphere
Ecosystems
Communities
Populations
Organisms
Organs and organ systems
Tissues
Cells
Organelles
Atoms
Molecules

Figure 1.4a

The biosphere

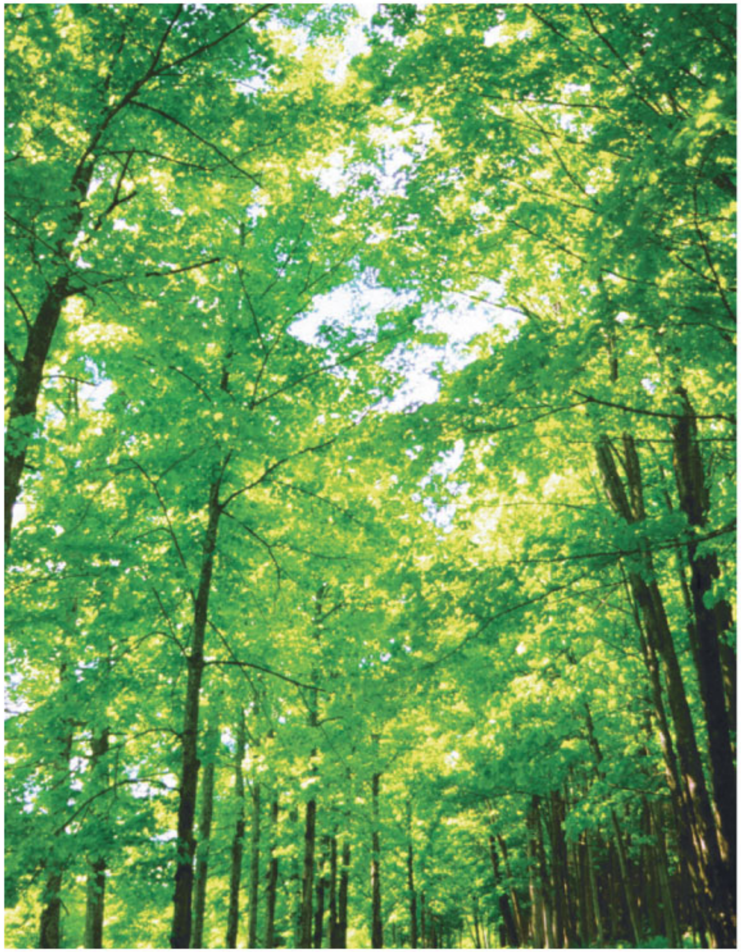
Figure 1.4b

Ecosystems

Figure 1.4c

Communities

Figure 1.4d

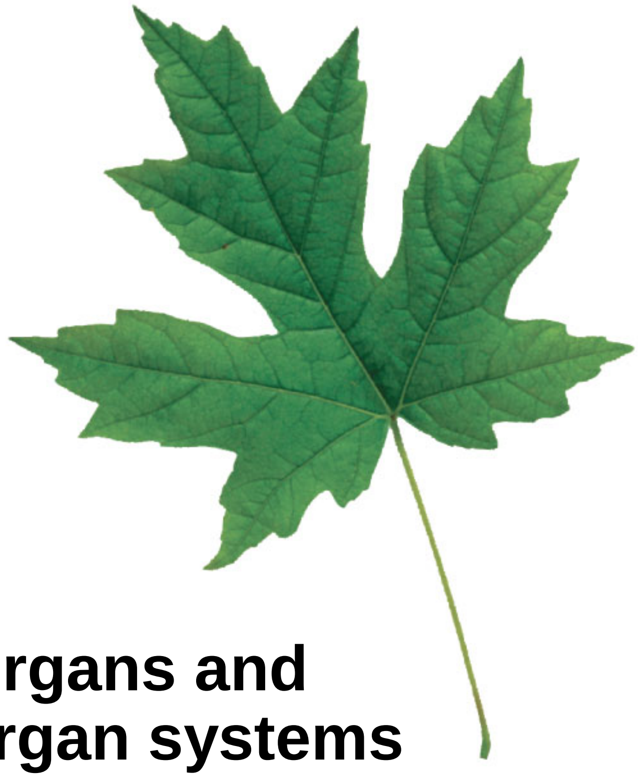


Populations

Figure 1.4e

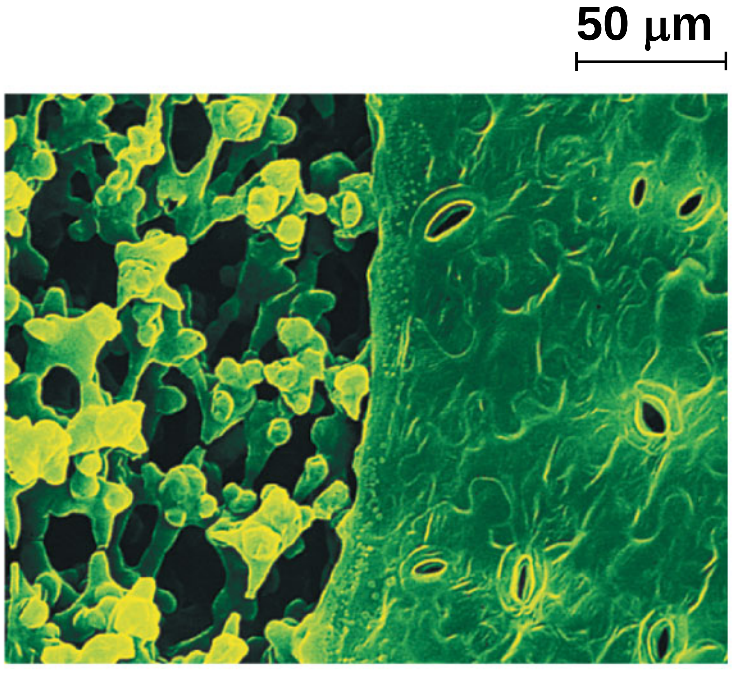
Organisms

Figure 1.4f



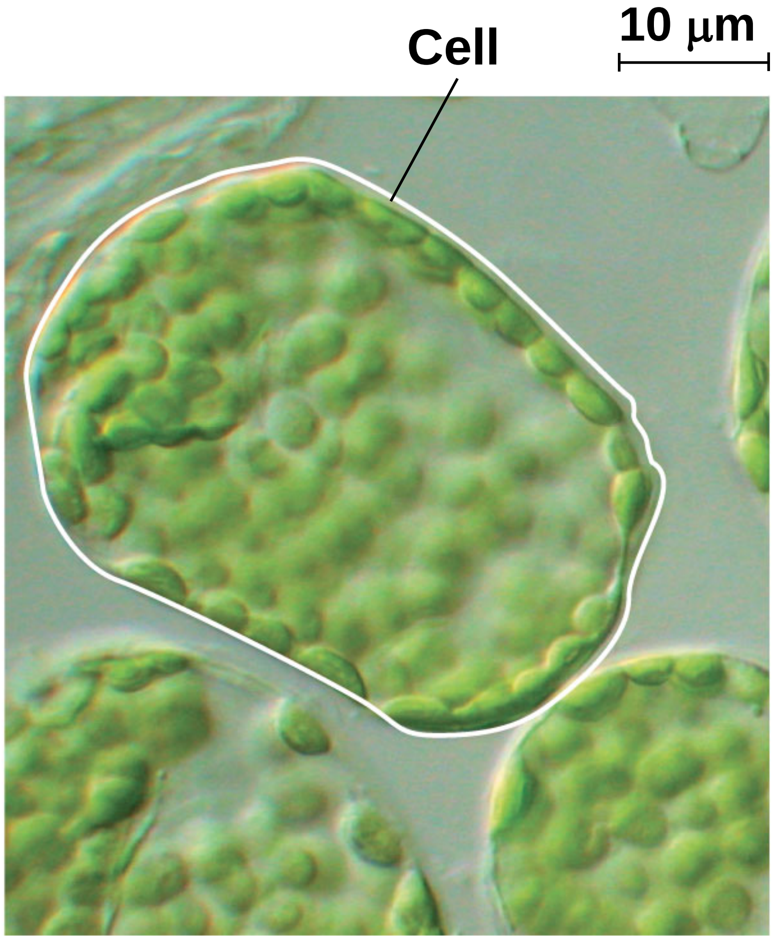
Organs and organ systems

Figure 1.4g



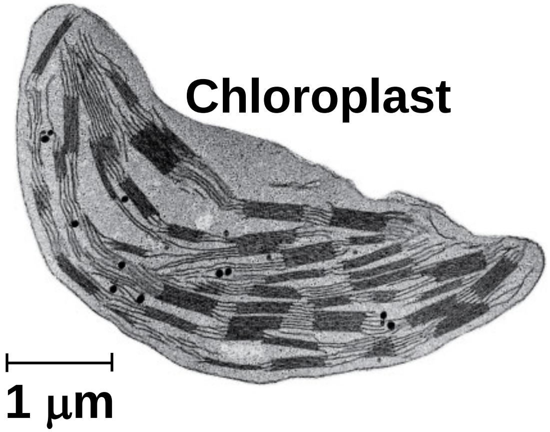
Tissues

Figure 1.4h



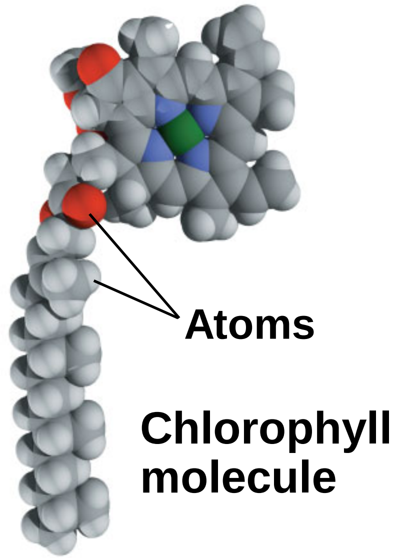
Cells

Figure 1.4i



Organelles

Figure 1.4j



Molecules

Emergent Properties

- **Emergent properties** result from the arrangement and interaction of parts within a system
- Emergent properties characterize nonbiological entities as well
  - For example, a functioning bicycle emerges only when all of the necessary parts connect in the correct way

The Power and Limitations of Reductionism

- Reductionism is the reduction of complex systems to simpler components that are more manageable to study
  - For example, studying the molecular structure of DNA helps us to understand the chemical basis of inheritance

- An understanding of biology balances reductionism with the study of emergent properties
  - For example, new understanding comes from studying the interactions of DNA with other molecules

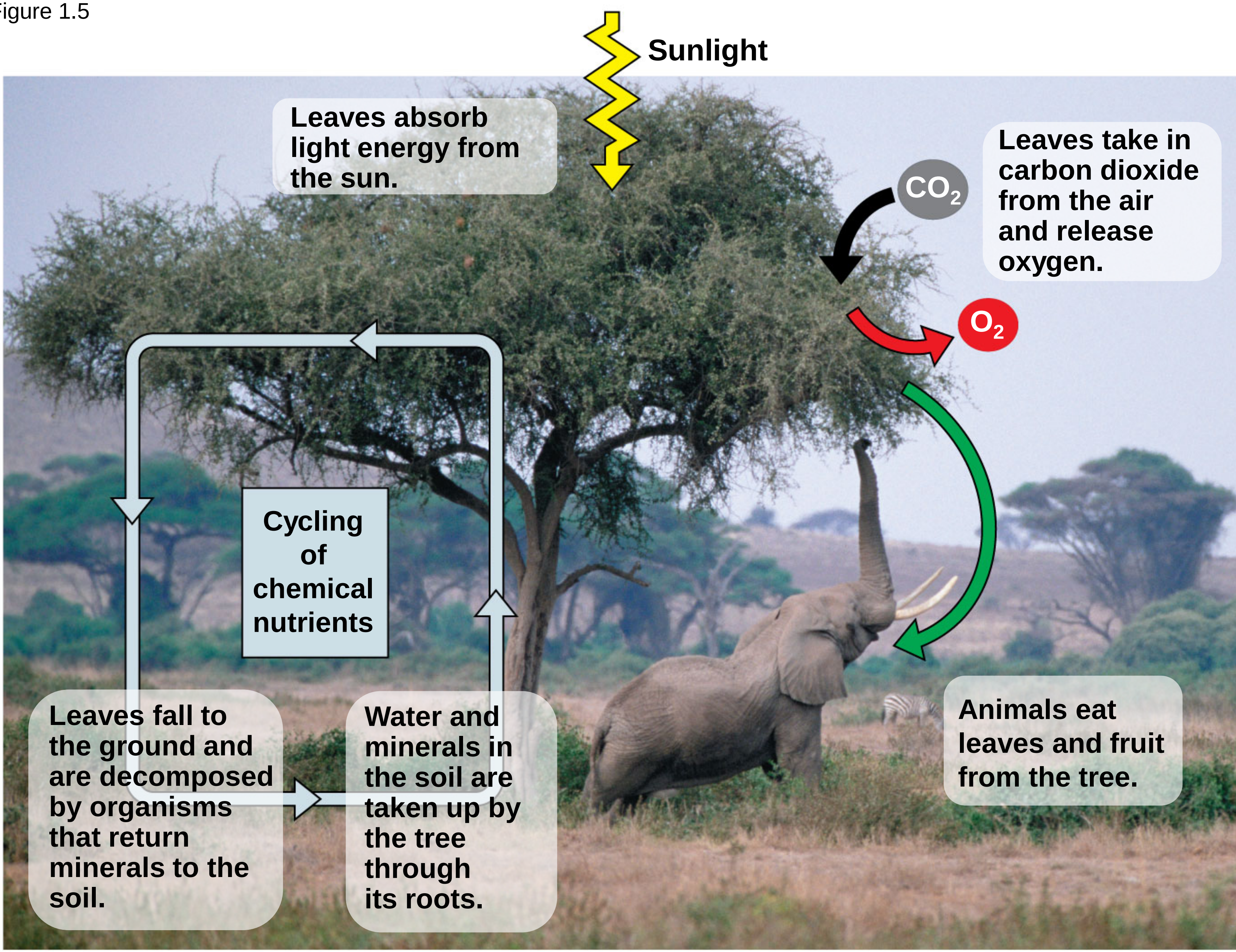
Systems Biology

- A system is a combination of components that function together
- **Systems biology** constructs models for the dynamic behavior of whole biological systems
- The systems approach poses questions such as
  - How does a drug for blood pressure affect other organs?
  - How does increasing CO_2 alter the biosphere?

Theme: Organisms Interact with Other Organisms and the Physical Environment

- Every organism interacts with its environment, including nonliving factors and other organisms
- Both organisms and their environments are affected by the interactions between them
  - For example, a tree takes up water and minerals from the soil and carbon dioxide from the air; the tree releases oxygen to the air and roots help form soil

Figure 1.5



Sunlight
Leaves absorb light energy from the sun.
CO_2
Leaves take in carbon dioxide from the air and release oxygen.
O_2
Cycling of chemical nutrients
Leaves fall to the ground and are decomposed by organisms that return minerals to the soil.
Water and minerals in the soil are taken up by the tree through its roots.
Animals eat leaves and fruit from the tree.

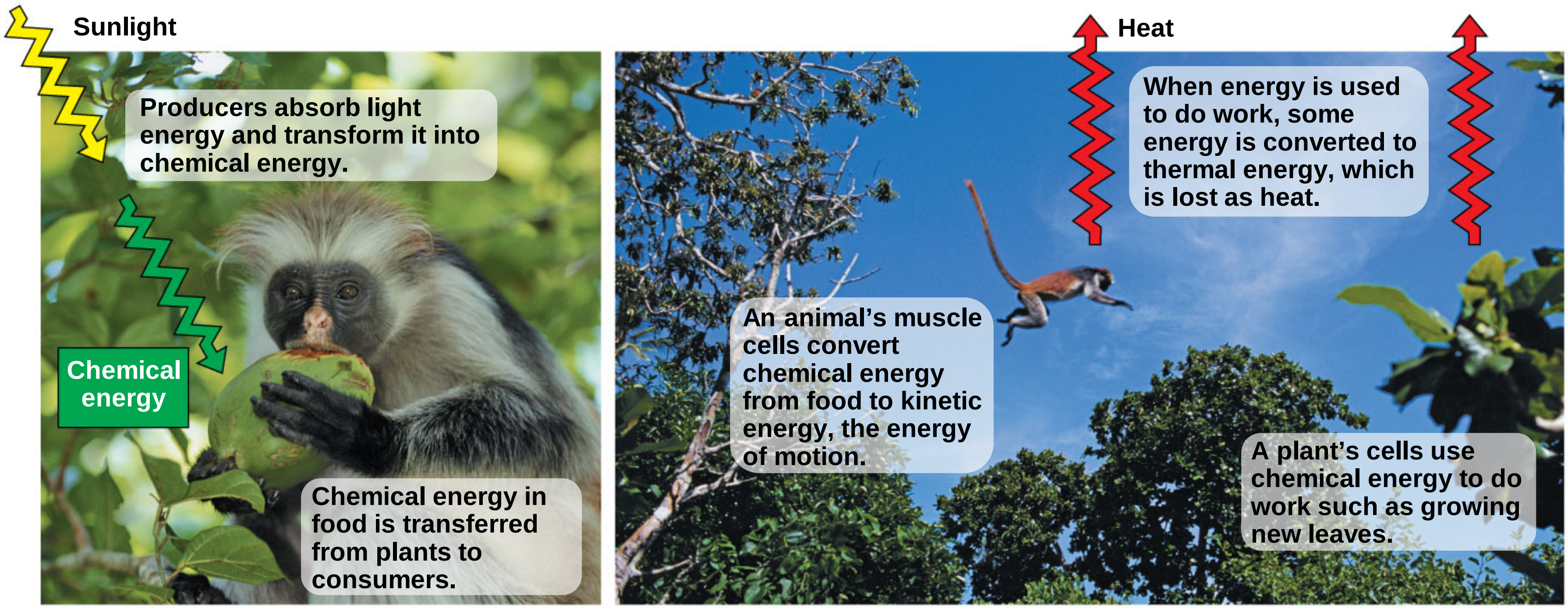
Figure 1.5a

- Humans have modified our environment
  - For example, half the human-generated CO_2 stays in the atmosphere and contributes to global warming
- Global warming is a major aspect of **global climate change**
- It is important to understand the effects of global climate change on the Earth and its populations

Theme: Life Requires Energy Transfer and Transformation

- A fundamental characteristic of living organisms is their use of energy to carry out life's activities
- Work, including moving, growing, and reproducing, requires a source of energy
- Living organisms transform energy from one form to another
  - For example, light energy is converted to chemical energy, then kinetic energy
- Energy flows through an ecosystem, usually entering as light and exiting as heat

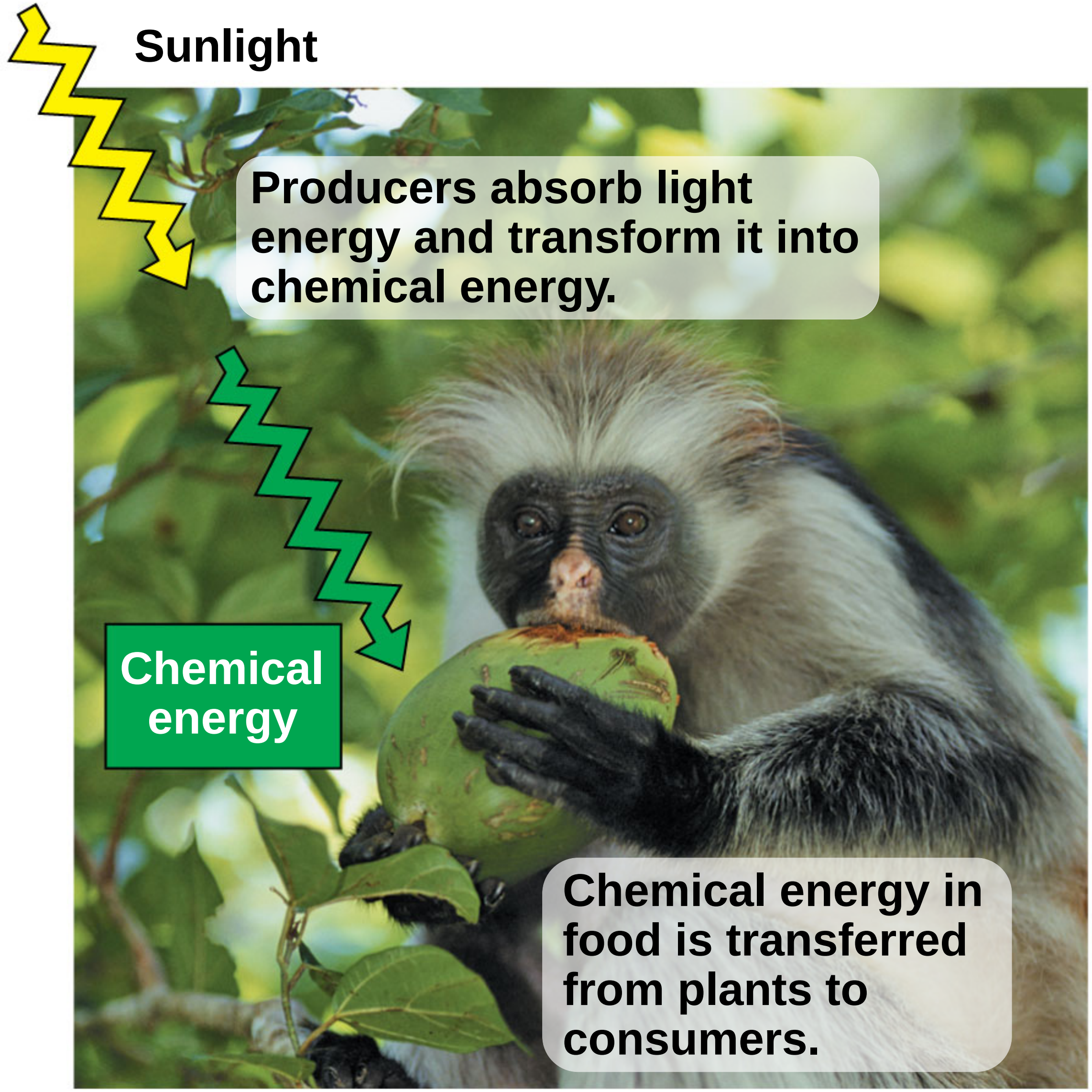
Figure 1.6



(a) Energy flow from sunlight to producers to consumers

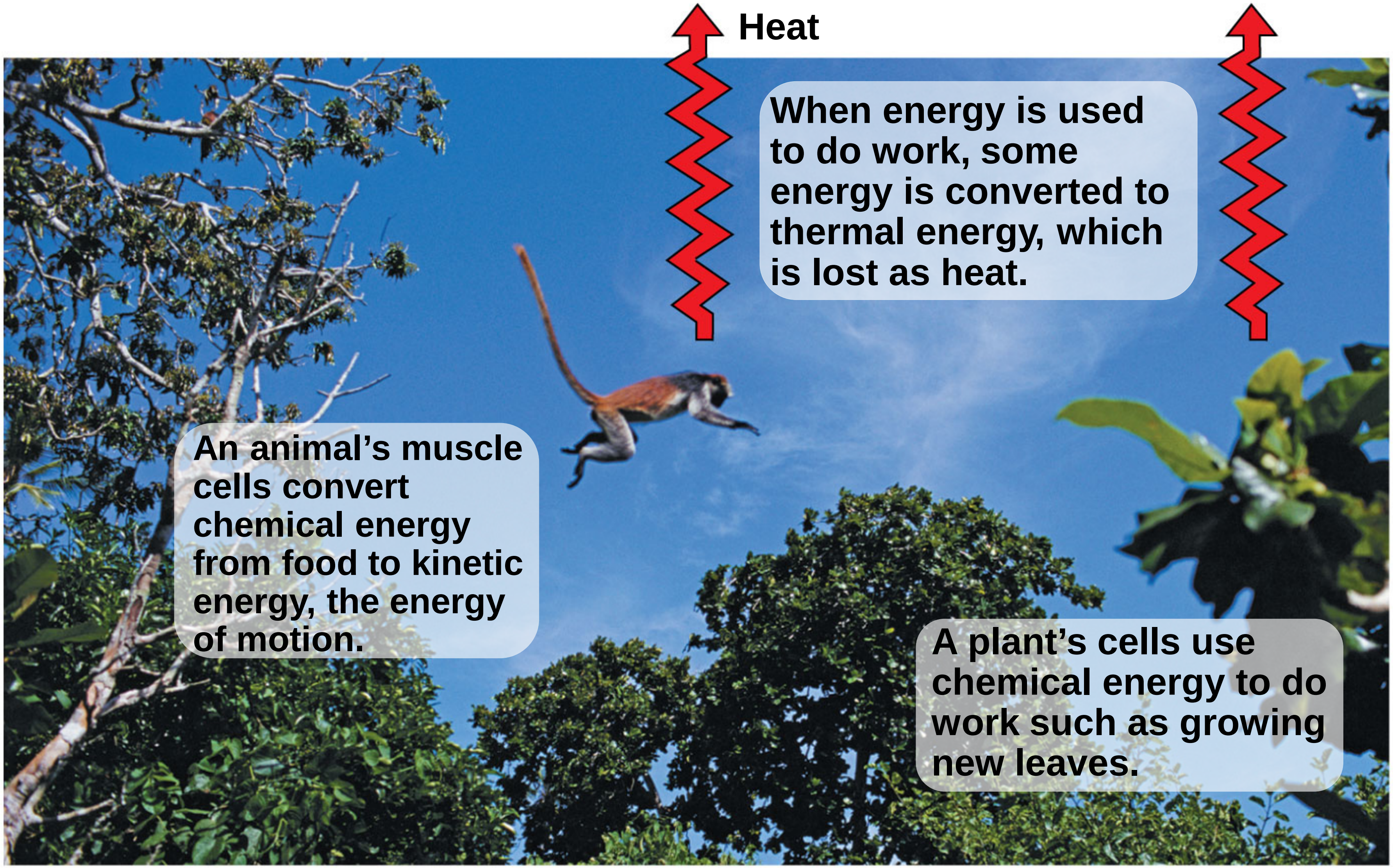
(b) Using energy to do work

Figure 1.6a



(a) Energy flow from sunlight to producers to consumers

Figure 1.6b



(b) Using energy to do work

Figure 1.6c

Figure 1.6d

Theme: Structure and Function Are Correlated at All Levels of Biological Organization

- Structure and function of living organisms are closely related
  - For example, a leaf is thin and flat, maximizing the capture of light by chloroplasts
  - For example, the structure of a bird’s wing is adapted to flight

Figure 1.7

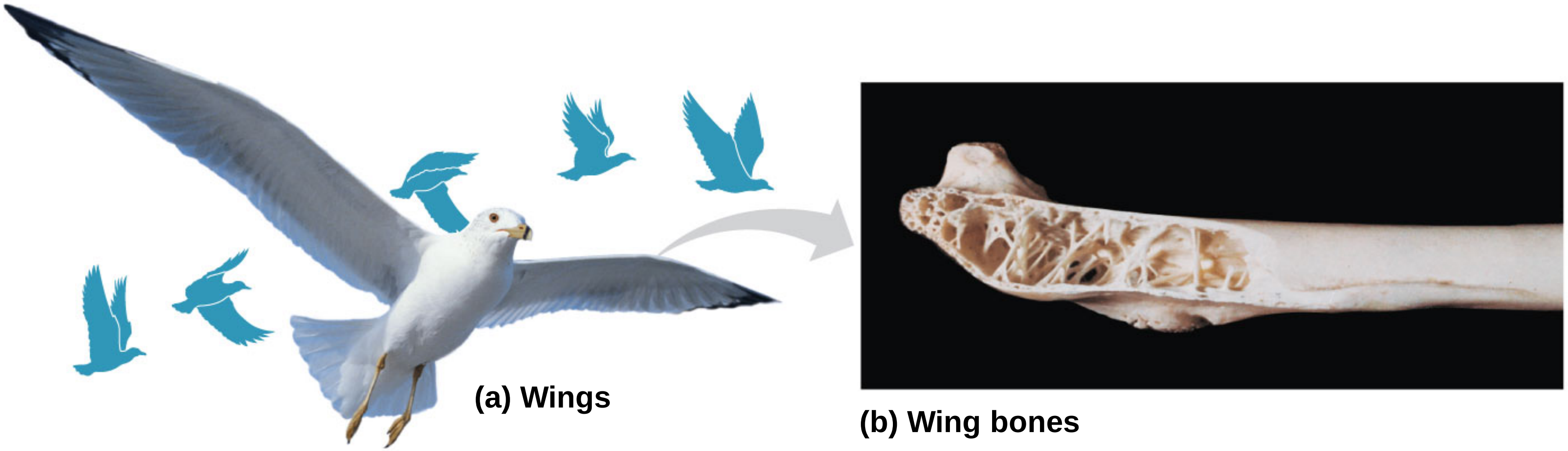
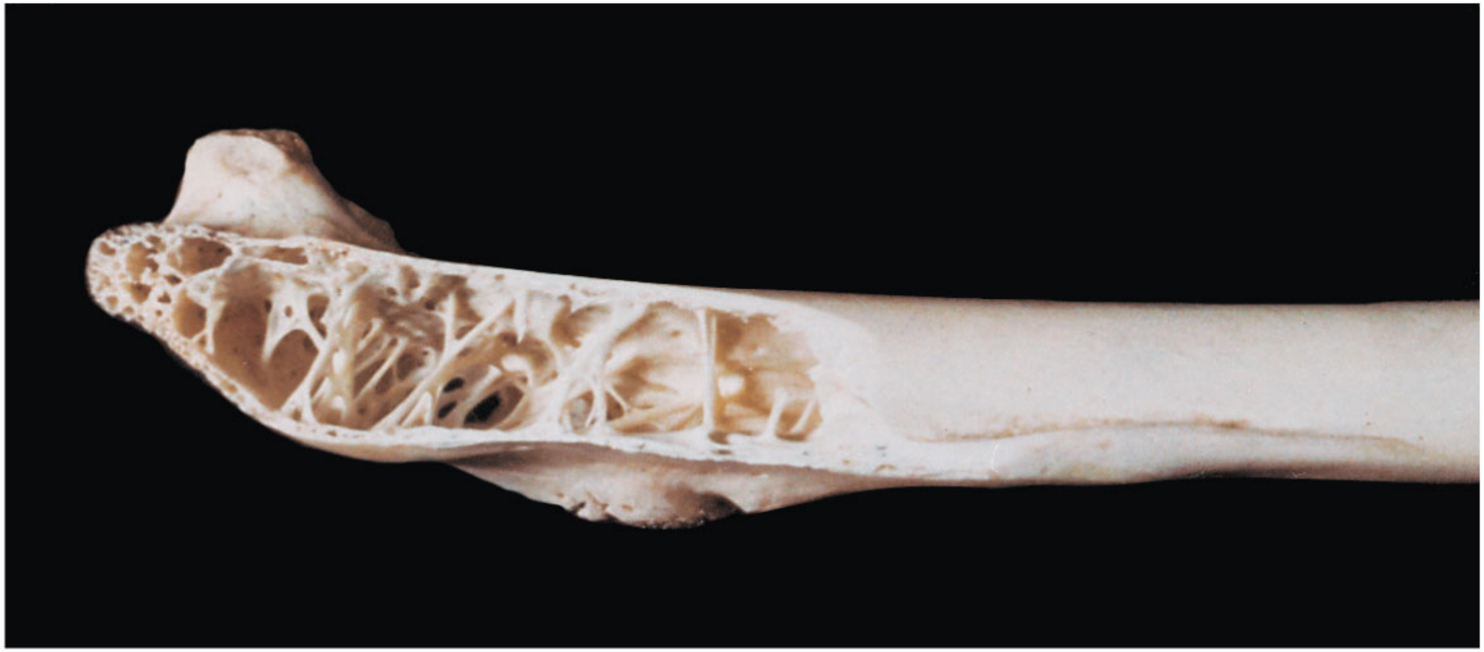


Figure 1.7a

(a) Wings

Figure 1.7b



(b) Wing bones

Figure 1.7c

Theme: The Cell Is an Organism’s Basic Unit of Structure and Function

- The cell is the lowest level of organization that can perform all activities required for life
- All cells
  - Are enclosed by a membrane
  - Use DNA as their genetic information

- A **eukaryotic cell** has membrane-enclosed organelles, the largest of which is usually the nucleus
- By comparison, a **prokaryotic cell** is simpler and usually smaller, and does not contain a nucleus or other membrane-enclosed organelles

Figure 1.8

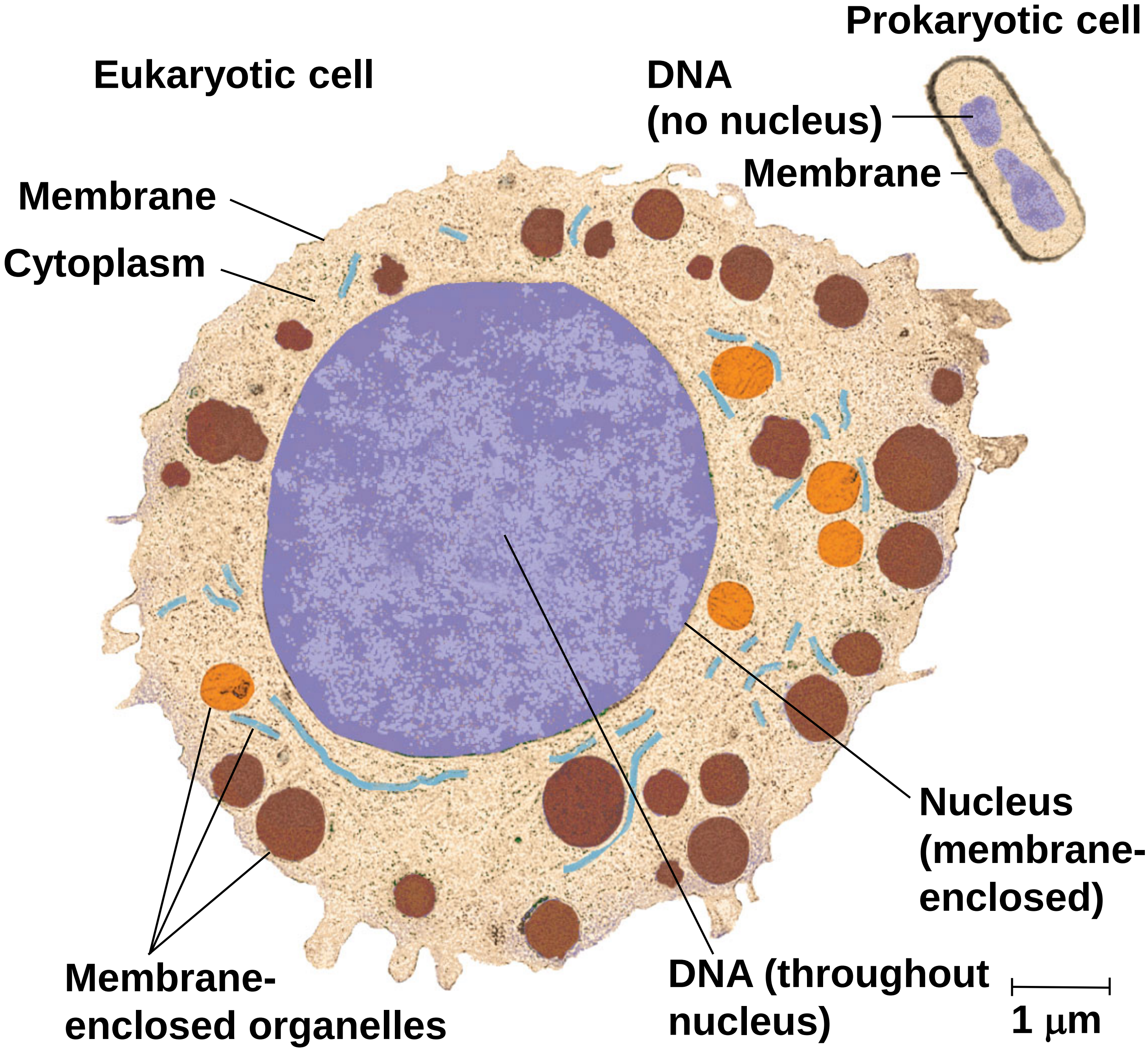

Prokaryotic cell
Eukaryotic cell
DNA
(no nucleus)
Membrane
Membrane
Cytoplasm
Nucleus
(membrane-
enclosed)
Membrane-
enclosed organelles
DNA (throughout
nucleus)
1 μm

Figure 1.8a

Eukaryotic cell

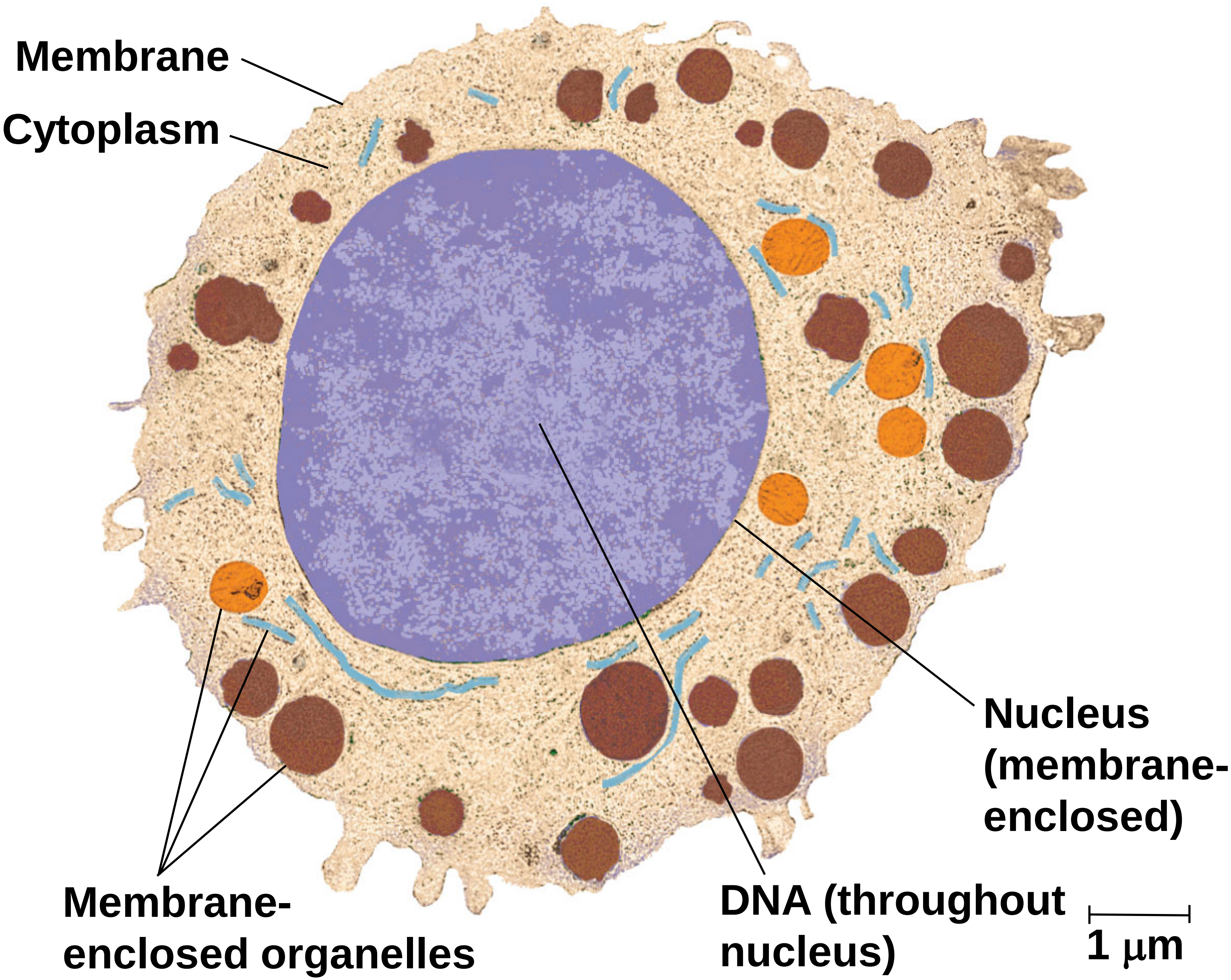
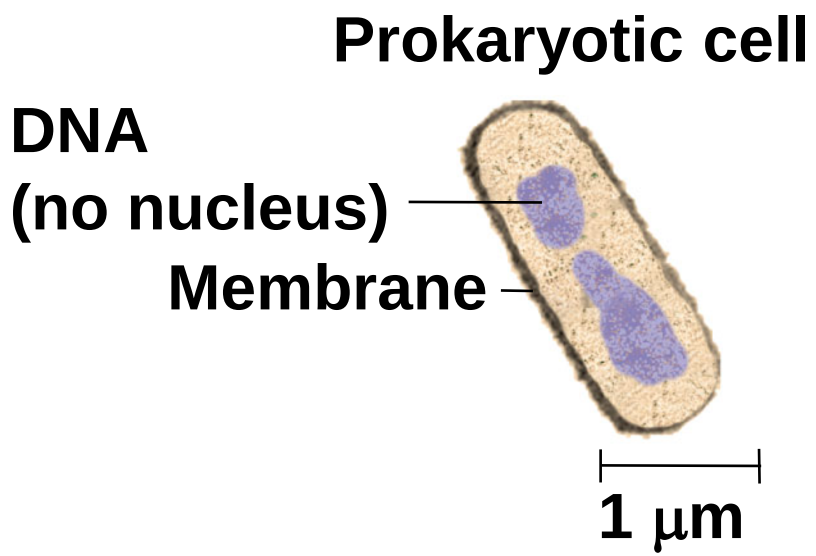


Figure 1.8b



Theme: The Continuity of Life Is Based on Heritable Information in the Form of DNA

- Chromosomes contain most of a cell's genetic material in the form of **DNA** (deoxyribonucleic acid)
- DNA is the substance of genes
- **Genes** are the units of inheritance that transmit information from parents to offspring
- The ability of cells to divide is the basis of all reproduction, growth, and repair of multicellular organisms

Figure 1.9

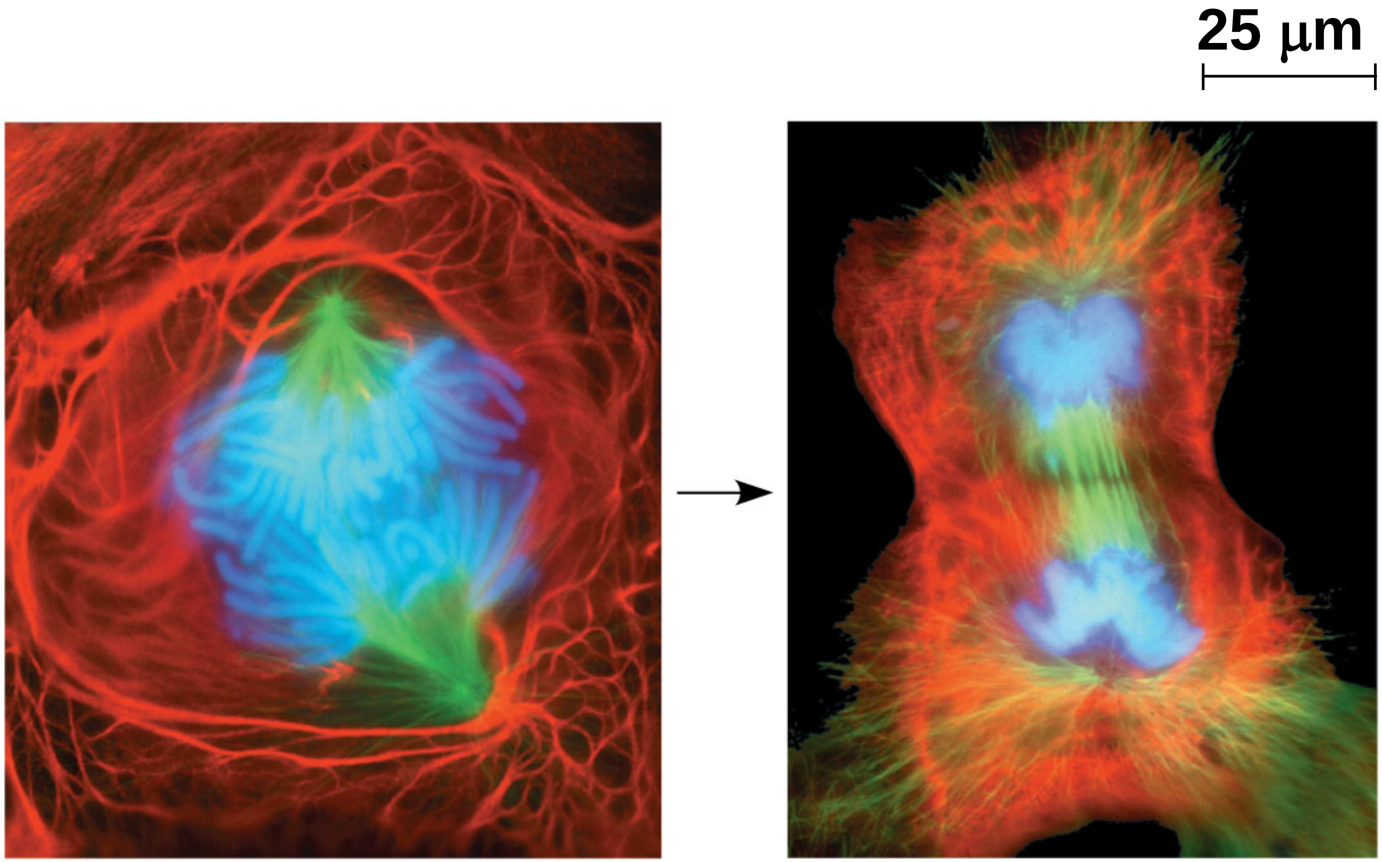


Figure 1.9a

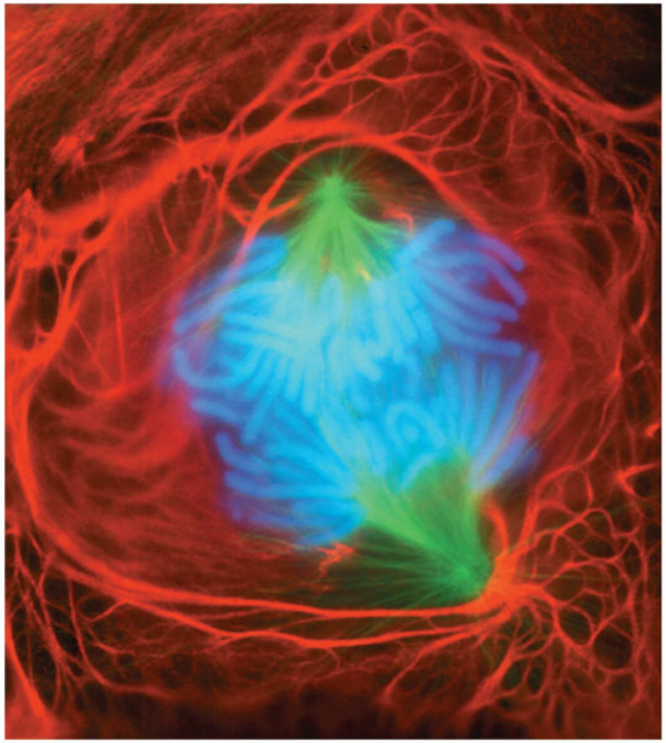
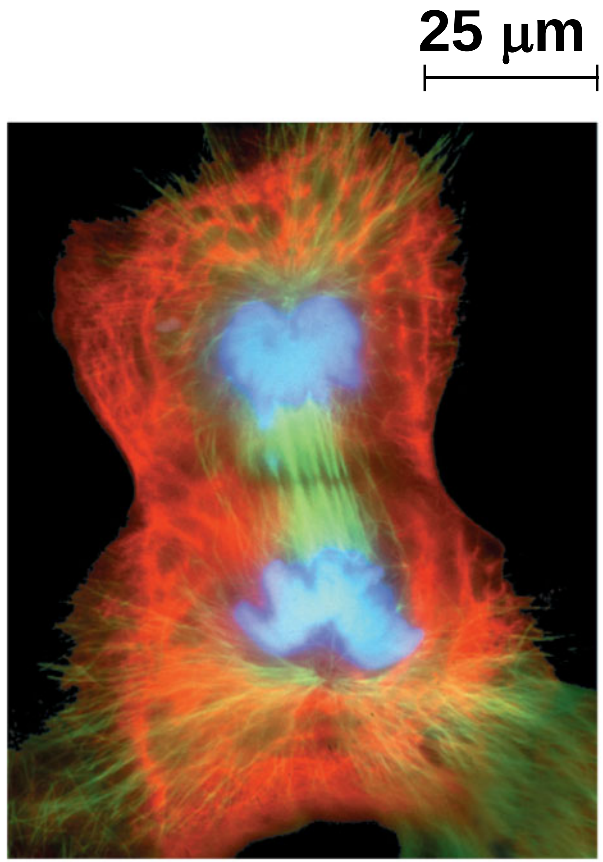


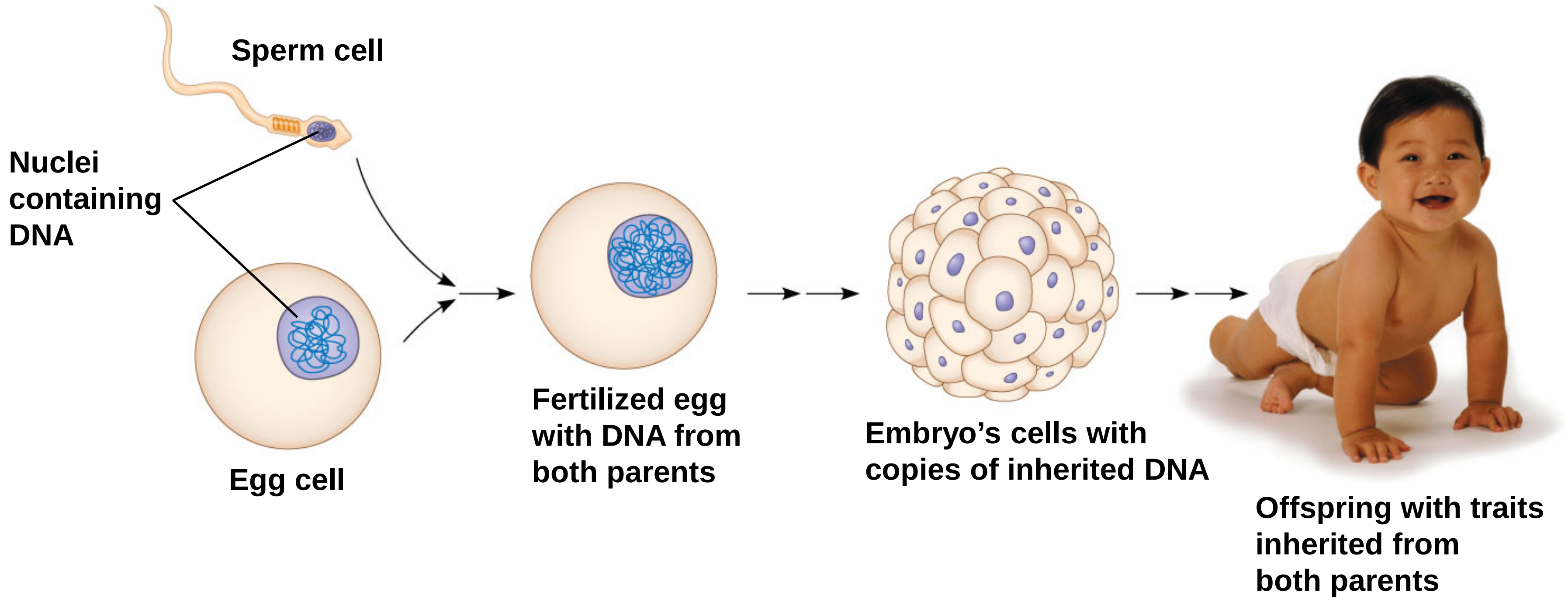
Figure 1.9b



DNA Structure and Function

- Each chromosome has one long DNA molecule with hundreds or thousands of genes
- Genes encode information for building proteins
- DNA is inherited by offspring from their parents
- DNA controls the development and maintenance of organisms

Figure 1.10

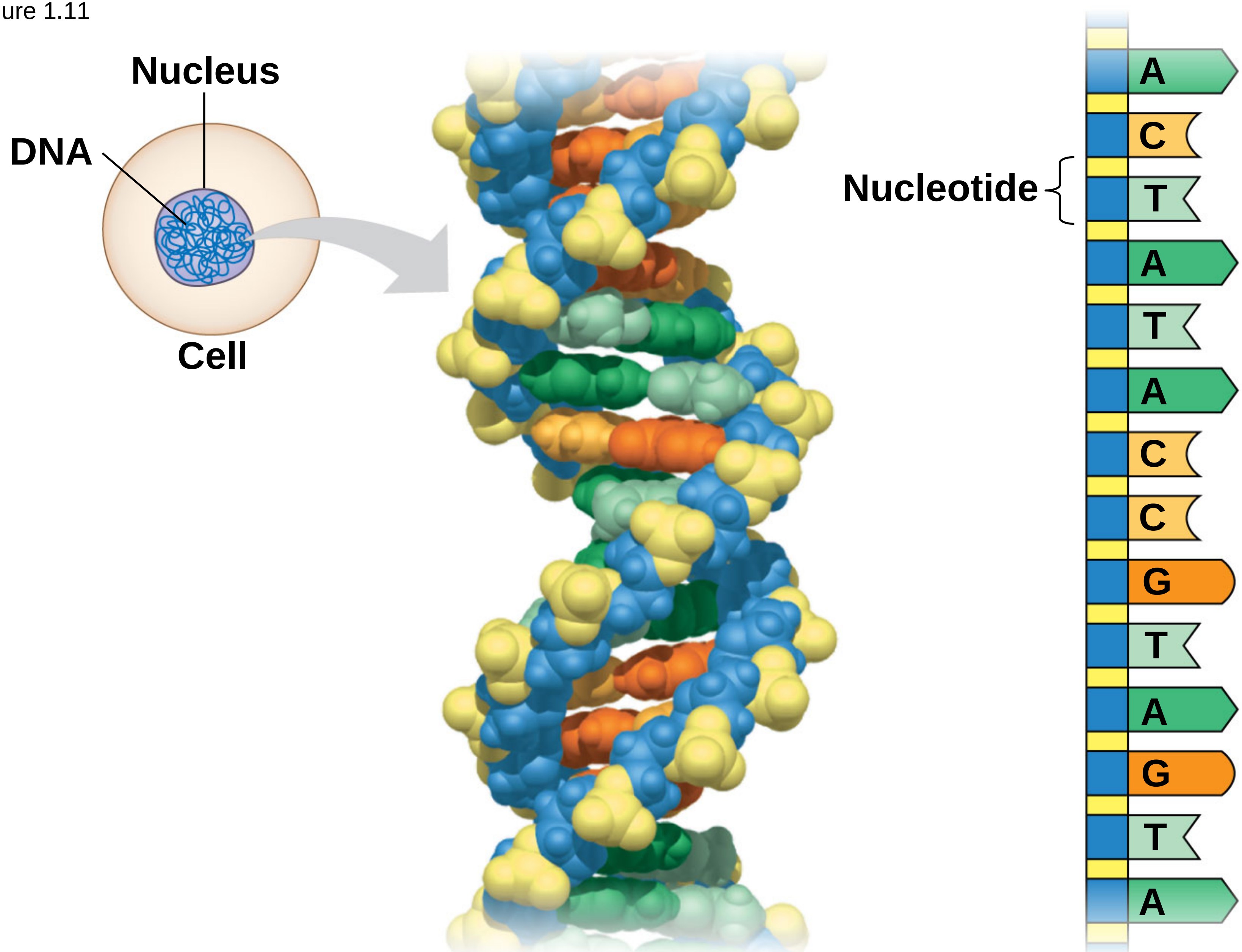


Sperm cell
Nuclei containing DNA
Egg cell
Fertilized egg with DNA from both parents
Embryo's cells with copies of inherited DNA
Offspring with traits inherited from both parents

Figure 1.10a

- Each DNA molecule is made up of two long chains arranged in a double helix
- Each link of a chain is one of four kinds of chemical building blocks called nucleotides and nicknamed A, G, C, and T

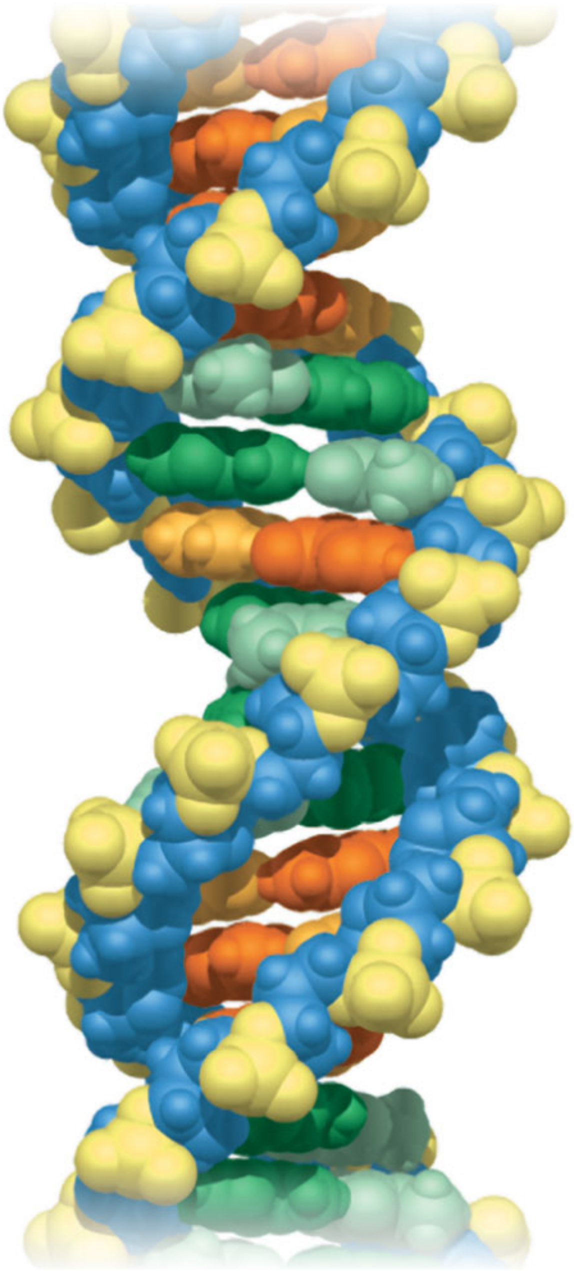
Figure 1.11



(a) DNA double helix

(b) Single strand of DNA

Figure 1.11a



- Genes control protein production indirectly
- DNA is transcribed into RNA then translated into a protein
- **Gene expression** is the process of converting information from gene to cellular product

Genomics: Large-Scale Analysis of DNA Sequences

- An organism's **genome** is its entire set of genetic instructions
- The human genome and those of many other organisms have been sequenced using DNA-sequencing machines
- **Genomics** is the study of sets of genes within and between species

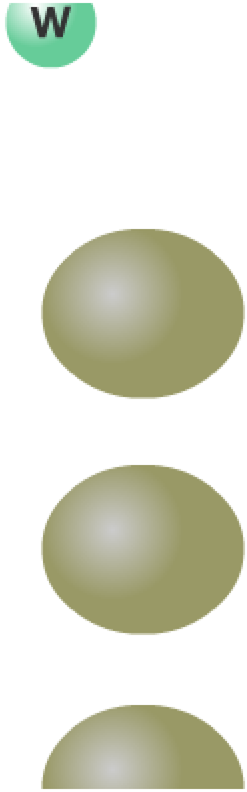
Figure 1.12

- The genomics approach depends on
  - “High-throughput” technology, which yields enormous amounts of data
  - **Bioinformatics,** which is the use of computational tools to process a large volume of data
  - Interdisciplinary research teams

Theme: Feedback Mechanisms Regulate Biological Systems

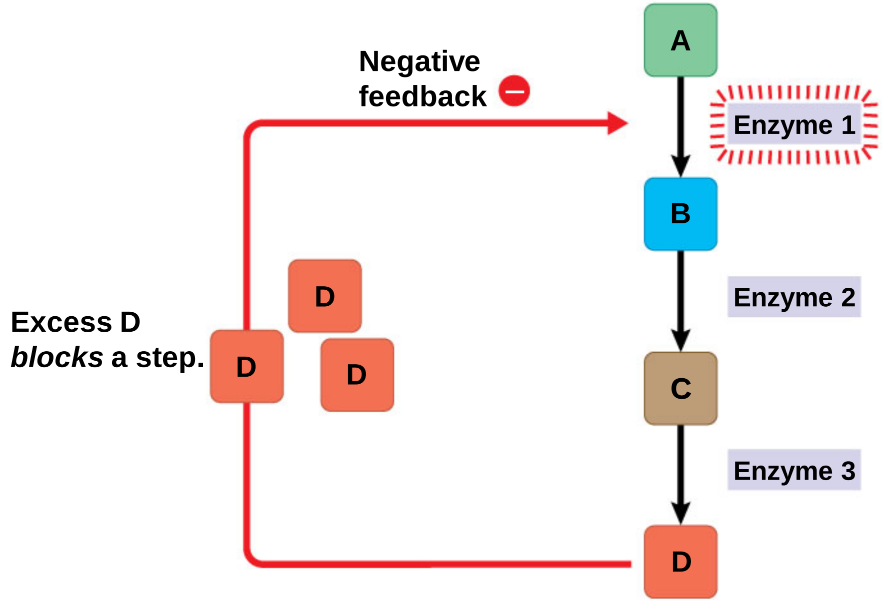
- Feedback mechanisms allow biological processes to self-regulate
- **Negative feedback** means that as more of a product accumulates, the process that creates it slows and less of the product is produced
- **Positive feedback** means that as more of a product accumulates, the process that creates it speeds up and more of the product is produced

Animation: Negative Feedback
Right-click slide / select "Play"

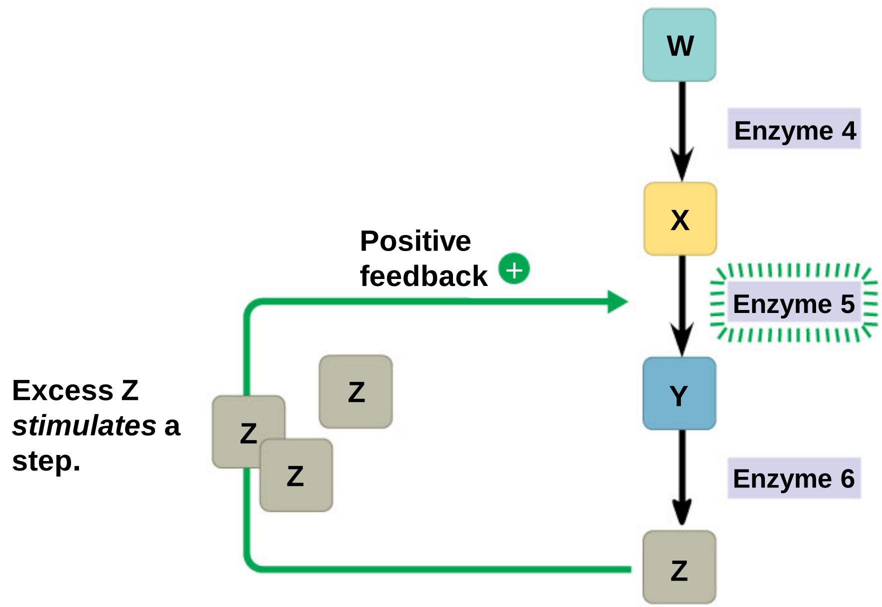


Animation: Positive Feedback
Right-click slide / select "Play"

Figure 1.13

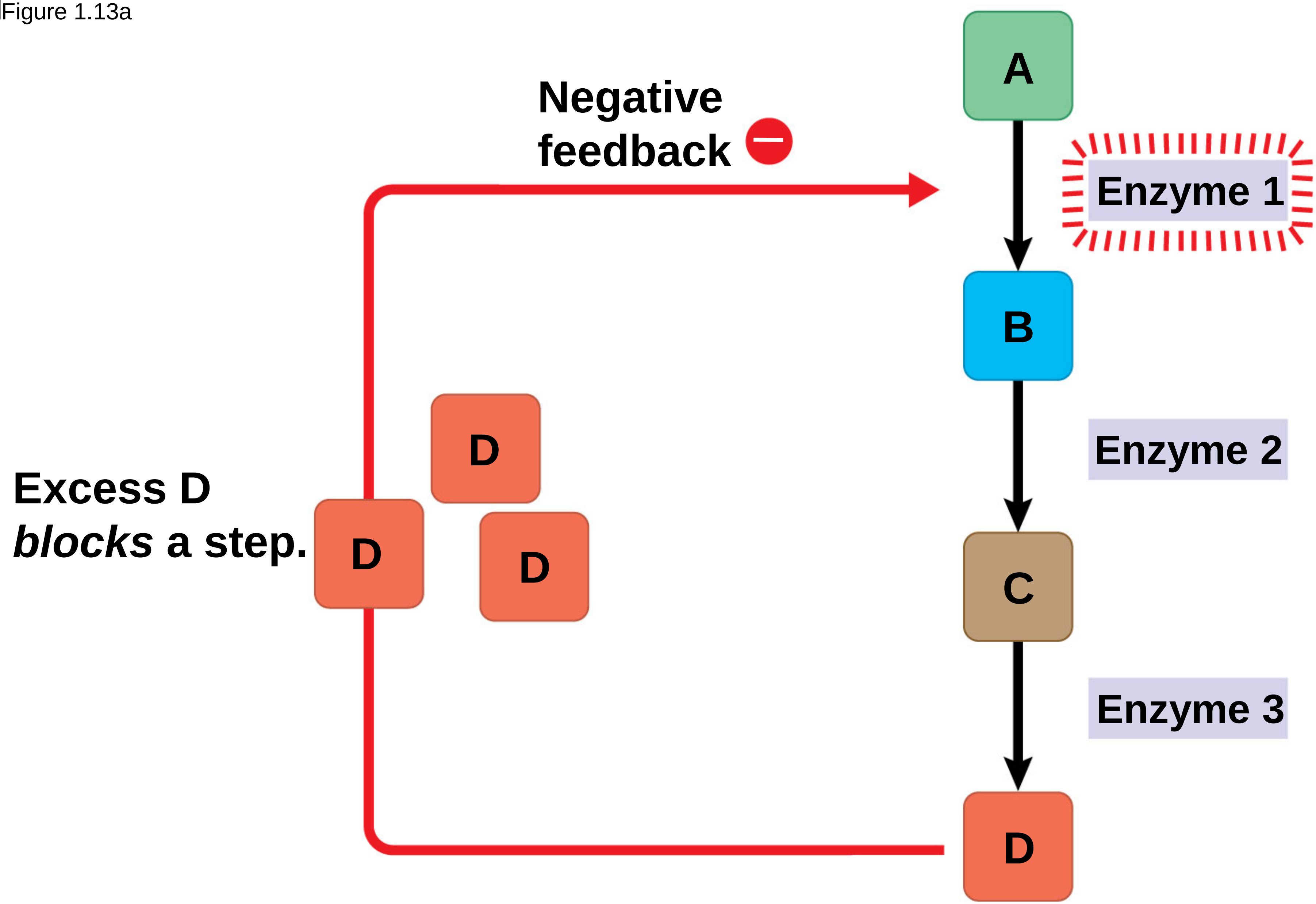


(a) Negative feedback



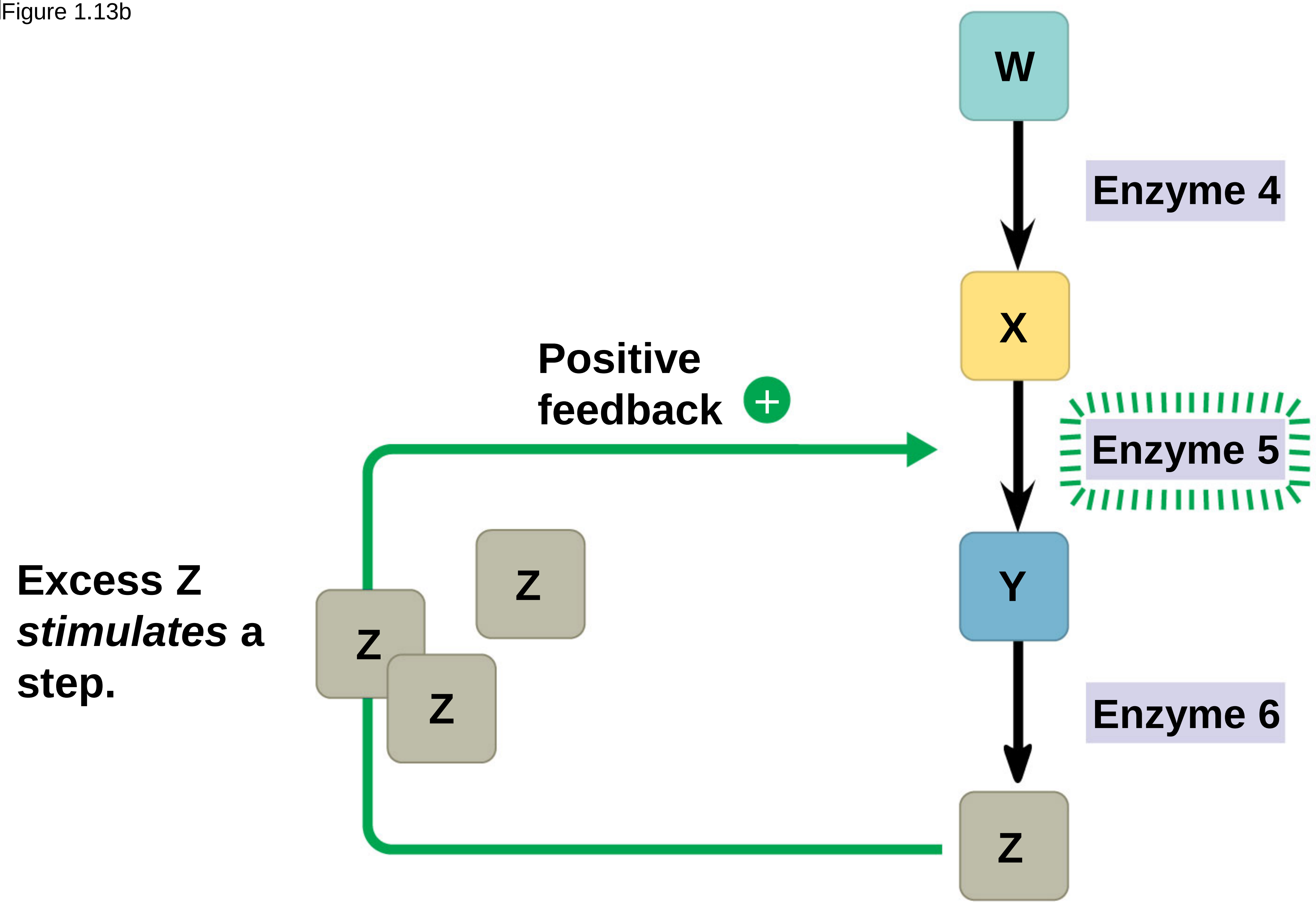
(b) Positive feedback

Figure 1.13a



(a) Negative feedback

Figure 1.13b



(b) Positive feedback

Evolution, the Overarching Theme of Biology

- Evolution makes sense of everything we know about biology
- Organisms are modified descendants of common ancestors

- Evolution explains patterns of unity and diversity in living organisms
- Similar traits among organisms are explained by descent from common ancestors
- Differences among organisms are explained by the accumulation of heritable changes

Concept 1.2: The Core Theme: Evolution accounts for the unity and diversity of life

- “Nothing in biology makes sense except in the light of evolution”—Theodosius Dobzhansky
- Evolution unifies biology at different scales of size throughout the history of life on Earth

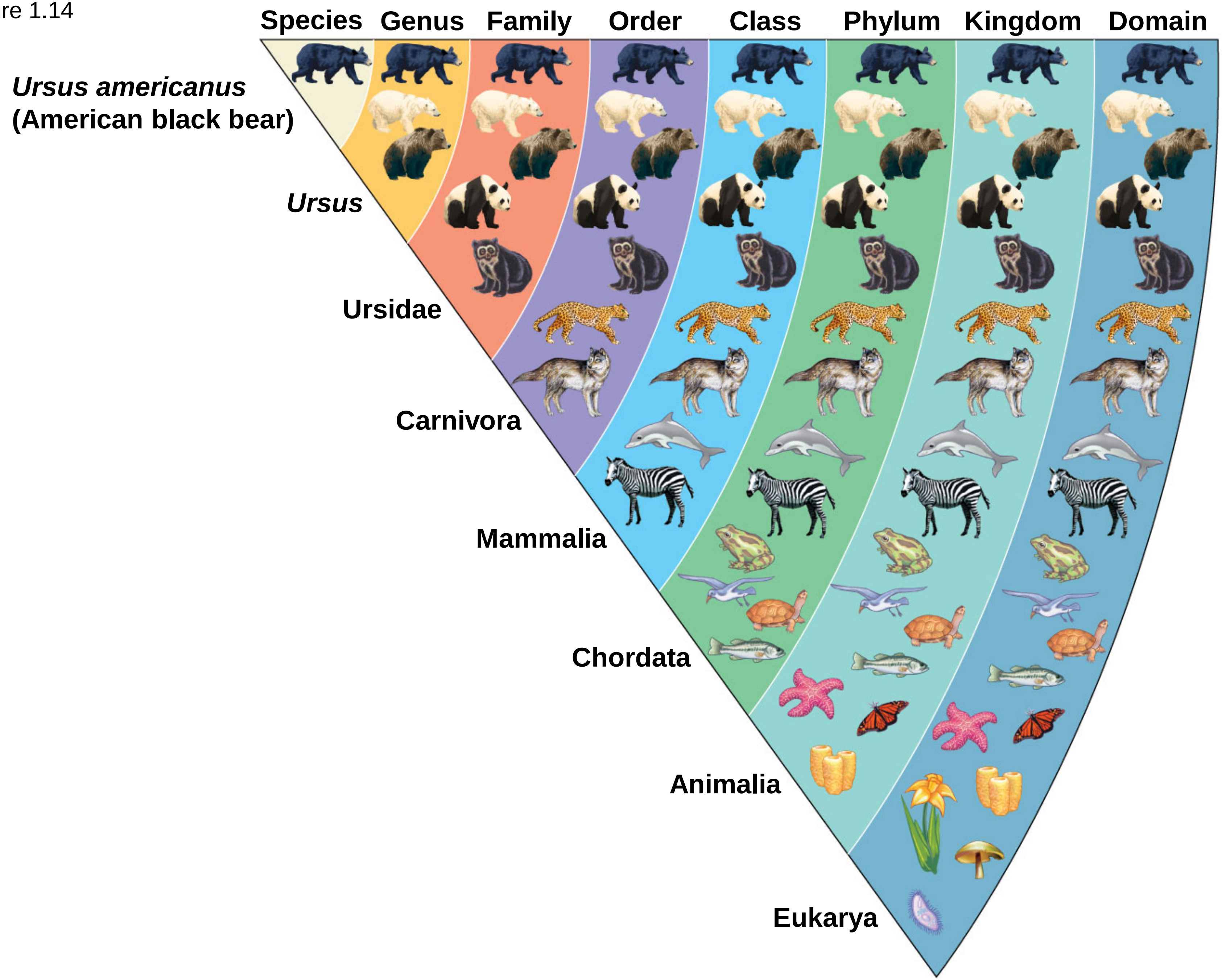
Classifying the Diversity of Life

- Approximately 1.8 million species have been identified and named to date, and thousands more are identified each year
- Estimates of the total number of species that actually exist range from 10 million to over 100 million

Grouping Species: The Basic Idea

- Taxonomy is the branch of biology that names and classifies species into groups of increasing breadth
- Domains, followed by kingdoms, are the broadest units of classification

Figure 1.14

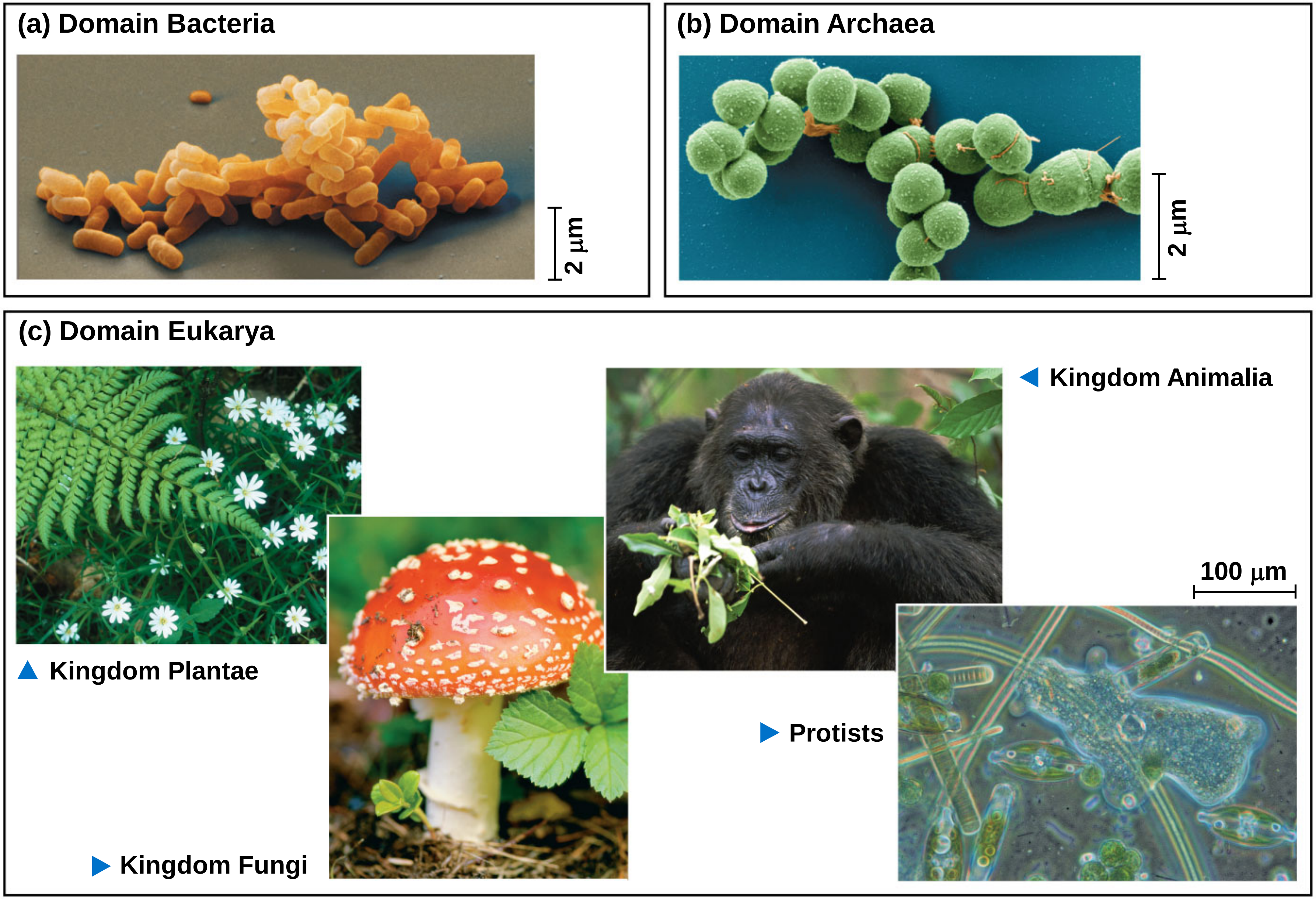


Species
Genus
Family
Order
Class
Phylum
Kingdom
Domain
Ursus americanus
(American black bear)
Ursus
Ursidae
Carnivora
Mammalia
Chordata
Animalia
Eukarya

The Three Domains of Life

- Organisms are divided into three domains
- Domain **Bacteria** and domain **Archaea** compose the prokaryotes
- Most prokaryotes are single-celled and microscopic

Figure 1.15



(a) Domain Bacteria
2 µm
(b) Domain Archaea
2 µm
(c) Domain Eukarya
Kingdom Animalia
100 µm
Kingdom Plantae
Protists
Kingdom Fungi

Figure 1.15a

(a) Domain Bacteria

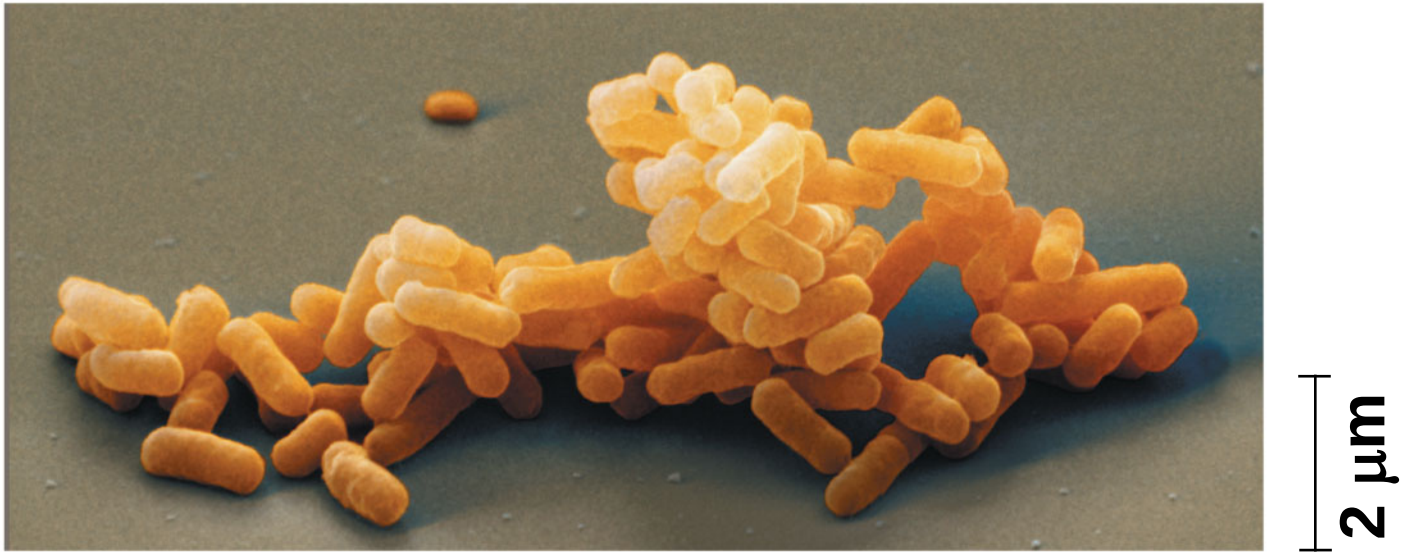


Figure 1.15b

(b) Domain Archaea

- Domain **Eukarya** includes all eukaryotic organisms
- Domain Eukarya includes three multicellular kingdoms
  - Plants, which produce their own food by photosynthesis
  - Fungi, which absorb nutrients
  - Animals, which ingest their food

- Other eukaryotic organisms were formerly grouped into the Protist kingdom, though these are now often grouped into many separate groups

Figure 1.15c

(c) Domain Eukarya

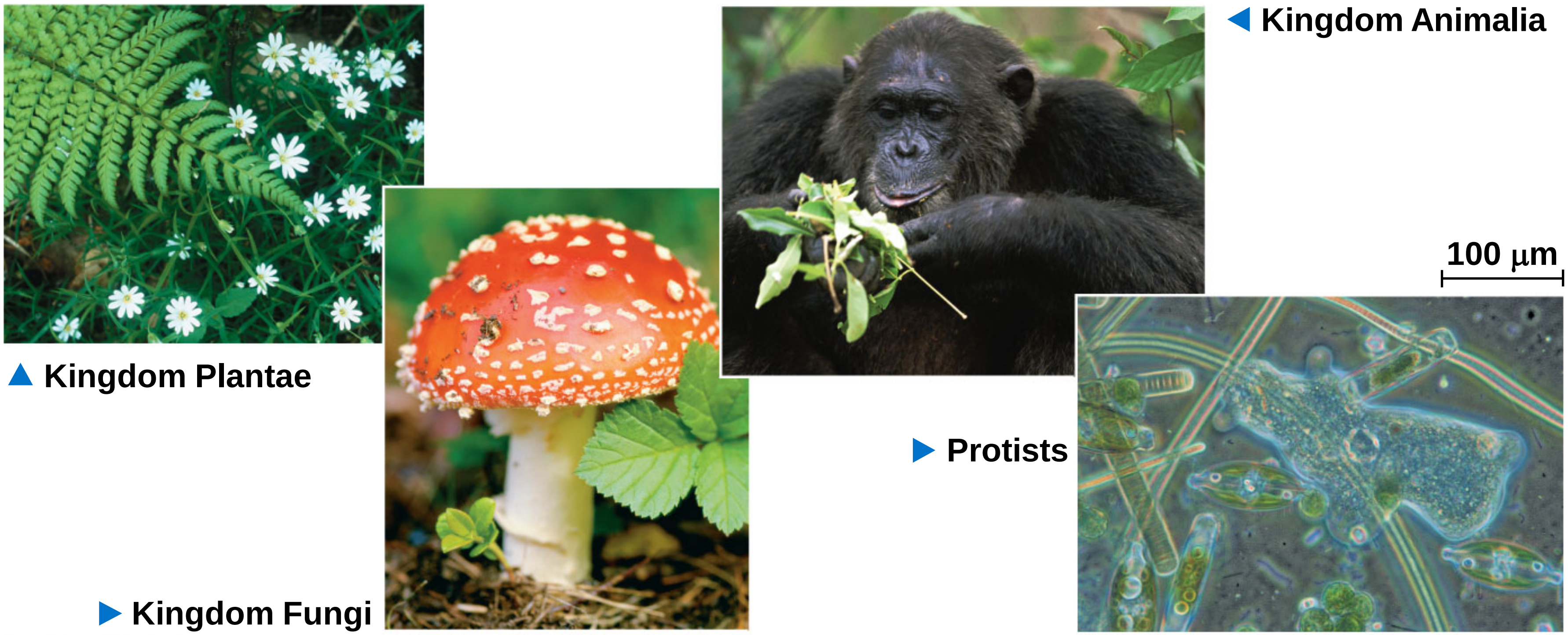


Figure 1.15ca

Kingdom Plantae

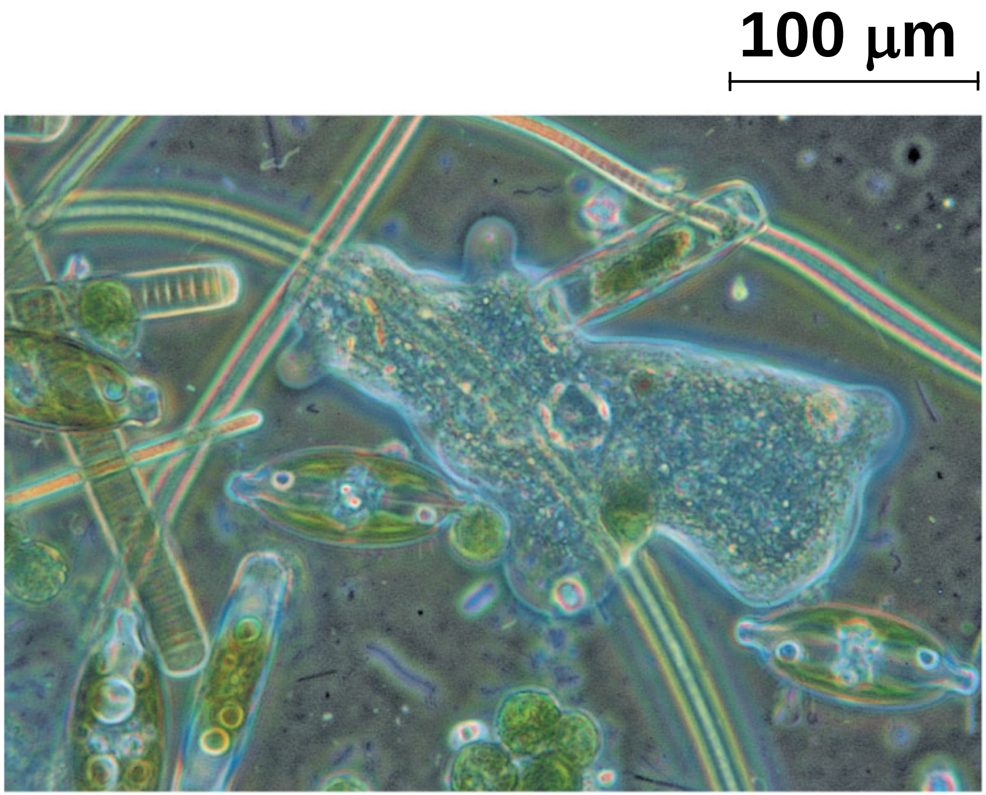
Figure 1.15cb

Kingdom Fungi

Figure 1.15cc

Kingdom Animalia

Figure 1.15cd



Protists

Unity in the Diversity of Life

- A striking unity underlies the diversity of life; for example
  - DNA is the universal genetic language common to all organisms
  - Unity is evident in many features of cell structure

Figure 1.16

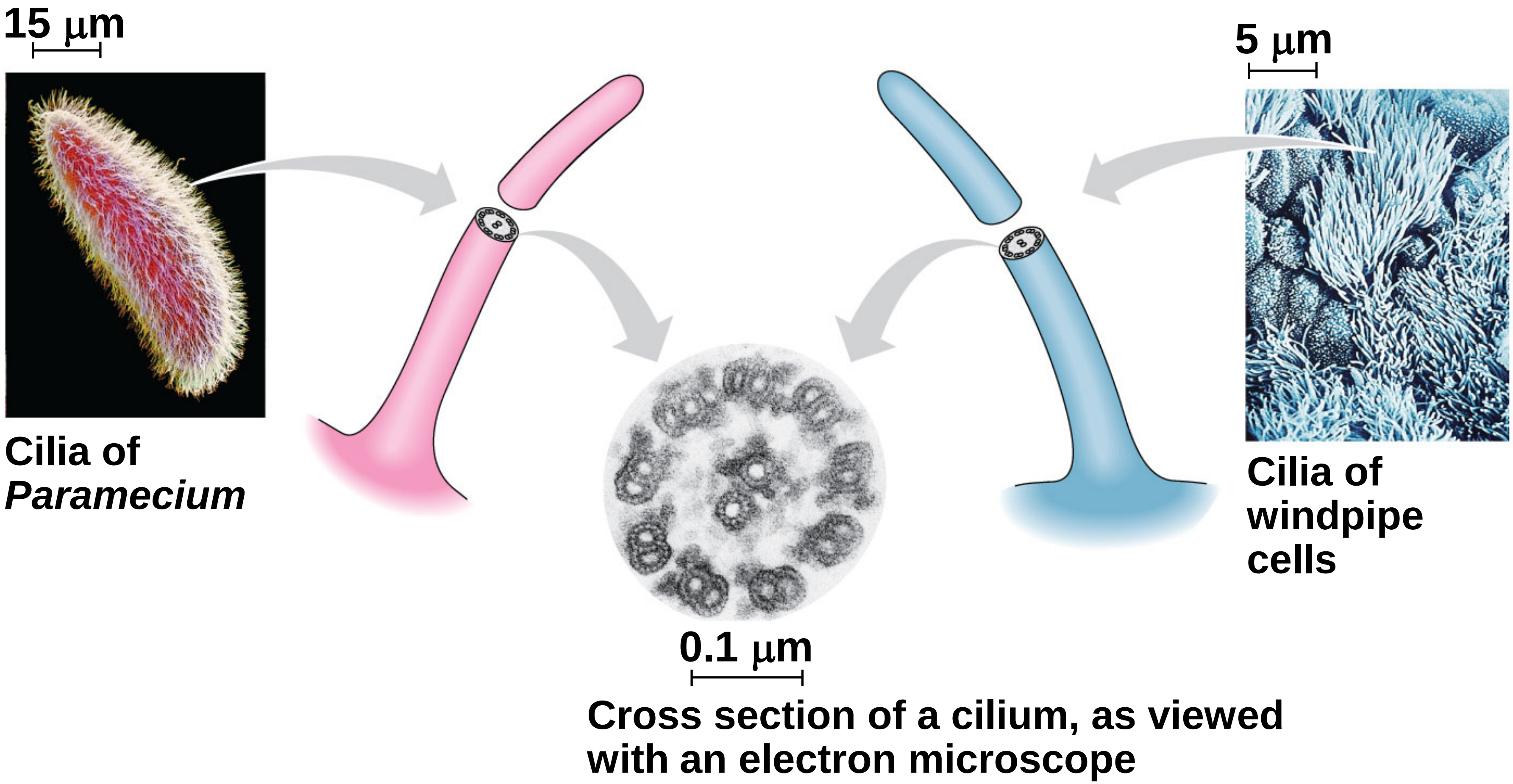
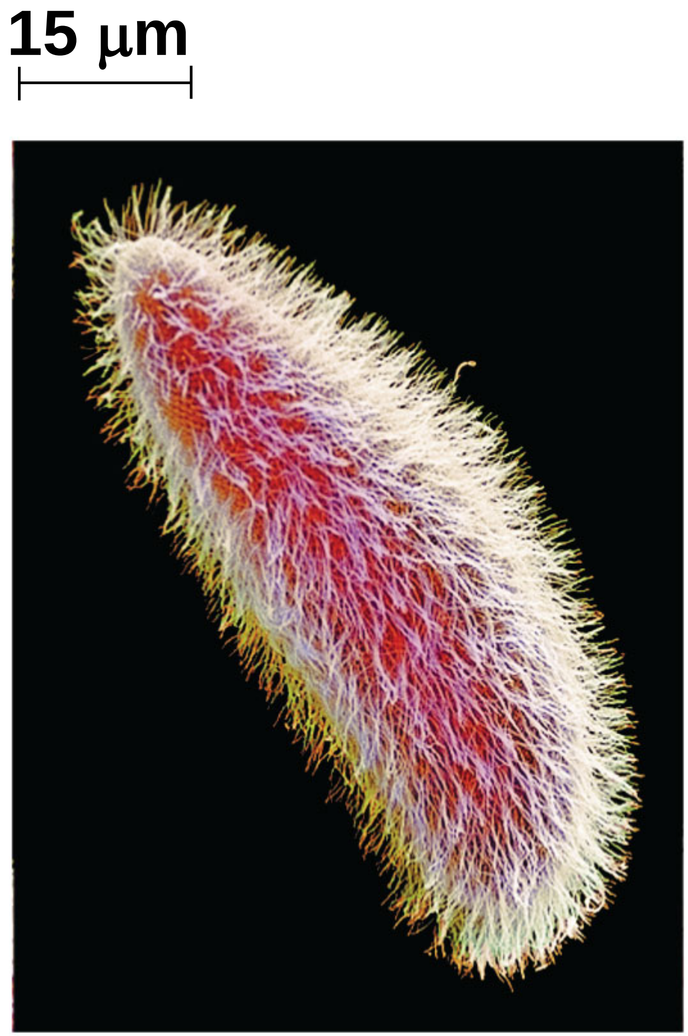

15 µm
Cilia of *Paramecium*
5 µm
Cilia of windpipe cells
0.1 µm
Cross section of a cilium, as viewed with an electron microscope

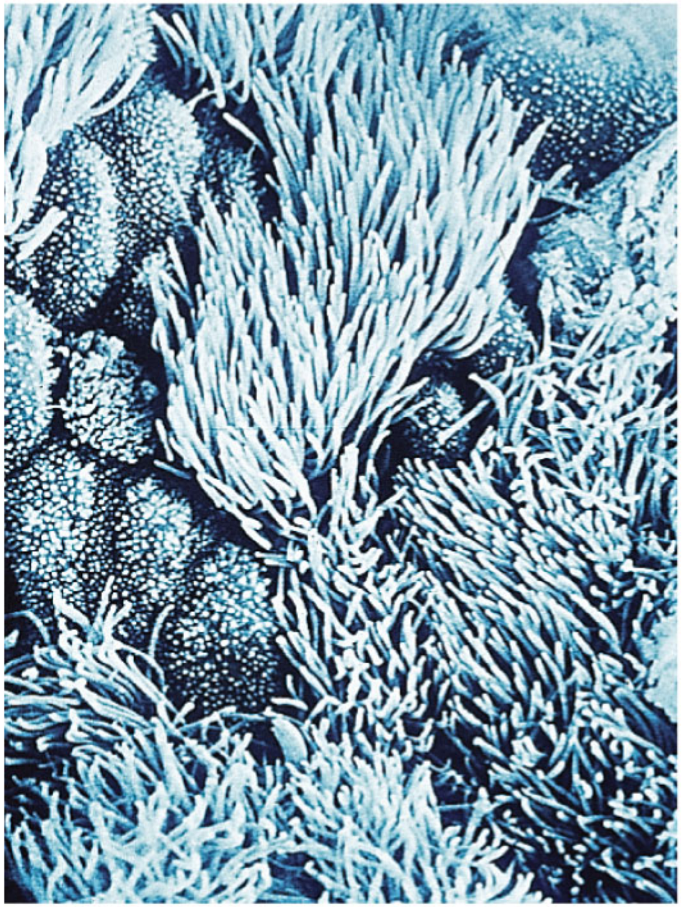
Figure 1.16a



Cilia of *Paramecium*

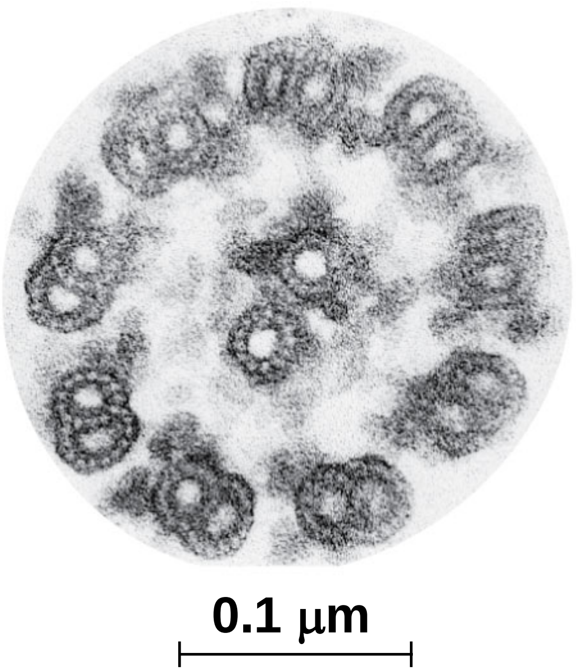
Figure 1.16b

5 µm



Cilia of windpipe cells

Figure 1.16c



Cross section of a cilium, as viewed with an electron microscope

Charles Darwin and the Theory of Natural Selection

- Fossils and other evidence document the evolution of life on Earth over billions of years

Figure 1.17

- Charles Darwin published *On the Origin of Species by Means of Natural Selection* in 1859
- Darwin made two main points
  - Species showed evidence of “descent with modification” from common ancestors
  - Natural selection is the mechanism behind “descent with modification”
- Darwin’s theory explained the duality of unity and diversity

Figure 1.18

Figure 1.19

Figure 1.19a

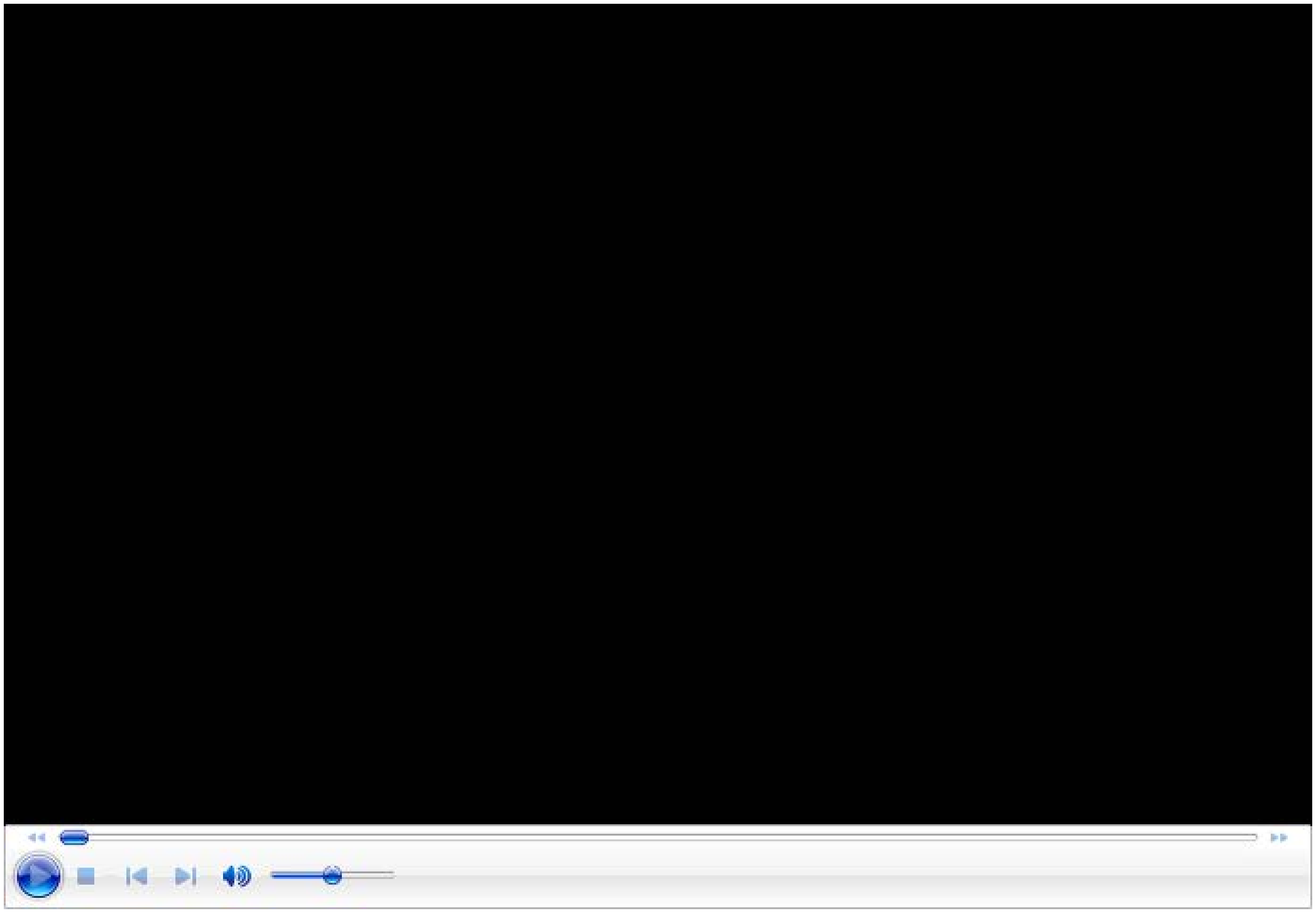
Figure 1.19b

Figure 1.19c

- Darwin observed that
  - Individuals in a population vary in their traits, many of which are heritable
  - More offspring are produced than survive, and competition is inevitable
  - Species generally suit their environment

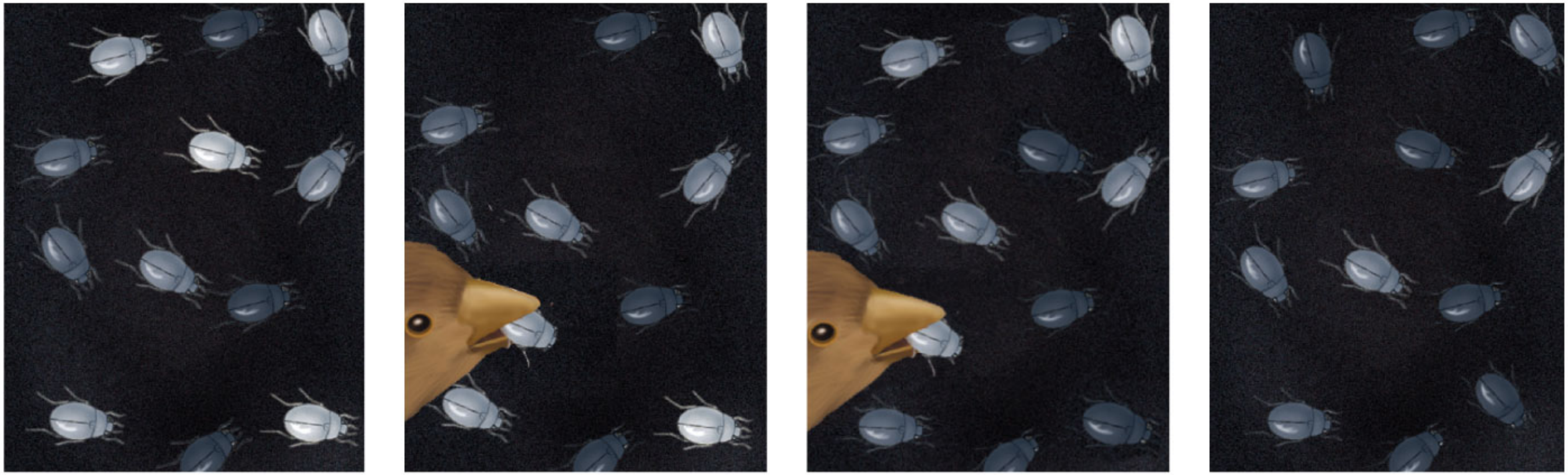
- Darwin inferred that
  - Individuals that are best suited to their environment are more likely to survive and reproduce
  - Over time, more individuals in a population will have the advantageous traits
- Evolution occurs as the unequal reproductive success of individuals

- In other words, the environment “selects” for the propagation of beneficial traits
- Darwin called this process **natural selection**



Video: Soaring Hawk

Figure 1.20



1 Population with varied inherited traits

2 Elimination of individuals with certain traits

3 Reproduction of survivors

4 Increasing frequency of traits that enhance survival and reproductive success

- Natural selection results in the adaptation of organisms to their environment
  - For example, bat wings are an example of adaptation

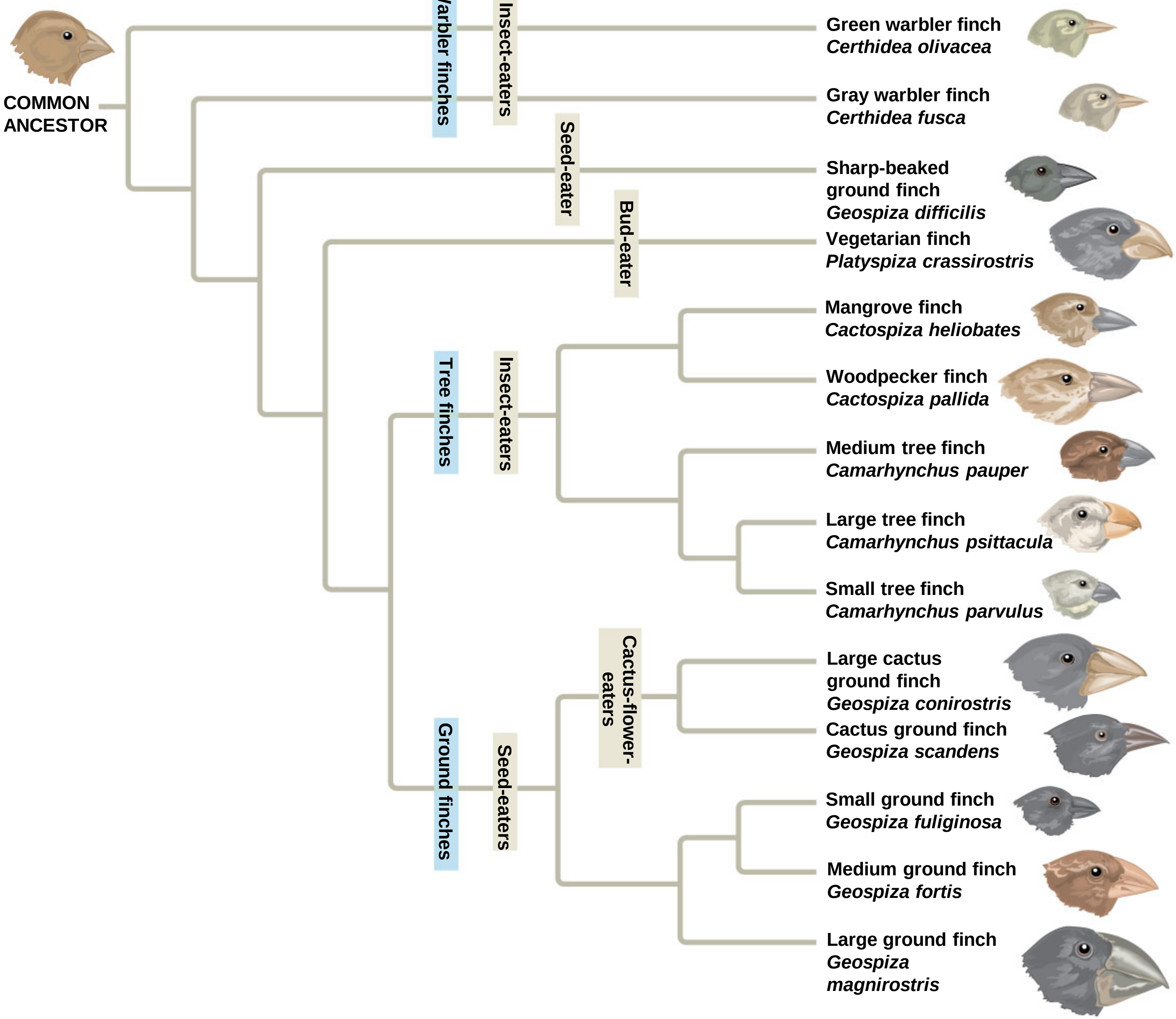
Figure 1.21

The Tree of Life

- “Unity in diversity” arises from “descent with modification”
  - For example, the forelimb of the bat, human, and horse and the whale flipper all share a common skeletal architecture
- Fossils provide additional evidence of anatomical unity from descent with modification

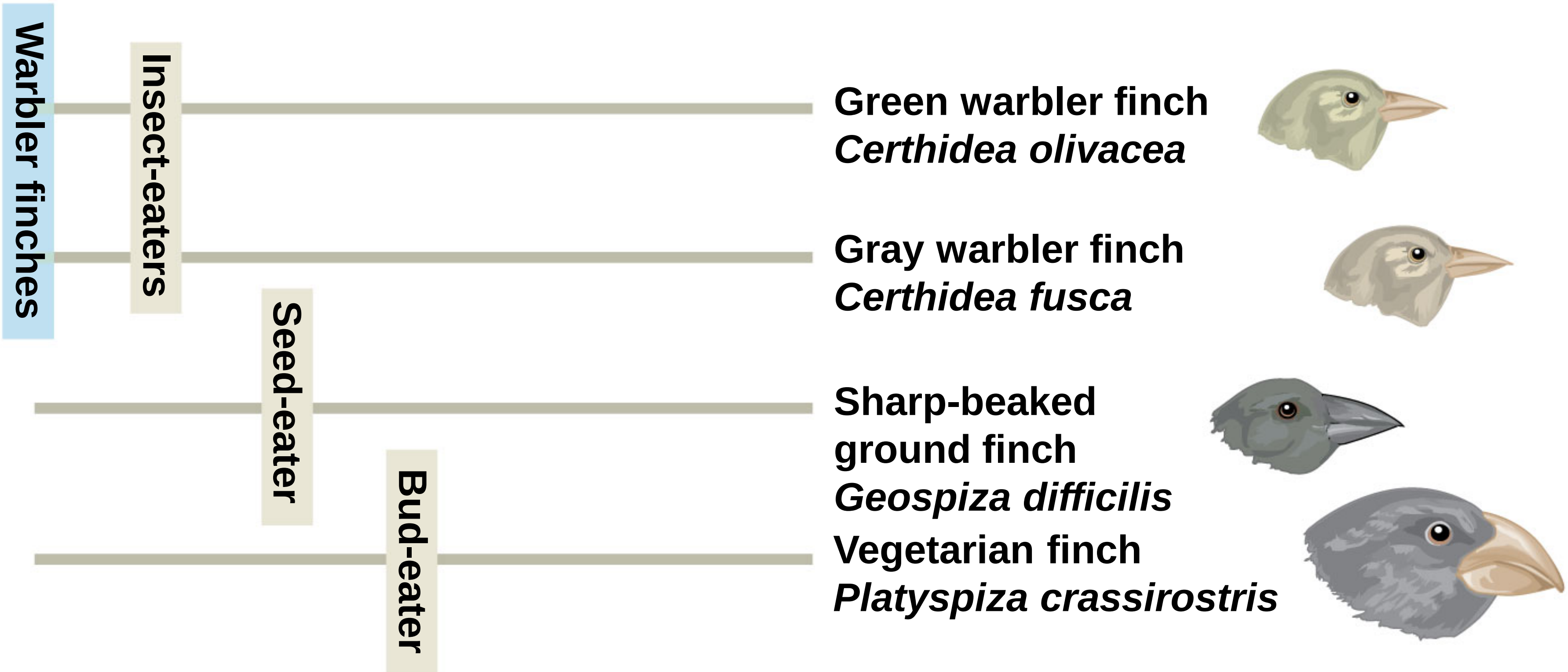
- Darwin proposed that natural selection could cause an ancestral species to give rise to two or more descendent species
  – For example, the finch species of the Galápagos Islands are descended from a common ancestor
- Evolutionary relationships are often illustrated with treelike diagrams that show ancestors and their descendants

Figure 1.22



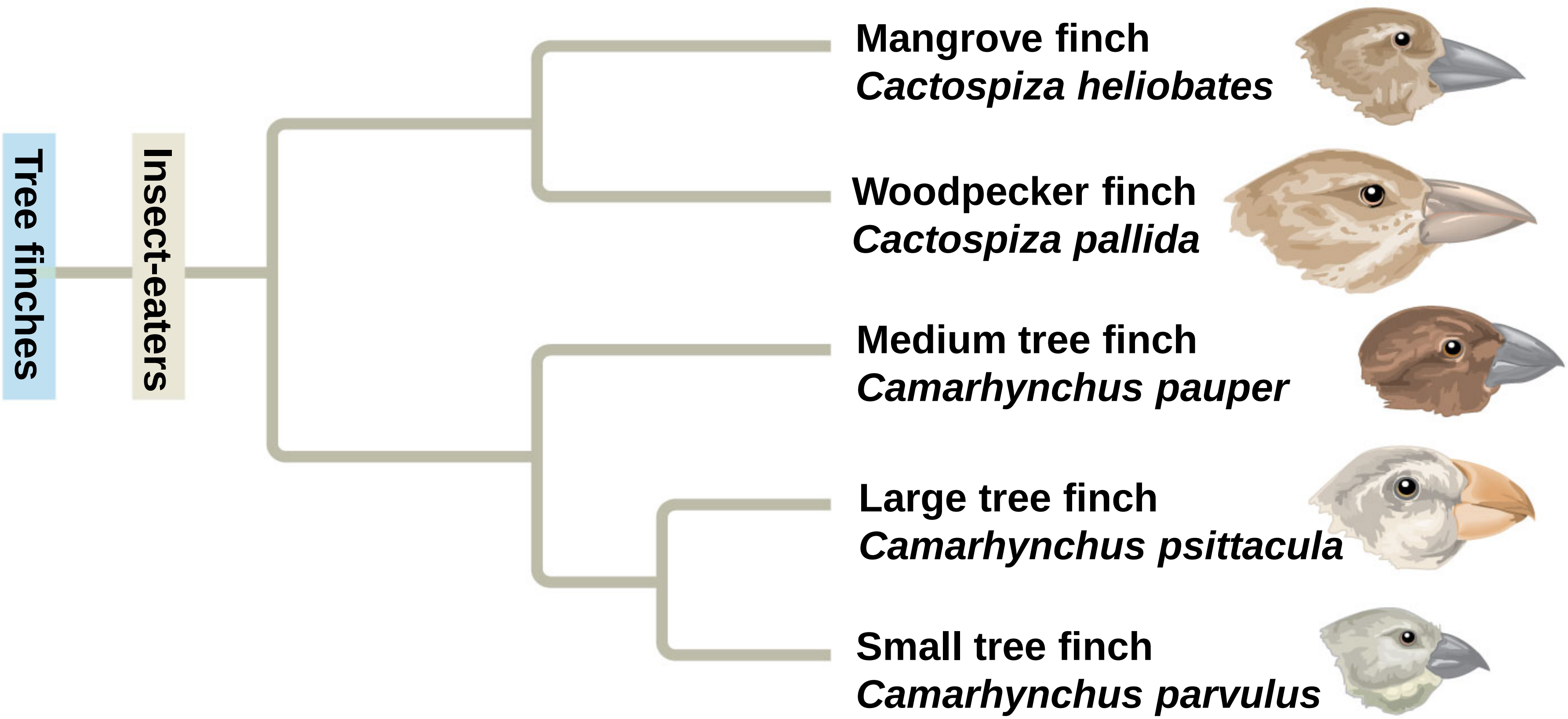
COMMON ANCESTOR
Warbler finches
Insect-eaters
Seed-eater
Bud-eater
Tree finches
Insect-eaters
Ground finches
Seed-eaters
Cactus-flower-eaters
Green warbler finch
Certhidea olivacea
Gray warbler finch
Certhidea fusca
Sharp-beaked ground finch
Geospiza difficilis
Vegetarian finch
Platyspiza crassirostris
Mangrove finch
Cactospiza heliobates
Woodpecker finch
Cactospiza pallida
Medium tree finch
Camarhynchus pauper
Large tree finch
Camarhynchus psittacula
Small tree finch
Camarhynchus parvulus
Large cactus ground finch
Geospiza conirostris
Cactus ground finch
Geospiza scandens
Small ground finch
Geospiza fuliginosa
Medium ground finch
Geospiza fortis
Large ground finch
Geospiza magnirostris

Figure 1.22a



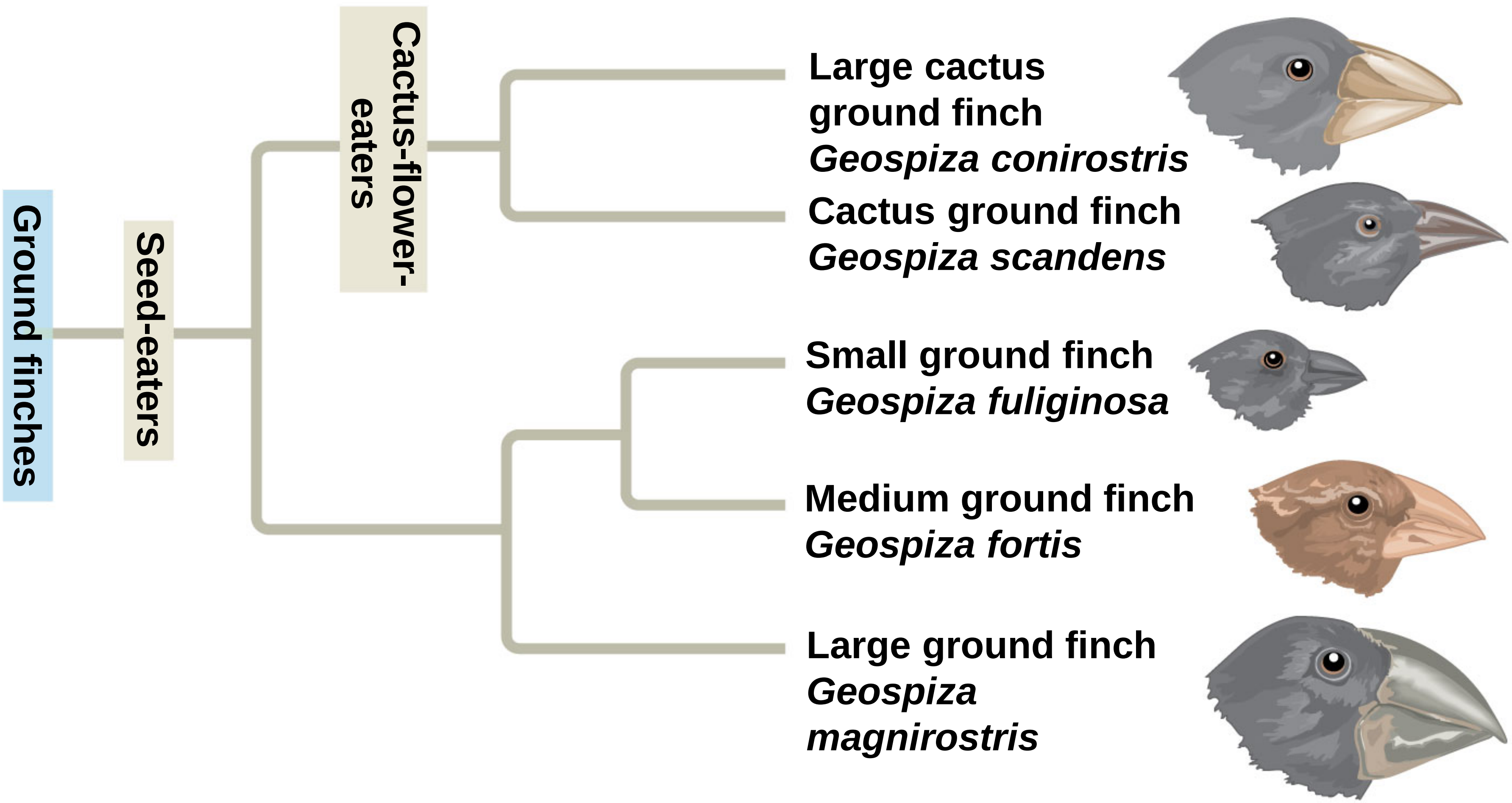
Warbler finches
Insect-eaters
Seed-eater
Bud-eater
Green warbler finch
Certhidea olivacea
Gray warbler finch
Certhidea fusca
Sharp-beaked ground finch
Geospiza difficilis
Vegetarian finch
Platyspiza crassirostris

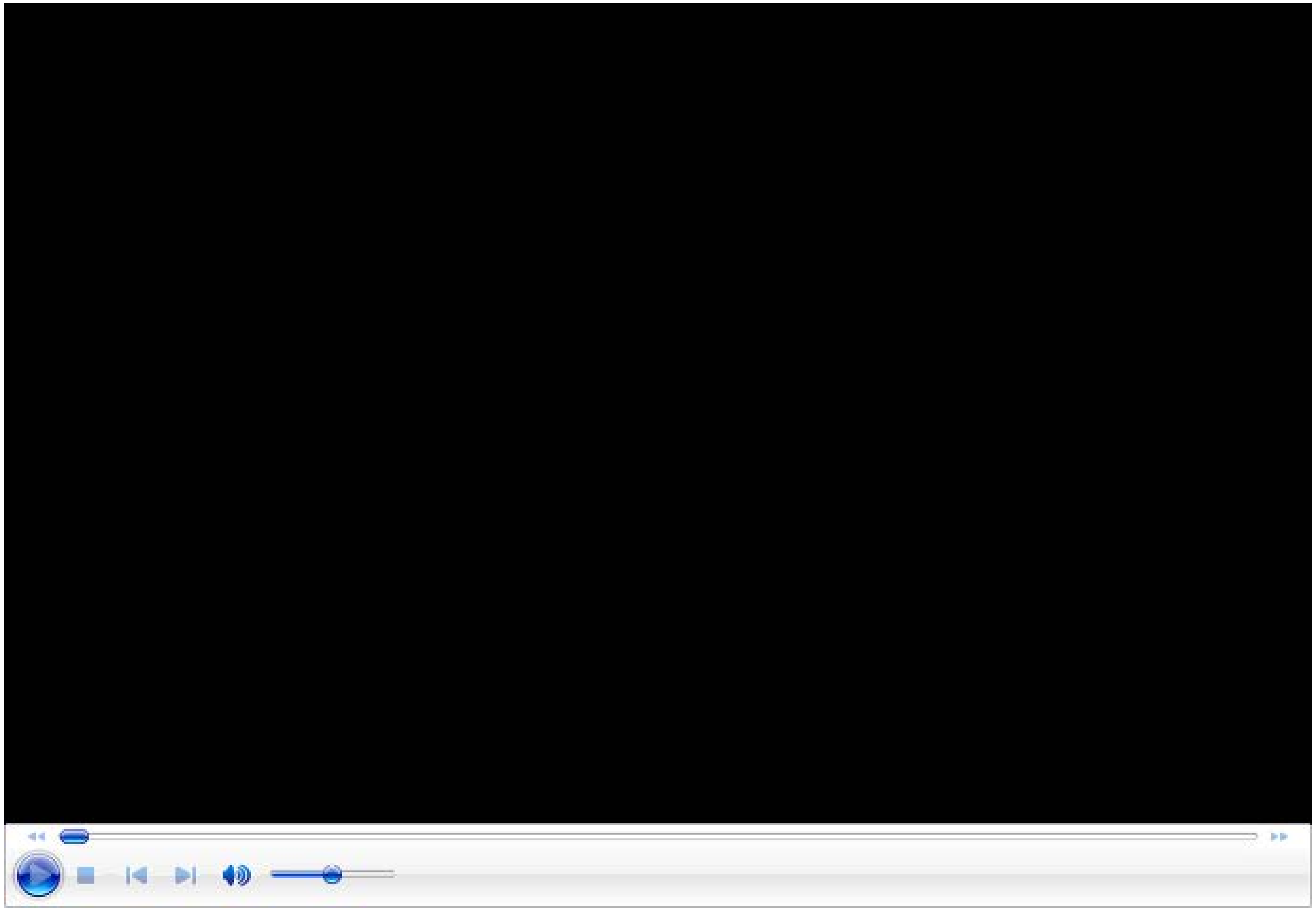
Figure 1.22b



Tree finches
Insect-eaters
Mangrove finch
Cactospiza heliobates
Woodpecker finch
Cactospiza pallida
Medium tree finch
Camarhynchus pauper
Large tree finch
Camarhynchus psittacula
Small tree finch
Camarhynchus parvulus

Figure 1.22c


Ground finches
Seed-eaters
Cactus-flower-eaters
Large cactus ground finch
Geospiza conirostris
Cactus ground finch
Geospiza scandens
Small ground finch
Geospiza fuliginosa
Medium ground finch
Geospiza fortis
Large ground finch
Geospiza magnirostris



Video: Albatross Courtship Ritual

Video: Blue-Footed Booby Courtship Ritual

Video: Galápagos Islands Overview

Video: Galápagos Marine Iguana

Video: Galápagos Sea Lion

Video: Galápagos Tortoise

Concept 1.3: In studying nature, scientists make observations and then form and test hypotheses

- The word **science** is derived from Latin and means “to know”
- **Inquiry** is the search for information and explanation
- The scientific process includes making observations, forming logical hypotheses, and testing them

Making Observations

- Biologists describe natural structures and processes
- This approach is based on observation and the analysis of data

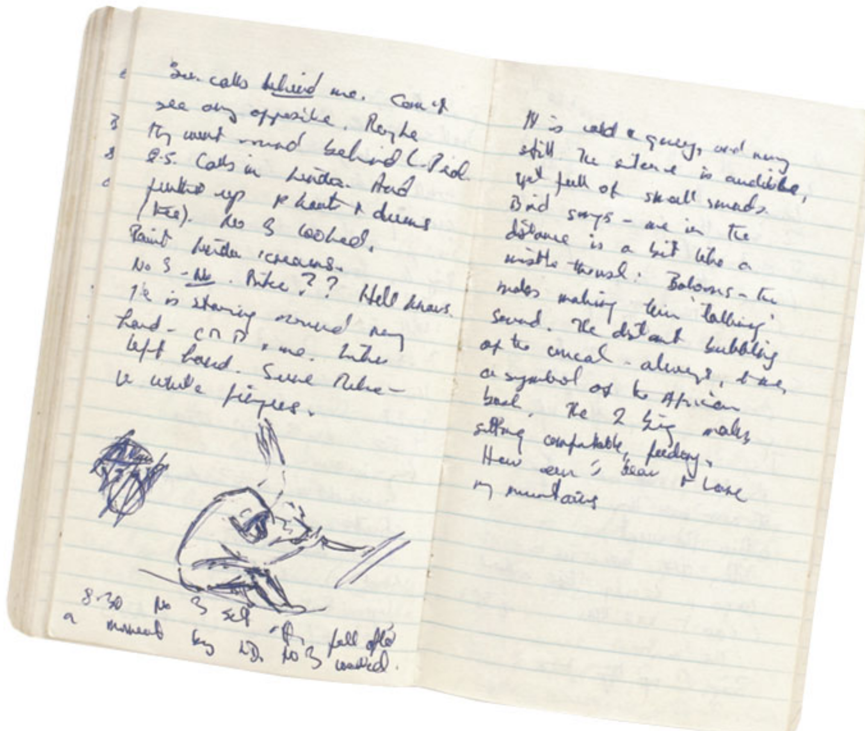
Types of Data

- **Data** are recorded observations or items of information; these fall into two categories
  - Qualitative data, or descriptions rather than measurements
    - For example, Jane Goodall's observations of chimpanzee behavior
  - Quantitative data, or recorded measurements, which are sometimes organized into tables and graphs

Figure 1.23

Figure 1.23a

Figure 1.23b



Inductive Reasoning

- **Inductive reasoning** draws conclusions through the logical process of induction
- Repeating specific observations can lead to important generalizations
  - For example, “the sun always rises in the east”

Forming and Testing Hypotheses

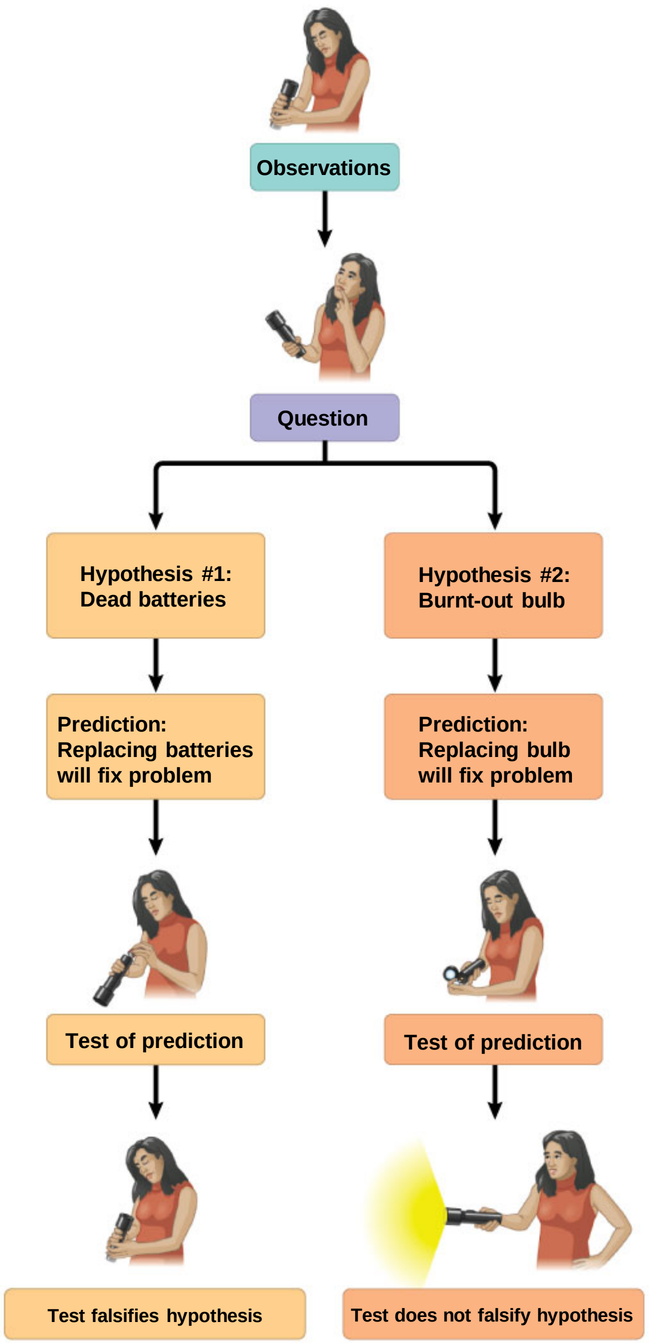
- Observations and inductive reasoning can lead us to ask questions and propose hypothetical explanations called hypotheses

The Role of Hypotheses in Inquiry

- A **hypothesis** is a tentative answer to a well-framed question
- A scientific hypothesis leads to predictions that can be tested by observation or experimentation

- For example,
  - – Observation: Your flashlight doesn’t work
  - – Question: Why doesn’t your flashlight work?
  - – Hypothesis 1: The batteries are dead
  - – Hypothesis 2: The bulb is burnt out
- Both these hypotheses are testable

Figure 1.24



Observations
Question
Hypothesis #1:
Dead batteries
Hypothesis #2:
Burnt-out bulb
Prediction:
Replacing batteries
will fix problem
Prediction:
Replacing bulb
will fix problem
Test of prediction
Test of prediction
Test falsifies hypothesis
Test does not falsify hypothesis

Figure 1.24a

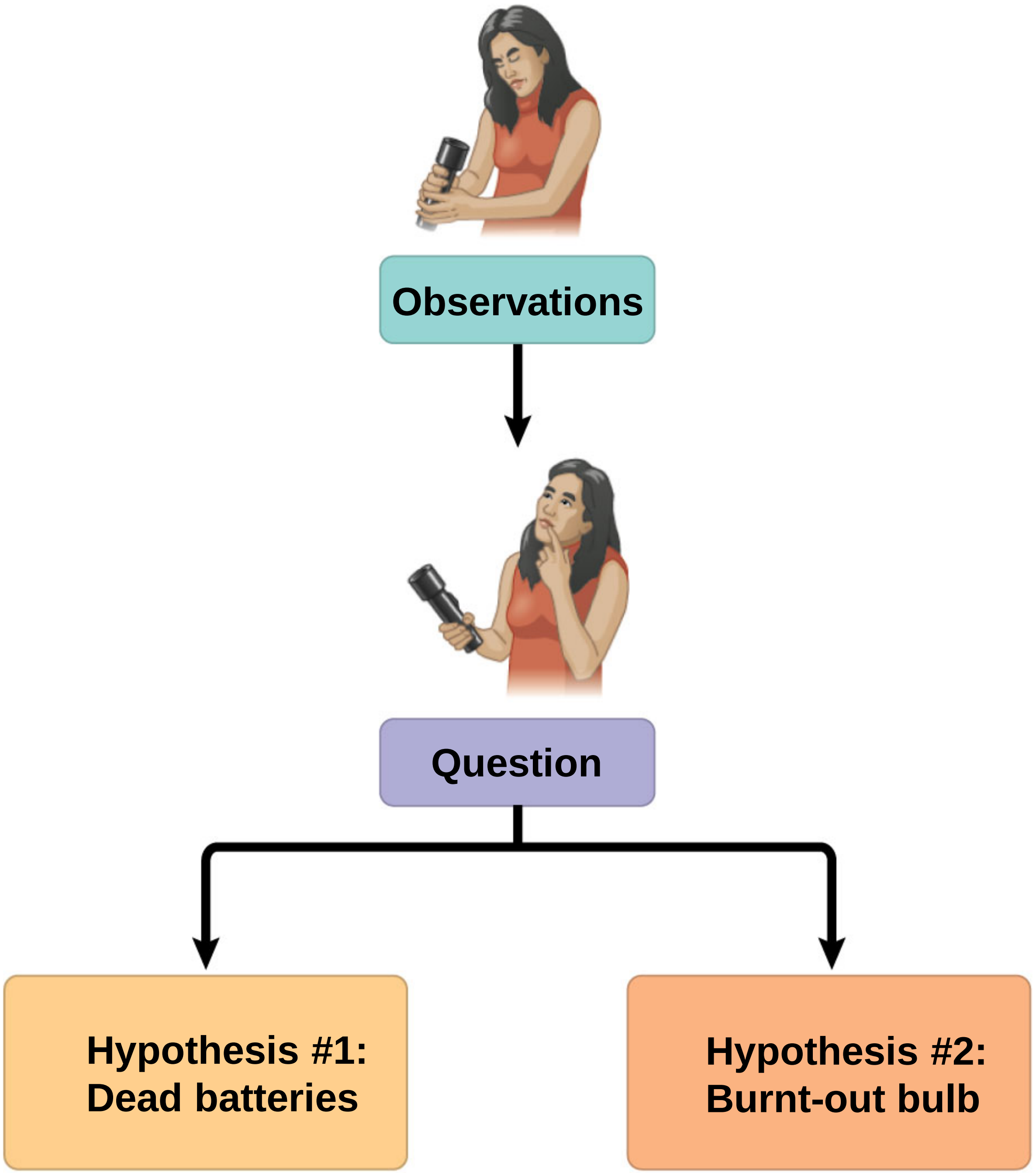
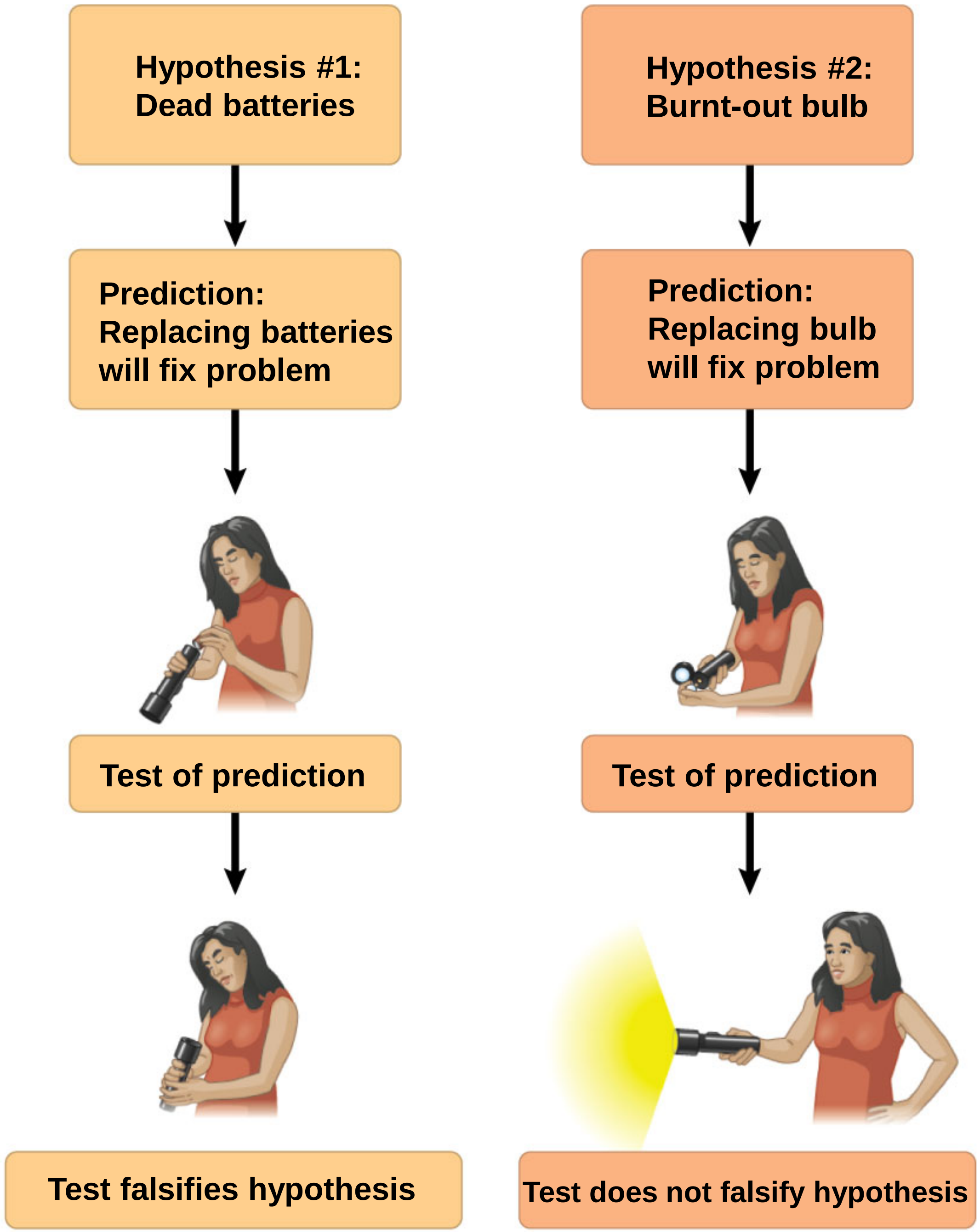

Observations
Question
Hypothesis #1:
Dead batteries
Hypothesis #2:
Burnt-out bulb

Figure 1.24b


Hypothesis #1:
Dead batteries
Hypothesis #2:
Burnt-out bulb
Prediction:
Replacing batteries
will fix problem
Prediction:
Replacing bulb
will fix problem
Test of prediction
Test of prediction
Test falsifies hypothesis
Test does not falsify hypothesis

Deductive Reasoning and Hypothesis Testing

- **Deductive reasoning** uses general premises to make specific predictions
- For example, if organisms are made of cells (premise 1), and humans are organisms (premise 2), then humans are composed of cells (deductive prediction)

- Hypothesis-based science often makes use of two or more alternative hypotheses
- Failure to falsify a hypothesis does not prove that hypothesis
  - For example, you replace your flashlight bulb, and it now works; this supports the hypothesis that your bulb was burnt out, but does not prove it (perhaps the first bulb was inserted incorrectly)

Questions That Can and Cannot Be Addressed by Science

- A hypothesis must be testable and falsifiable
  - For example, a hypothesis that ghosts fooled with the flashlight cannot be tested
- Supernatural and religious explanations are outside the bounds of science

The Flexibility of the Scientific Method

- The scientific method is an idealized process of inquiry
- Hypothesis-based science is based on the "textbook" scientific method but rarely follows all the ordered steps

A Case Study in Scientific Inquiry: Investigating Mimicry in Snake Populations

- Many poisonous species are brightly colored, which warns potential predators
- Mimics are harmless species that closely resemble poisonous species
- Henry Bates hypothesized that this mimicry evolved in harmless species as an evolutionary adaptation that reduces their chances of being eaten

- This hypothesis was tested with the venomous eastern coral snake and its mimic the nonvenomous scarlet kingsnake
- Both species live in the Carolinas, but the kingsnake is also found in regions without venomous coral snakes
- If predators inherit an avoidance of the coral snake's coloration, then the colorful kingsnake will be attacked less often in the regions where coral snakes are present

Figure 1.25

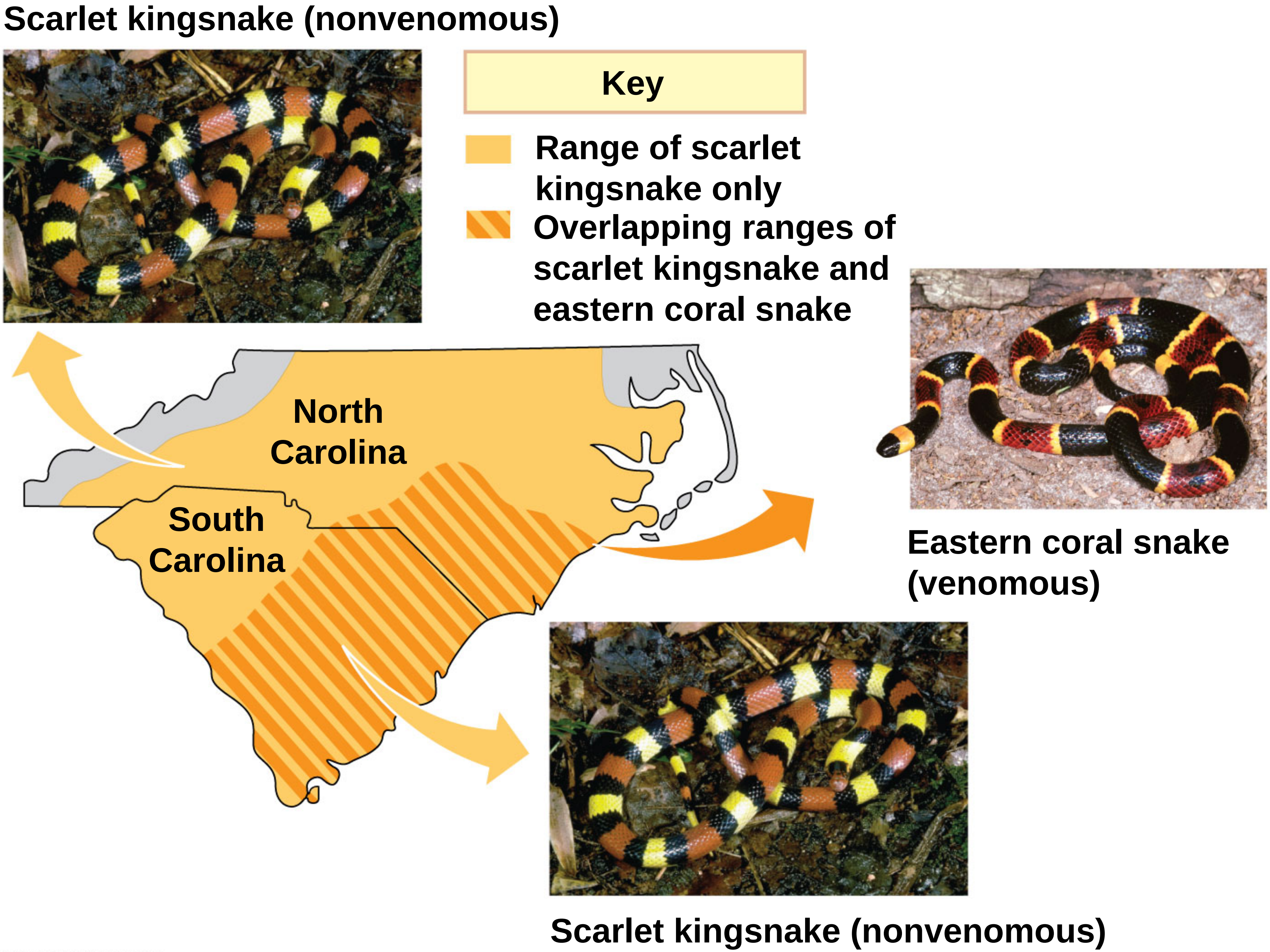

Scarlet kingsnake (nonvenomous)
Key
Range of scarlet kingsnake only
Overlapping ranges of scarlet kingsnake and eastern coral snake
North Carolina
South Carolina
Eastern coral snake (venomous)
Scarlet kingsnake (nonvenomous)

Figure 1.25a

Scarlet kingsnake

Figure 1.25b

Eastern coral snake (venomous)

Field Experiments with Artificial Snakes

- To test this mimicry hypothesis, researchers made hundreds of artificial snakes:
  - An experimental group resembling kingsnakes
  - A control group resembling plain brown snakes
- Equal numbers of both types were placed at field sites, including areas without poisonous coral snakes

Figure 1.26

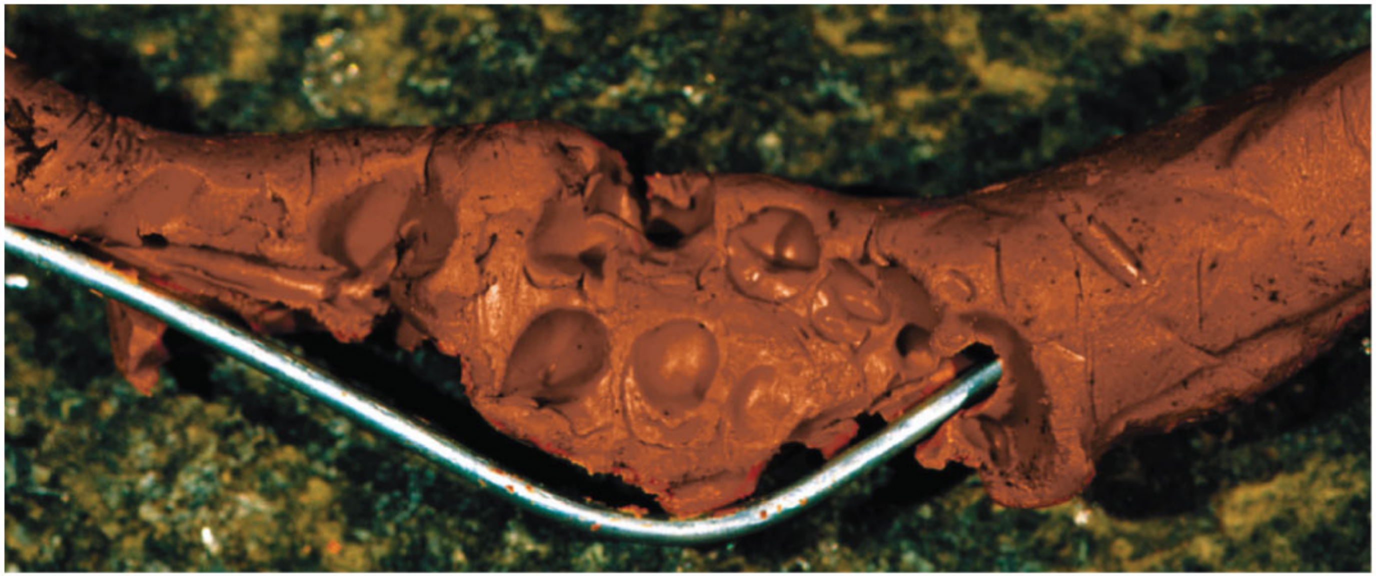
(a) Artificial kingsnake

(b) Brown artificial snake that has been attacked

Figure 1.26a

(a) Artificial kingsnake

Figure 1.26b

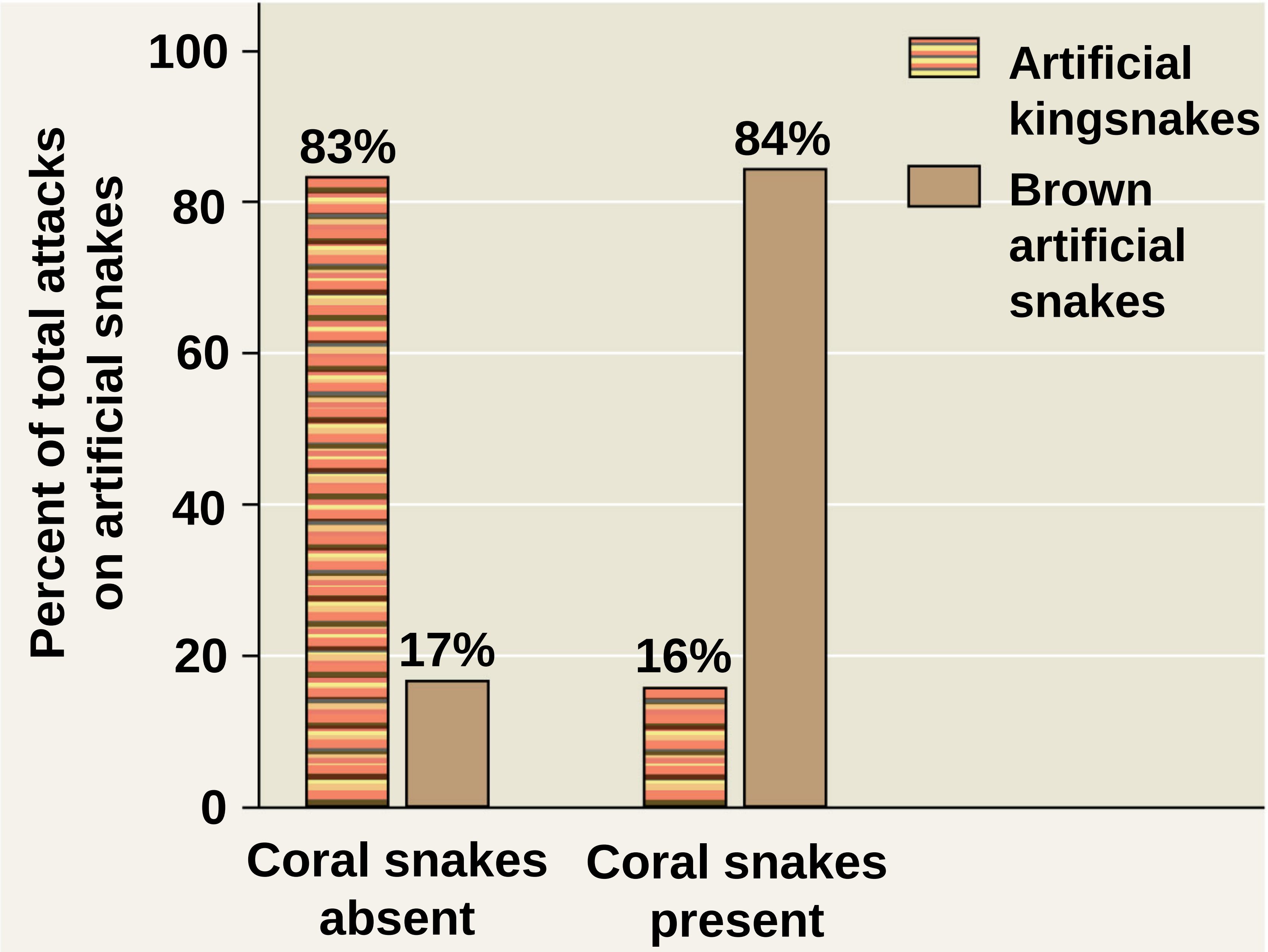


(b) Brown artificial snake that has been attacked

- After four weeks, the scientists retrieved the artificial snakes and counted bite or claw marks
- The data fit the predictions of the mimicry hypothesis: the ringed snakes were attacked less frequently in the geographic region where coral snakes were found

Figure 1.27

RESULTS



Experimental Controls and Repeatability

- A **controlled experiment** compares an experimental group (the artificial kingsnakes) with a control group (the artificial brown snakes)
- Ideally, only the variable of interest (the effect of coloration on the behavior of predators) differs between the control and experimental groups
- A controlled experiment means that control groups are used to cancel the effects of unwanted variables
- A controlled experiment does not mean that all unwanted variables are kept constant

- In science, observations and experimental results must be repeatable

Theories in Science

- In the context of science, a **theory** is
  - Broader in scope than a hypothesis
  - General, and can lead to new testable hypotheses
  - Supported by a large body of evidence in comparison to a hypothesis

Concept 1.4: Science benefits from a cooperative approach and diverse viewpoints

- Most scientists work in teams, which often include graduate and undergraduate students
- Good communication is important in order to share results through seminars, publications, and websites

Figure 1.28

Building on the Work of Others

- Scientists check each others' claims by performing similar experiments
- It is not unusual for different scientists to work on the same research question
- Scientists cooperate by sharing data about **model organisms** (e.g., the fruit fly *Drosophila melanogaster*)

Science, Technology, and Society

- The goal of science is to understand natural phenomena
- The goal of **technology** is to apply scientific knowledge for some specific purpose
- Science and technology are interdependent
- Biology is marked by "discoveries," while technology is marked by "inventions"

- The combination of science and technology has dramatic effects on society
  – For example, the discovery of DNA by James Watson and Francis Crick allowed for advances in DNA technology such as testing for hereditary diseases
- Ethical issues can arise from new technology, but have as much to do with politics, economics, and cultural values as with science and technology

Figure 1.29

The Value of Diverse Viewpoints in Science

- Many important inventions have occurred where different cultures and ideas mix
  - For example, the printing press relied on innovations from China (paper and ink) and Europe (mass production in mills)
- Science benefits from diverse views from different racial and ethnic groups, and from both women and men

Figure 1.UN01

Figure 1.UN02

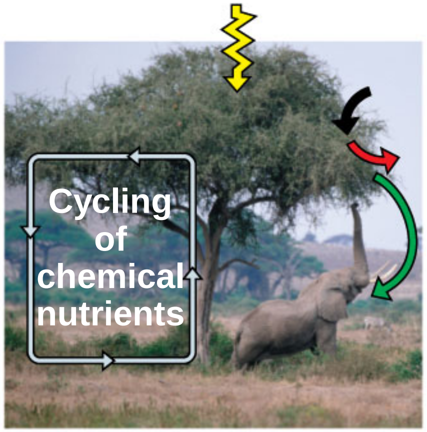


Figure 1.UN03

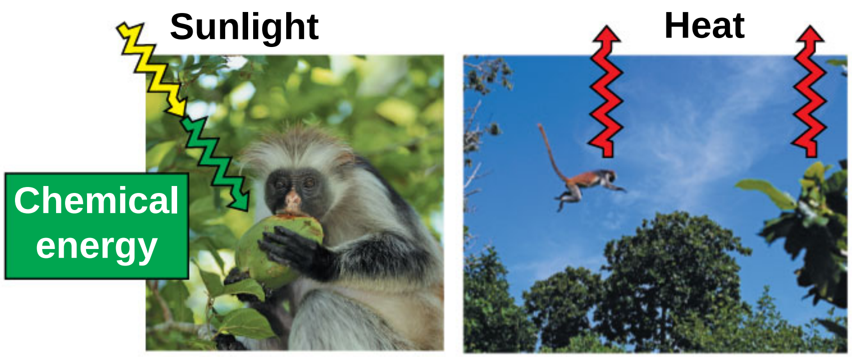


Figure 1.UN04

Figure 1.UN05

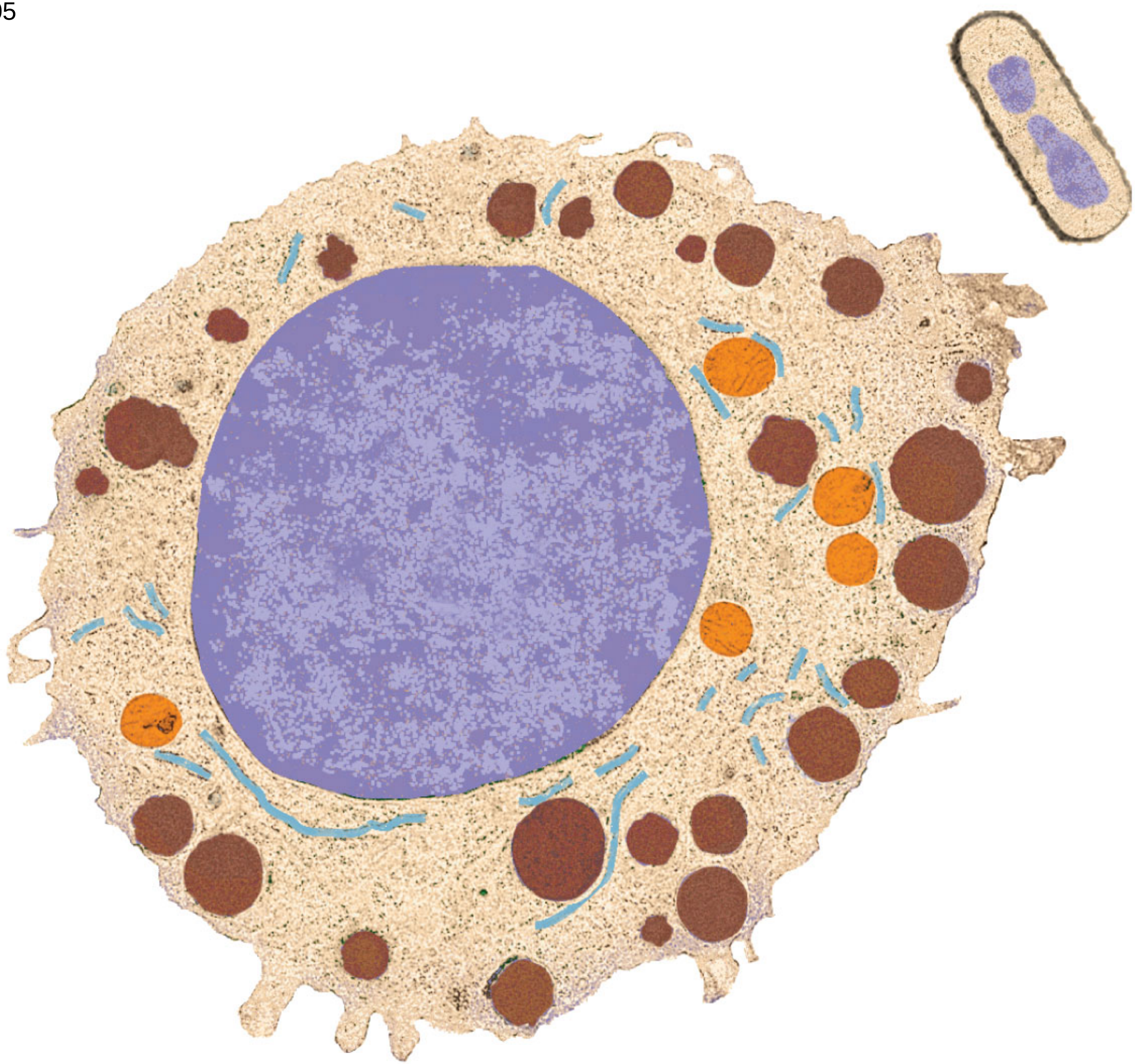


Figure 1.UN06

Figure 1.UN07

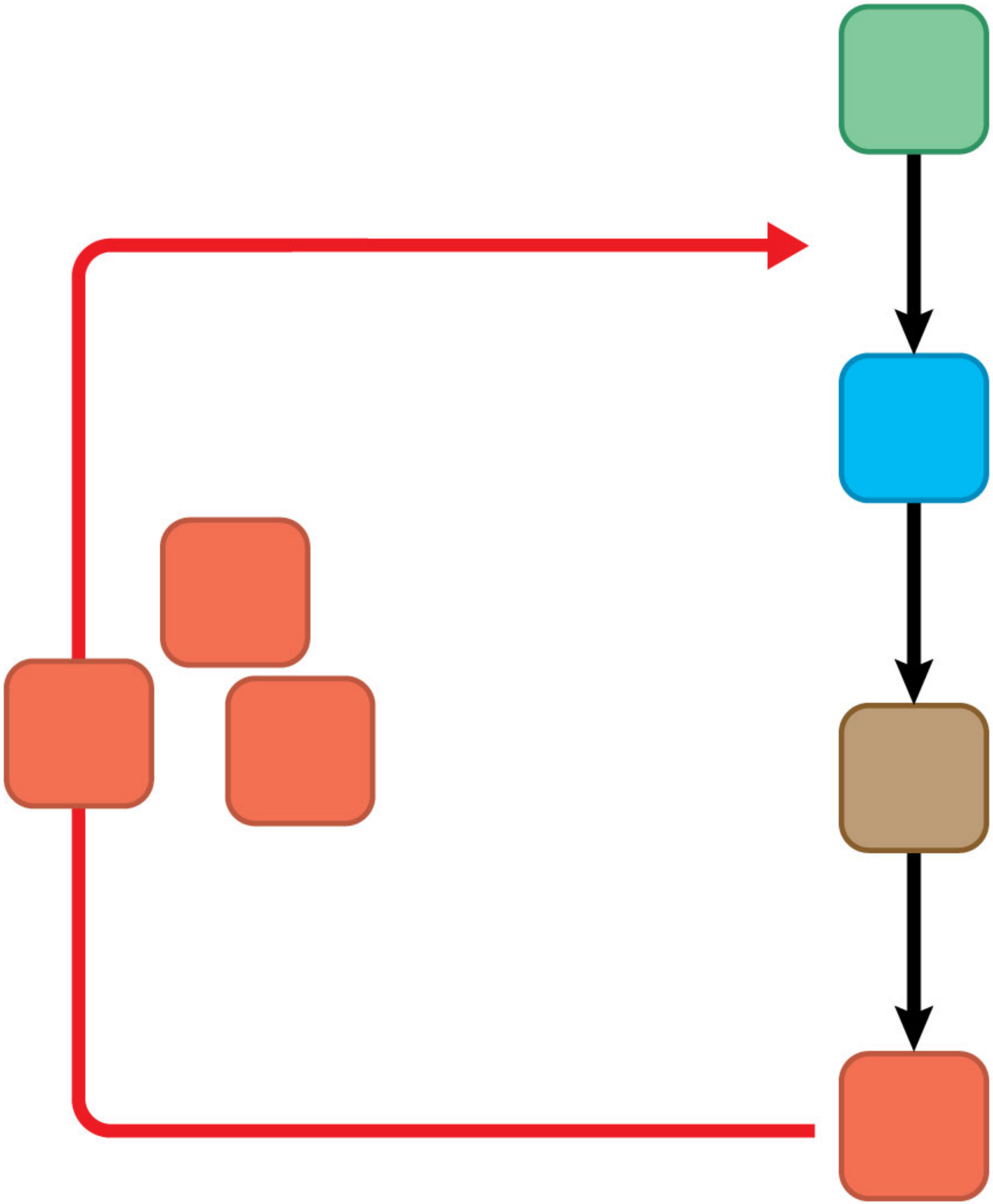


Figure 1.UN08

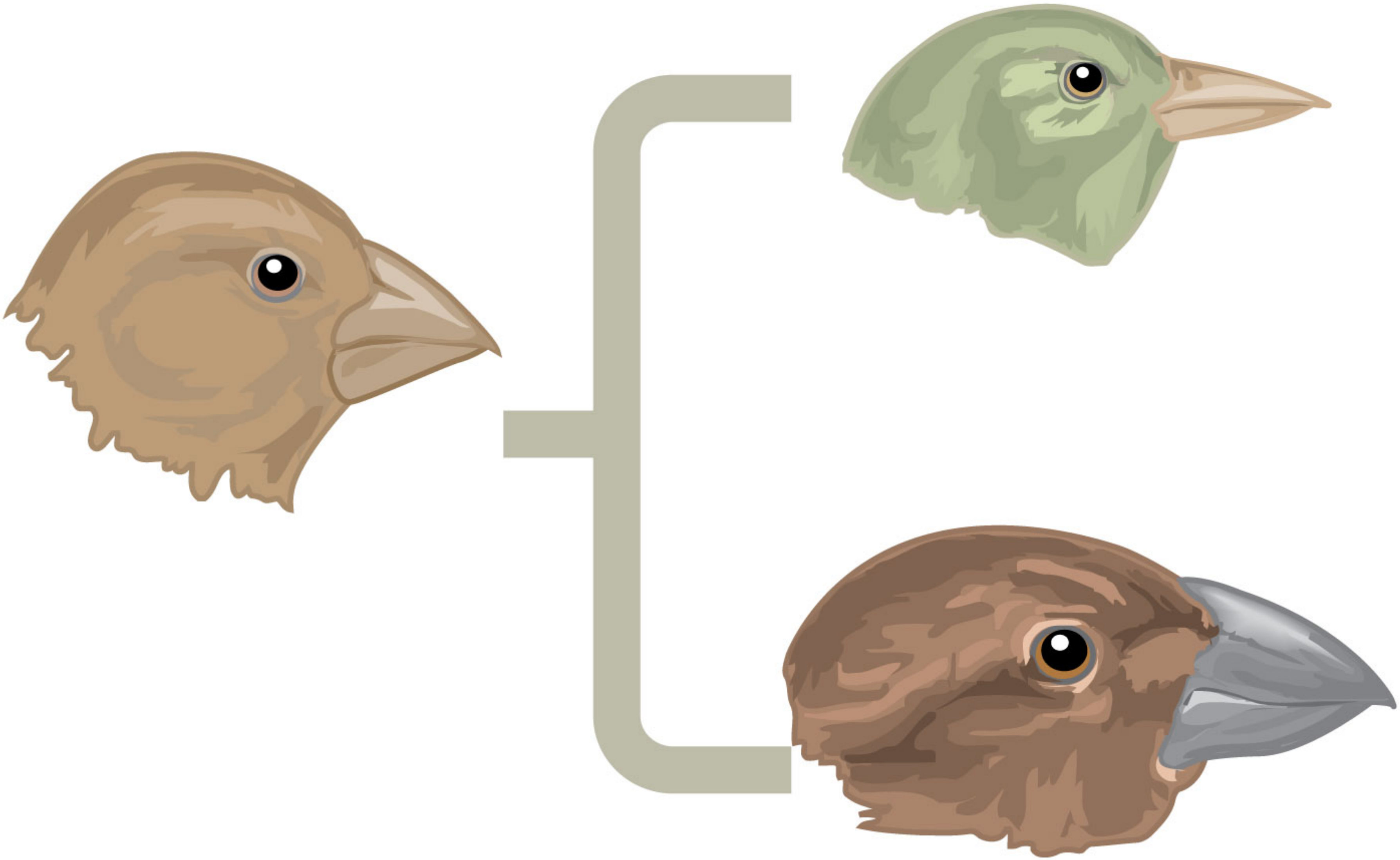


Figure 1.UN09

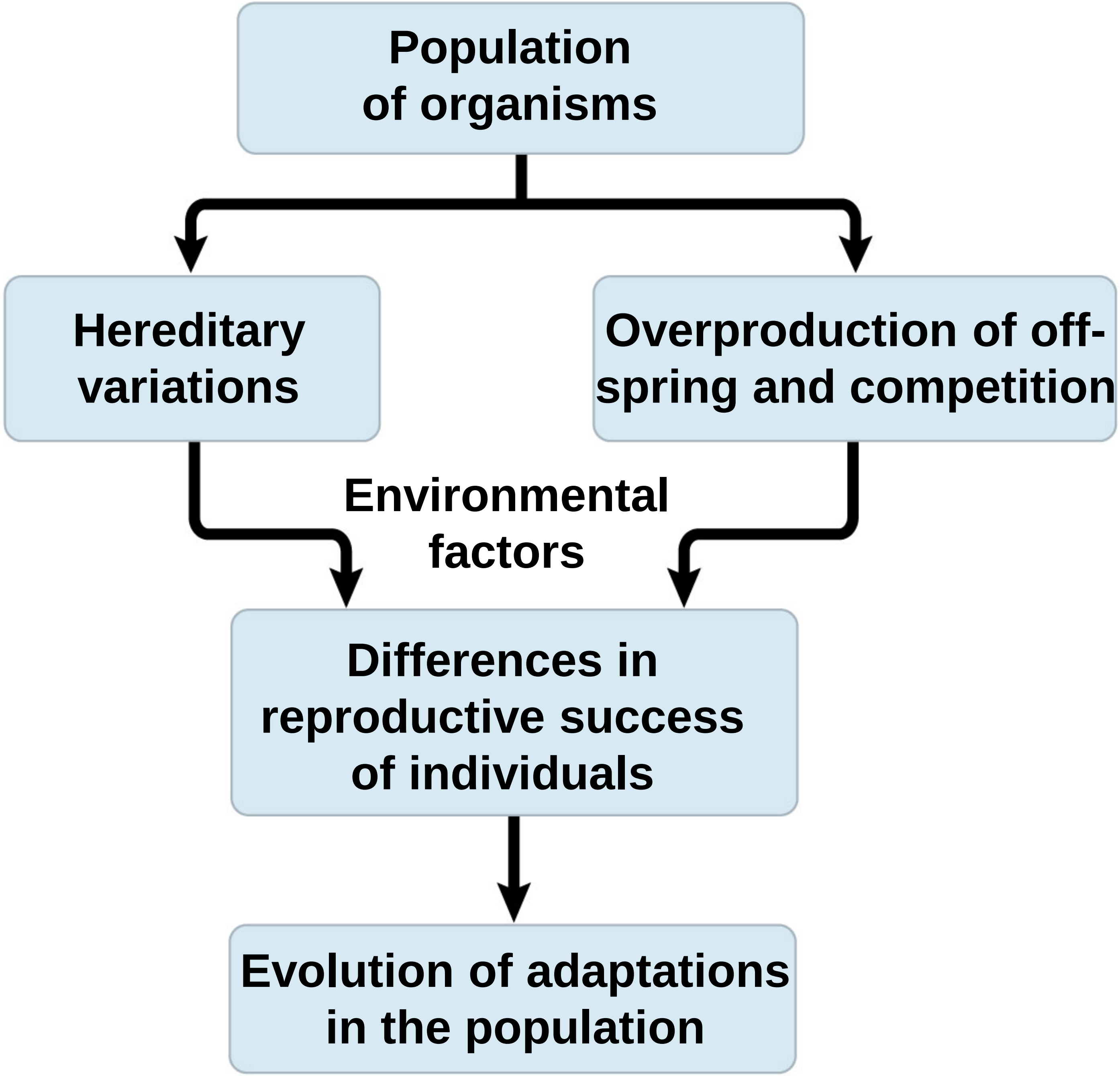
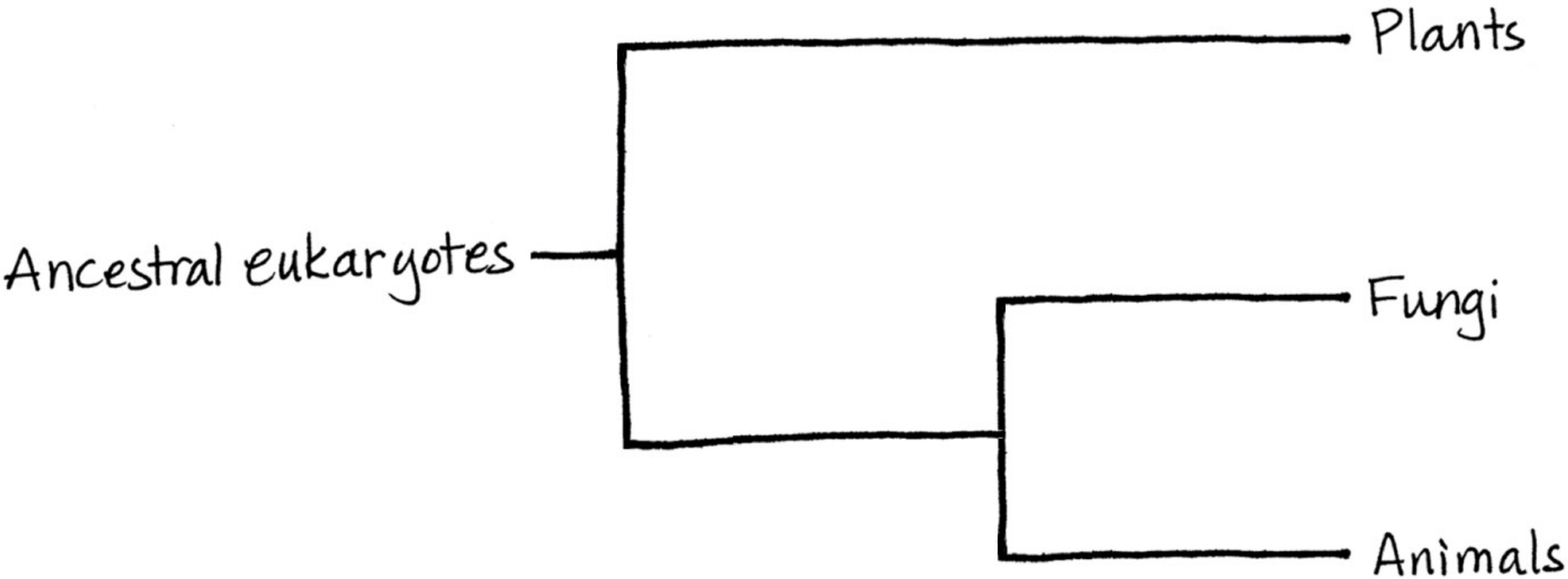


Figure 1.UN10

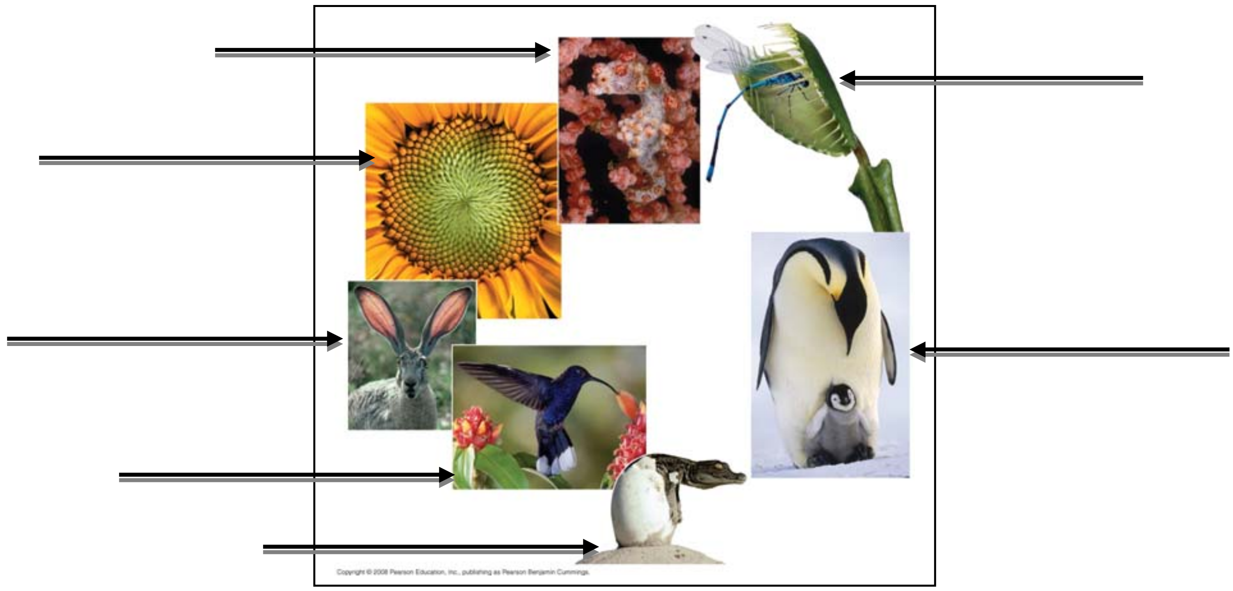


Name______________________Period__________

Chapter 1: Introduction: Themes in the Study of Life

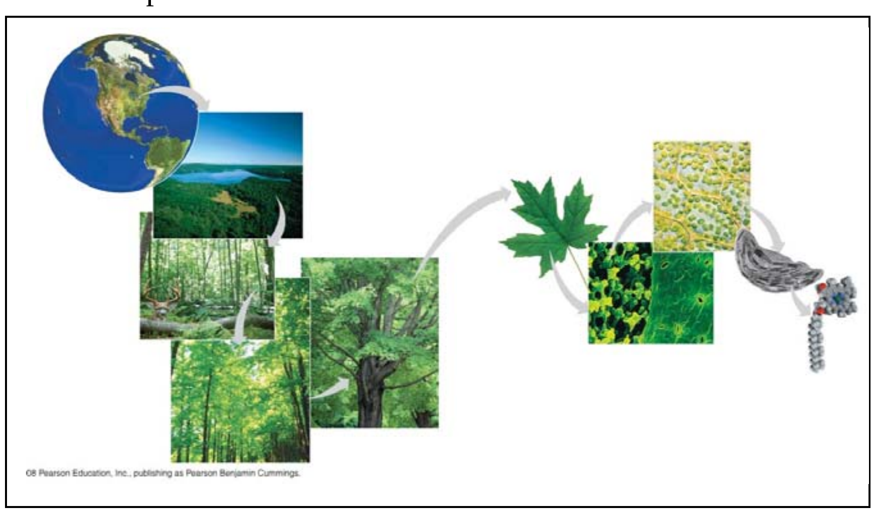
Begin your study of biology this year by reading Chapter 1. It will serve as a reminder about biological concepts that you may have learned in an earlier course and give you an overview of what you will study this year.

1. In the overview, Figure 1.3 recalls many of the properties of life. Label the seven properties illustrated here, and give a *different* example of each.



Concept 1.1 Themes connect the concepts of biology

2. What are **emergent properties?** Give two examples.



3. Life is organized on many scales. Figure 1.4 zooms you in from viewing Earth from space all the way to the level of molecules. As you study this figure, write in a brief definition of each level.

biosphere

ecosystem

community

population

organism

organs/organ systems

tissues

cells

organelles

molecules

4. Our study of biology will be organized around recurring themes. Make a list here of the themes that are presented, and give an example that illustrates each theme. Watch for these themes throughout your study this entire year. This will help you see the big picture and organize your thinking. (Go to the *Summary of Key Concepts* at the end of the chapter for a concise look at the themes.)

Theme 1	*Example*
Theme 2:	
Theme 3:	
Theme 4:	
Theme 5:	
Theme 6:	
Theme 7: (Find it in 1.2.)	

5. As you read this section, you will be reminded of things you may have studied in an earlier course. Since this material will be presented in detail in future chapters, you will come back to these ideas, so don't fret if some of the concepts presented are unfamiliar. However, to guide your study, define each of the terms in bold as you come to them.

eukaryotic cell

prokaryotic cell

DNA

genes

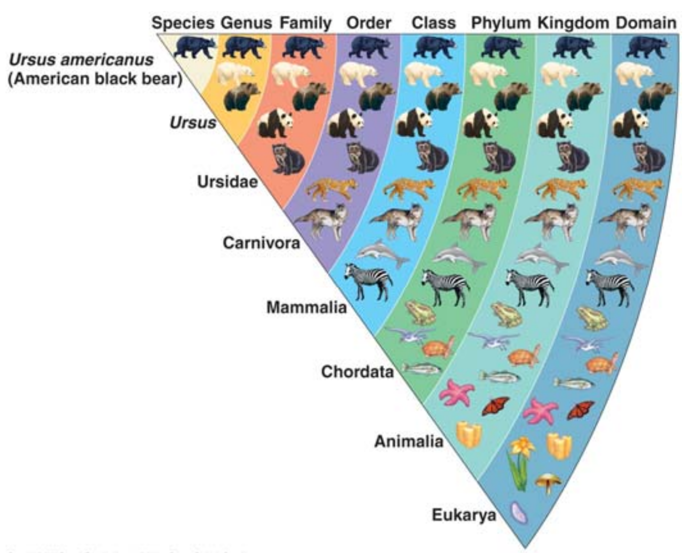
genome

negative feedback/positive feedback

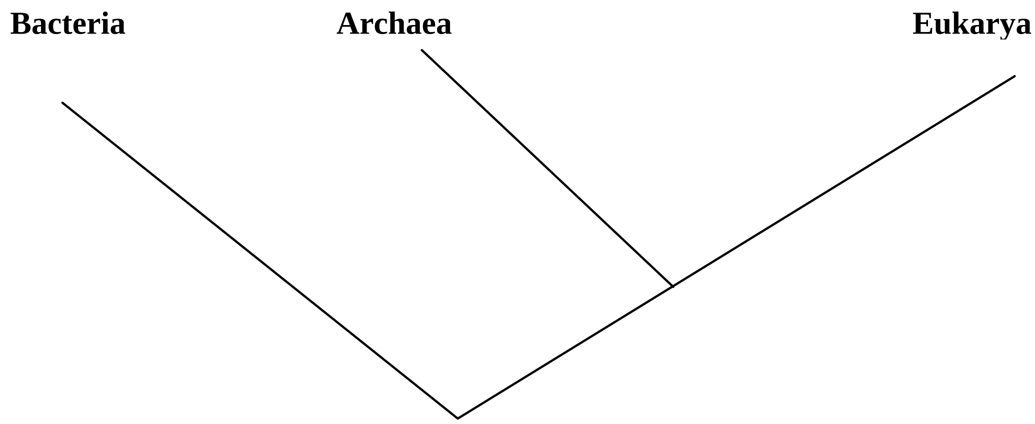
Concept 1.2 The Core Theme: Evolution accounts for the unity and diversity of life

6. Life is organized into groups. Study Figure 1.14.

- Which level contains the greatest diversity of organism?
- The least?
- Write out the levels of organization in order.
- Most people use a mnemonic device to remember these levels. If you have one, write it here.



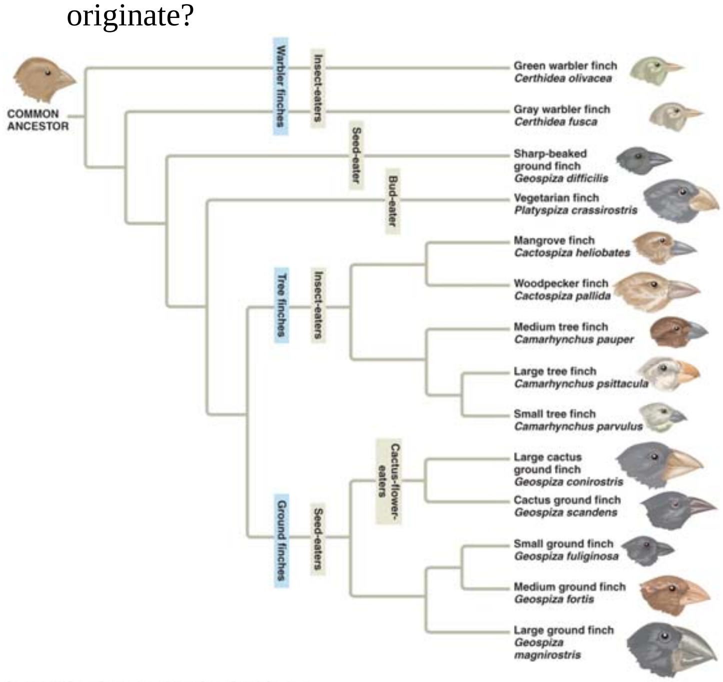
7. Taxonomy is the branch of biology that names and classifies organisms. Because of new molecular information, there have been many changes in placement of certain groups in recent years. Notice that all life is now organized in your text into 3 domains rather than the 5 kingdoms you may have learned earlier. Put the kingdoms mentioned in the text in the space above the proper domain names shown here.



8. What two main points were articulated in Darwin's *The Origin of Species*?

9. What did Darwin propose as the mechanism of evolution? Summarize this mechanism.

10. Study Figure 1.22, which shows an evolutionary "tree." What is indicated by each twig? What do the branch points represent? Where did the "common ancestor" of the Galápagos finches originate?



Concept 1.3 Scientists use two main forms of inquiry in their study of nature

11. What are the two main types of scientific inquiry? Give an example of each.

12. What is *data*?

13. Distinguish between quantitative and qualitative data. Which type would be presented in a data chart and could be graphed? Which type is found in the field sketches made by Jane Goodall?

14. In science, how do we define *hypothesis*?

15. A scientific hypothesis has two important qualities. The first is that it is *testable*. What is the second?

16. Are scientific hypotheses proved? Explain your answer!

17. Look at Figure 1.24. Use it to write a hypothesis using the "If . . . then . . ." format.

18. What is a *controlled experiment*?

19. The text points out a common misconception about the term "controlled experiment". In the snake mimicry experiment, what factors were held *constant*?

20. Why are supernatural explanations outside the bounds of science?

21. Explain what is meant by a scientific *theory* by giving the three ways your text separates a theory from a hypothesis or mere speculation.

    1.

    2.

    3.

Testing Your Knowledge: Self-Quiz Answers

Now you should be ready to test your knowledge. Place your answers here:

1. ___________
2.___________
3. ___________
4. ___________
5. ___________
6. ___________
7. ___________
8. ___________
9. ___________
10. __________

The King's Academy
AP Biology
Mrs. Carruthers
Test - Chapter 1

INTRODUCTION: THEMES IN THE STUDY OF LIFE

Multiple Choice: Identify the choice that best completes the statement or answers the question.

1) Which of the following types of cells utilize deoxyribonucleic acid (DNA) as their genetic material but do not have their DNA encased within a nuclear envelope?
A) animal
B) plant
C) archaea
D) fungi
E) protists

2) To understand the chemical basis of inheritance, we must understand the molecular structure of DNA. This is an example of the application of which concept to the study of biology?
A) evolution
B) emergent properties
C) reductionism
D) the cell theory
E) feedback regulation

3) Once labor begins in childbirth, contractions increase in intensity and frequency until delivery. The increasing labor contractions of childbirth are an example of which type of regulation?
A) a bioinformatic system
B) positive feedback
C) negative feedback
D) feedback inhibition
E) enzymatic catalysis

-continue-

4) When the body's blood glucose level rises, the pancreas secretes insulin and, as a result, the blood glucose level declines. When the blood glucose level is low, the pancreas secretes glucagon and, as a result, the blood glucose level rises. Such regulation of the blood glucose level is the result of
A) catalytic feedback.
B) positive feedback.
C) negative feedback.
D) bioinformatic regulation.
E) protein-protein interactions.

5) Global warming, as demonstrated by observations such as melting of glaciers, increasing CO_2 levels, and increasing average ambient temperatures, has already had many effects on living organisms. Which of the following might best offer a solution to this problem?
A) Continue to measure these and other parameters of the problem.
B) Increase the abilities of animals to migrate to more suitable habitats.
C) Do nothing; nature will attain its own balance.
D) Limit the burning of fossil fuels and regulate our loss of forested areas.
E) Recycle as much as possible.

6) A water sample from a hot thermal vent contained a single-celled organism that had a cell wall but lacked a nucleus. What is its most likely classification?
A) Eukarya
B) Archaea
C) Animalia
D) Protista
E) Fungi

7) A filamentous organism has been isolated from decomposing organic matter. This organism has a cell wall but no chloroplasts. How would you classify this organism?
A) domain Bacteria, kingdom Prokaryota
B) domain Archaea, kingdom Bacteria
C) domain Eukarya, kingdom Plantae
D) domain Eukarya, kingdom Protista
E) domain Eukarya, kingdom Fungi

-continue-

8) Which of these provides evidence of the common ancestry of all life?
A) ubiquitous use of catalysts by living systems
B) near universality of the genetic code
C) structure of the nucleus
D) structure of cilia
E) structure of chloroplasts

9) Which of these individuals is likely to be most successful in an evolutionary sense?
A) a reproductively sterile individual who never falls ill
B) an organism that dies after five days of life but leaves 10 offspring, all of whom survive to reproduce
C) a male who mates with 20 females and fathers one offspring
D) an organism that lives 100 years and leaves two offspring, both of whom survive to reproduce
E) a female who mates with 20 males and produces one offspring that lives to reproduce

10) In a hypothetical world, every 50 years people over 6 feet tall are eliminated from the population before they reproduce. Based on your knowledge of natural selection, you would predict that the average height of the human population will
A) remain unchanged.
B) gradually decline.
C) rapidly decline.
D) gradually increase.
E) rapidly increase.

11) Through time, the lineage that led to modern whales shows a change from four-limbed land animals to aquatic animals with two limbs that function as flippers. This change is best explained by
A) natural philosophy.
B) creationism.
C) the hierarchy of the biological organization of life.
D) natural selection.
E) feedback inhibition.

-continue-

12) Which of the following categories of organisms is least likely to be revised?
A) kingdom
B) class
C) order
D) phylum
E) species

13) Similarities and differences among/between life-forms over time are most efficiently recorded by scientists in which field(s) of study?
A) paleontology
B) paleontology and anatomy
C) paleontology, anatomy, and taxonomy
D) paleontology, anatomy, taxonomy, and genetics
E) paleontology, anatomy, taxonomy, genetics, and ecology

14) Why is the theme of evolution considered to be the core theme of biology by biologists?
A) It provides a framework within which all biological investigation makes sense.
B) It is recognized as the core theme of biology by organizations such as the National Science Foundation.
C) Controversy about this theory provides a basis for a great deal of experimental research.
D) Since it cannot be proven, biologists will be able to study evolutionary possibilities for many years.
E) Biologists do not subscribe to alternative models.

15) Collecting data based on observation is an example of ________; analyzing this data to reach a conclusion is an example of ________ reasoning.
A) hypothesis-based science; inductive
B) the process of science; deductive
C) discovery science; inductive
D) descriptive science; deductive
E) hypothesis-based science; deductive

-continue-

16) A controlled experiment is one in which
A) the experiment is repeated many times to ensure that the results are accurate.
B) the experiment proceeds at a slow pace to guarantee that the scientist can carefully observe all reactions and process all experimental data.
C) there are at least two groups, one of which does not receive the experimental treatment.
D) there are at least two groups, one differing from the other by two or more variables.
E) there is one group for which the scientist controls all variables.

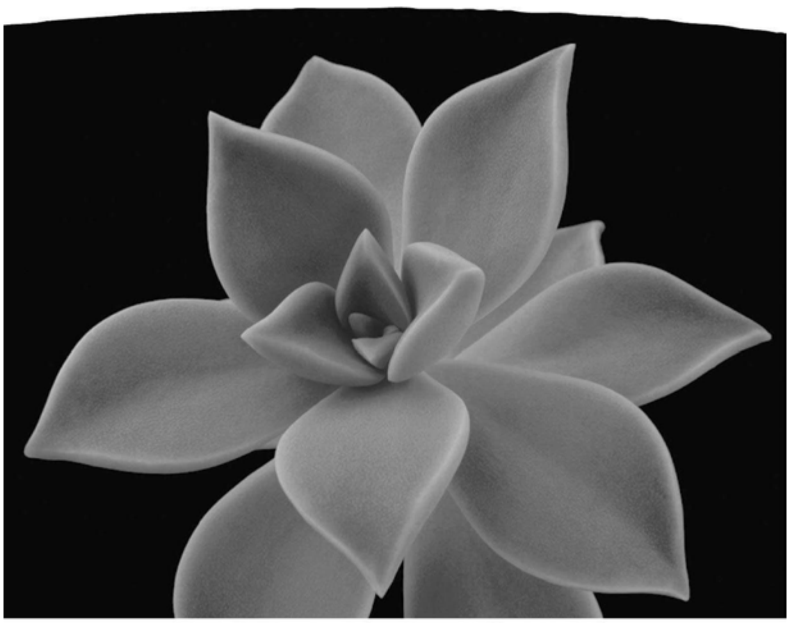
17) Why is it important that an experiment include a control group?
A) The control group is the group that the researcher is in control of, the group in which the researcher predetermines the results.
B) The control group provides a reserve of experimental subjects.
C) A control group is required for the development of an "If…then" statement.
D) A control group assures that an experiment will be repeatable.
E) Without a control group, there is no basis for knowing if a particular result is due to the variable being tested.

18) In presenting data that result from an experiment, a group of students show that most of their measurements fall on a straight diagonal line on their graph. However, two of their data points are "outliers" and fall far to one side of the expected relationship. What should they do?
A) Do not show these points but write a footnote that the graph represents the correct data.
B) Average several trials and therefore rule out the improbable results.
C) Show all results obtained and then try to explore the reason(s) for these outliers.
D) Throw out this set of data and try again.
E) Change the details of the experiment until they can obtain the expected results.

19) Given the cooperativity of science, which of the following is most likely to result in an investigator being intellectually looked down upon by other scientists?
A) Making money as the result of studies in which a new medication is discovered.
B) Doing meticulous experiments that show data that contradict what has been previously reported by the scientific community.
C) Spending most of a lifetime investigating a small and seemingly unimportant organism.
D) Getting negative results from the same set of experiments.
E) Being found to have falsified or created data to better fit a hypothesis.

-continue-

20) Why is a scientific topic best discussed by people of varying points of view, a variety of subdisciplines, and diverse cultures?
A) They can rectify each other's approach to make it truly scientific.
B) Robust and critical discussion between diverse groups improves scientific thinking.
C) Scientists can explain to others that they need to work in isolation to utilize the scientific method more productively.
D) This is another way of making science more reproducible.
E) Scientists need to exchange their ideas with other disciplines and cultures so that all groups are in consensus with the course of future research.



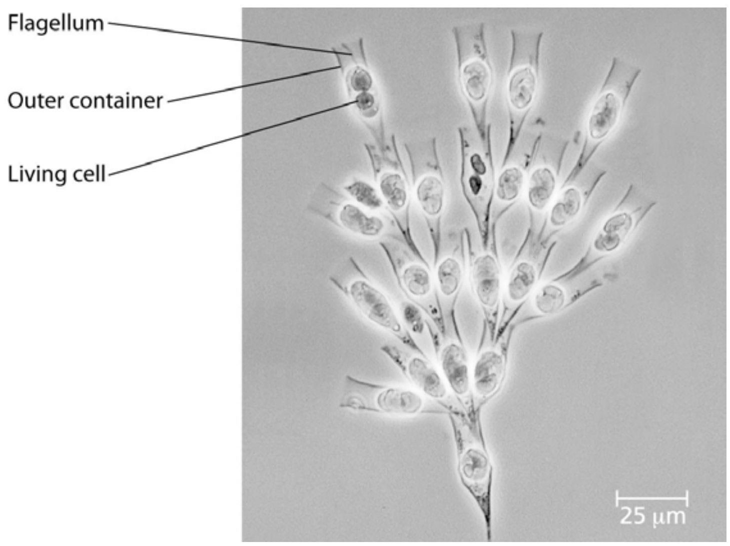
Mother of pearl

Ocotello in southwestern United States desert

21) What do these two plants have in common?
A) adaptations to extreme heat
B) adaptations to conserve water
C) identical stem structures
D) identical flower structures
E) lack of photosynthesis

-continue-

Golden algae are a group of protists whose color is due to carotenoid pigments: yellow and brown. Most have two flagella and all are photosynthetic. A group of students was given a significant sample of one of these (*Dinobryon*) that is colonial. Their instructions for the project were to design two or more experiments that could be done with these organisms.



22) The students decide that for one of their experiments, they want to see whether the organisms can photosynthesize. Which of the following is the best hypothesis?
A) If the *Dinobryon* can live > 5 days without added food, they must be able to photosynthesize.
B) If the *Dinobryon* can live without exposure to light for > 5 days, they must be able to photosynthesize.
C) If the *Dinobryon* photosynthesize, they must need no other minerals or nutrients and will be able to live in distilled water and light alone.
D) If the *Dinobryon* are kept in the dark, one-half will be expected to die in 5 days.
E) If the *Dinobryon* are able to photosynthesize, the students should be able to extract photosynthetic pigments.

23) For their second experiment, the students want to know whether the *Dinobryon* have to live in colonies or can be free living. How might they proceed?
A) Observe each day to see whether new organisms are ever reproduced as single cells.
B) Observe whether only specialized cells are able to divide to produce new colonies.
C) Divide a sample into single cells and measure the length of time they remain this way.
D) Divide a sample into single cells and observe them.
E) Divide a sample into single cells and see whether they come back together.

-continue-

24) The students plan to gather data from the project. Which of the following would be the best way to present what they gather from experimental groups as opposed to controls?
A) qualitatively, noting color, size, and so on
B) measuring the number of new colonies formed during every 12-hour period
C) counting the number of new colonies after a week
D) measuring the size of each new colony in millimeters (mm) of length
E) measuring the dry weight of all new colonies in grams

The following is a list of biology themes discussed in Chapter 1. Use them to answer the following questions.

I. New properties emerge at each level in the biological hierarchy.
II. Organisms interact with other organisms and the physical environment.
III. Life requires energy transfer and transformation.
IV. Structure and function are correlated at all levels of biological organization.
V. Cells are an organism's basic units of structure and function.
VI. The continuity of life is based on heritable information in the form of DNA.
VII. Feedback mechanisms regulate biological systems.
VIII. Evolution accounts for the unity and diversity of life.

25) Which theme(s) is/are best illustrated by an experiment in which a biologist seeks a medication that will inhibit pain responses in a cancer patient?
A) II
B) VII
C) III and V
D) V and VIII
E) VI and VII

26) Which theme(s) is/are best illustrated by a group of investigators who are trying to classify and explain the ecology of an area known as the Big Thicket?
A) I only
B) II only
C) VIII only
D) IV and VI
E) I and II

-continue-

27) Which theme(s) is/are illustrated when a group of students is trying to establish which phase of cell division in root tips happens most quickly?
A) IV only
B) V only
C) VII only
D) IV, V, and VI
E) V, VI, and VII

28) Which theme(s) is/are illustrated when a biology class is comparing the rates of photosynthesis between leaves of a flowering plant species (*Gerbera jamesonii*) and a species of fern (*Polypodium polypodioides*)?
A) I only
B) II only
C) I and III
D) I and VII
E) I, III, and V

-continue-

Short Answer Essay: Thoroughly answer each question using complete sentences. Diagrams may be used to help clarify but should not be used alone without explanation.

1. Exobiology is the study of life on other planets. In recent years, scientists have sent various spacecraft out into the galaxy in search for extraterrestrial life. Assuming that all life shares common properties, what should exobiologists be looking for as they explore other worlds?

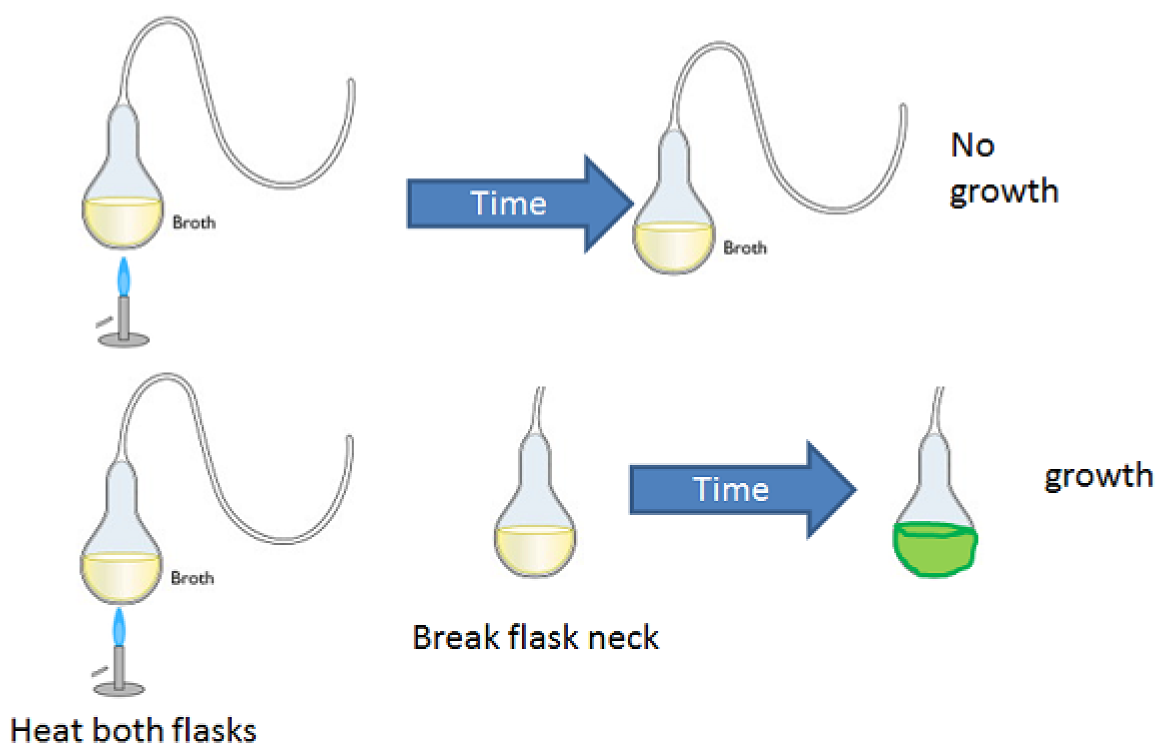
-continue-

Question: *What is the source of contamination that occurs in a flask of nutrient broth left exposed to the air?*

Germ Hypothesis: *Preexisting microorganisms present in the air contaminate nutrient broth.*
Prediction: *Sterilized broth will remain sterile if microorganisms are prevented from entering flask.*

Spontaneous Generation Hypothesis: *Living organisms will spontaneously generate from nonliving organic molecules in broth.*
Prediction: *Organisms will spontaneously generate from organic molecules in broth after sterilization.*

Test: *Use swan-necked flasks to prevent entry of microorganisms. To ensure that broth can still support life, break swan-neck after sterilization.*



Result: *No growth occurs in sterile swan-necked flasks. When the neck is broken off, and the broth is exposed to air, growth occurs.*

Conclusion: *Growth in broth is of preexisting microorganisms.*

-continue-

2. The classic experiment by Pasteur (figure on previous page) tested the hypothesis that cells arise from other cells. In this experiment cell growth was measured following sterilization of broth in a swan-necked flask or in a flask with a broken neck.

   a. Which variables were kept the same in these two experiments?

   b. How does the shape of the flask affect the experiment?

   c. Predict the outcome of each experiment based on the two hypotheses.

   d. Some bacteria are capable of producing heat-resistant spores that protect the cell and allow it to continue to grow after the environment cools. How would the outcome of this experiment have been affected if spore-forming bacteria were present in the broth?

-continue-

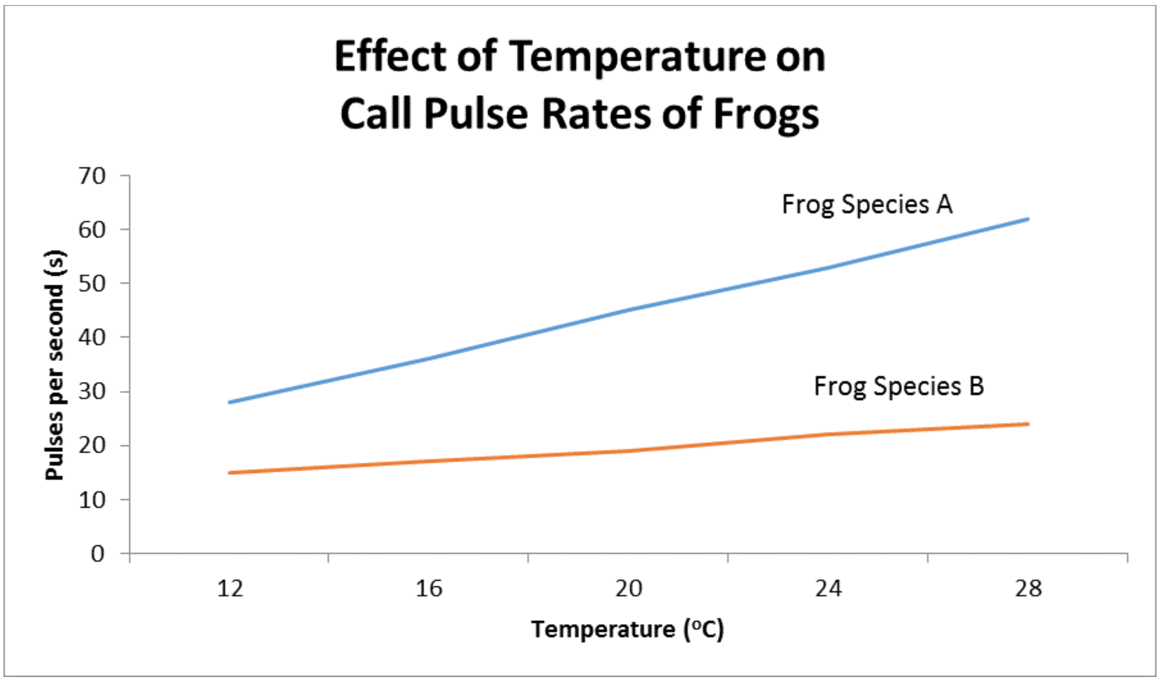
3. As a field biologist, you have observed that populations of sparrows in the northern portion of the United States have larger bodies than the populations of sparrows in the southern United States. You hypothesize that these differences in body size relative to geography are the result of natural selection, because several hundred years ago all of the birds in this species were of similar size.

   Describe an experimental design that would help you determine if colder weather selects for the larger birds in this species. Include in your description an **explanation** of what type of data you would collect, describe how the data would be **represented visually** (graphically), and how you would **evaluate** the data to investigate the role of natural selection in the evolution of these birds.

-continue-

How does temperature affect the pulse rate of calling in tree frogs?
Male tree frogs make calls that females can identify easily based on the rate of the sound pulses in the call.

Data and Observations
The graph shows the pulse rate of two species of frogs versus temperature.



4. **Interpret Data** What is the relationship between sound pulses and temperature?

5. **Compare** How did temperature affect the rate of pulses in species A and in species B?

6. **Infer** Why is it important that the two species of frogs not have the same pulse rate in their calls at the same temperature?

Chapter 2

The Chemical Context of Life

Lecture Outline

Overview: A Chemical Connection to Biology

- Living organisms and the world they live in are subject to the basic laws of physics and chemistry.
- Biology is a multidisciplinary science, drawing on insights from other sciences.
- Life can be organized into a hierarchy of structural levels.
    - Atoms are organized into molecules, and molecules are organized into cells.
    - At each successive level, additional emergent properties appear.
    - Somewhere in the transition from molecules to cells, we cross the boundary between nonlife and life.

Concept 2.1 Matter consists of chemical elements in pure form and in combinations called compounds

- Organisms are composed of **matter**, defined as anything that takes up space and has mass.
    - Matter is made up of elements.
- An **element** is a substance that cannot be broken down into other substances by chemical reactions.
    - There are 92 naturally occurring elements.
    - Each element has a unique symbol, usually the first one or two letters of its name. Some symbols are derived from Latin or German names.
- A **compound** is a substance that consists of two or more elements in a fixed ratio.
    - Table salt (sodium chloride or NaCl) is a compound with equal numbers of atoms of the elements chlorine and sodium.
    - Although pure sodium is a metal and chlorine is a gas, they combine to form an edible compound.
    - This change in characteristics when elements combine to form a compound is an example of an emergent property.

Twenty-five chemical elements are essential for life.

- About 20–25% of the 92 naturally occurring elements are **essential elements** that are necessary for living things.

    - There is some variation: humans have 25 essential elements, while plants have only 17.
- Four elements—oxygen (O), carbon (C), hydrogen (H), and nitrogen (N)—make up 96% of living matter.
    - Most of the remaining 4% of an organism's weight consists of calcium (Ca), phosphorus (P), potassium (K), and sulfur (S).
- **Trace elements** are required by an organism but only in minute quantities.
    - Some trace elements, like iron (Fe), are required by all organisms.
    - Other trace elements are required by only some species.
        - For example, vertebrates (animals with backbones) require the element iodine (I) for normal activity of the thyroid gland. A daily intake of only 0.15 milligram (mg) of iodine is adequate for normal activity of the human thyroid.
- Some naturally occurring elements, such as arsenic, are toxic to most organisms.
    - Some species have become adapted to environments containing toxic elements.
    - For example, serpentine plant communities are able to survive in soils containing chromium, nickel, and cobalt.

Concept 2.2 An element's properties depend on the structure of its atoms

- Each element consists of unique atoms. An **atom** is the smallest unit of matter that still retains the properties of an element.
- Atoms are composed of even smaller parts called *subatomic particles*.
    - Two subatomic particles, **neutrons** and **protons**, are packed together to form a dense core, the **atomic nucleus**, at the center of an atom.
    - **Electrons** can be visualized as forming a cloud of negative charge around the nucleus.
- Each electron has one unit of negative charge, each proton has one unit of positive charge, and neutrons are electrically neutral.
    - The attractions between the positive charges in the nucleus and the negative charges of the electrons keep the electrons in the vicinity of the nucleus.
- A neutron and a proton have almost identical mass: about 1.7×10^{-24} gram per particle.
- For convenience, a smaller unit, the **dalton,** is used to measure the masses of subatomic particles, atoms, and molecules.
    - The mass of a neutron or a proton is close to 1 dalton.
- The mass of an electron is about 1/2,000 the mass of a neutron or proton.
    - We typically ignore the contribution of electrons when determining the total mass of an atom.
- All atoms of a particular element have the same number of protons in their nuclei.
    - This number of protons is the element's unique **atomic number**.
    - The atomic number is written as a subscript before the symbol for the element. For example, $_2He$ means that an atom of helium has 2 protons in its nucleus.

- Unless otherwise indicated, atoms have equal numbers of protons and electrons and, therefore, no net charge.
    - Therefore, the atomic number tells the number of protons and the number of electrons in a neutral atom of a specific element.
- The **mass number** is the sum of the number of protons and the number of neutrons in the nucleus of an atom.
    - We can determine the number of neutrons in an atom by subtracting the number of protons (the atomic number) from the mass number.
    - The mass number is written as a superscript before an element's symbol (for example, ^{4}He).
    - Because neutrons and protons each have a mass very close to 1 dalton, the mass number is an approximation of the total mass of an atom, called its **atomic mass.**
- Two atoms of the same element that differ in the number of neutrons are called **isotopes.**
- In nature, an element occurs as a mixture of isotopes.
    - For example, 99% of carbon atoms have 6 neutrons (^{12}C).
    - Most of the remaining 1% of carbon atoms have 7 neutrons (^{13}C), while the rarest carbon isotope, with 8 neutrons, is ^{14}C.
- Most isotopes are stable; they do not tend to lose particles.
    - Both ^{12}C and ^{13}C are stable isotopes.
- The nuclei of some isotopes are unstable and decay spontaneously, emitting particles and energy.
    - ^{14}C is one of these unstable isotopes, or **radioactive isotopes**.
    - When ^{14}C decays, one of its neutrons is converted to a proton and an electron. In this process, ^{14}C is converted to ^{14}N, a different element.
- Radioactive isotopes have many applications in biological research.
    - Radioactive decay rates can be used to date fossils.
    - Radioactive isotopes can be used to trace atoms through metabolic processes.
- Radioactive isotopes are also used to diagnose medical disorders.
    - A known quantity of a substance labeled with a radioactive isotope can be injected into the blood, and its rate of excretion in the urine can be measured.
    - Radioactive tracers can be used with imaging instruments such as PET scanners to monitor the body's chemical processes, such as those involved in cancerous growths.
- Though useful in research and medicine, the energy emitted in radioactive decay is hazardous to life.
    - This energy can damage molecules within living cells.
    - The severity of damage depends on the type and amount of radiation that the organism absorbs.

Electron configuration influences the chemical behavior of an atom.

- Simplified models of the atom greatly distort the atom's relative dimensions.
- In an accurate representation of the relative proportions of an atom, if an atom of helium were the size of Yankee Stadium, the nucleus would be only the size of a pencil eraser in the center of the field.

- The electrons would be like two gnats buzzing around the stadium.
- Atoms are mostly empty space.

- When two elements interact during a chemical reaction, it is actually their electrons that are involved.
  - The nuclei do not come close enough to interact.
- The electrons of an atom vary in the amounts of energy they possess.
- **Energy** is the ability to cause change, by doing work.
- **Potential energy** is the energy that matter stores because of its structure or location.
  - Water stored behind a dam has potential energy due to its altitude.
  - That potential energy can be used to do work turning electric generators.
  - Because potential energy has been expended, the water stores less energy at the bottom of the dam than it did in the reservoir.
- Electrons have potential energy because of their positions relative to the nucleus.
  - The negatively charged electrons are attracted to the positively charged nucleus.
  - The farther electrons are from the nucleus, the more potential energy they have.
- Changes in an electron's potential energy can occur only in steps of a fixed amount, moving the electron to a fixed location relative to the nucleus.
  - An electron cannot exist between these fixed locations.
- The different states of potential energy of the electrons of an atom are called **electron shells.**
  - The first shell, closest to the nucleus, has the lowest potential energy.
  - Electrons in outer shells have higher potential energy.
  - Electrons can change their position only if they absorb or release a quantity of energy that matches the difference in potential energy between the two levels.
- The chemical behavior of an atom is determined by its electron configuration—the distribution of electrons in its electron shells.
- An abbreviated *periodic table of the elements* shows the distribution of electrons in the first 18 elements from hydrogen to argon.
  - The elements are arranged in three rows or periods, corresponding to the number of electron shells in their atoms.
  - Elements in the same row have the same shells filled with electrons.
  - As we move from left to right in the table, each element has one more electron (and proton) than the element before.
- The first electron shell can hold only 2 electrons.
  - The 2 electrons of helium fill the first shell.
- Atoms with more than 2 electrons must have the extra electrons in higher shells.
  - Lithium, with 3 electrons, has 2 electrons in the first shell and 1 in the second shell.
- The second shell can hold up to 8 electrons.
  - Neon, with 10 total electrons, has 2 in the first shell and 8 in the second, thus filling both shells.

- The chemical behavior of an atom depends mostly on the number of electrons in its outermost shell, the **valence shell.**
  - Electrons in the valence shell are known as **valence electrons.**
  - Lithium has 1 valence electron; neon has 8.
- Atoms with the same number of valence electrons have similar chemical behaviors.
- An atom with a completed valence shell, like neon, is *inert* or chemically nonreactive.
- All other atoms are chemically reactive because they have incomplete valence shells.
- The paths of electrons are often portrayed as concentric paths, like planets orbiting the sun. In reality, an electron occupies a more complex three-dimensional space, an **orbital.**
- The orbital is the space in which the electron is found 90% of the time.
  - Each orbital can hold a maximum of 2 electrons.
  - The first shell has room for a single spherical 1*s* orbital for its pair of electrons.
  - The second shell can pack pairs of electrons into one spherical 2*s* orbital and three dumbbell-shaped 2*p* orbitals.
- The reactivity of atoms arises from the presence of unpaired electrons in one or more orbitals of their valence shells.
  - Electrons occupy separate orbitals within the valence shell until forced to share orbitals.
  - The 4 valence electrons of carbon each occupy separate orbitals, but the 5 valence electrons of nitrogen are distributed into three unshared orbitals and one shared orbital.
- When atoms interact to complete their valence shells, it is the *unpaired* electrons that are involved.

Concept 2.3 The formation and function of molecules depend on chemical bonding between atoms

- Atoms with incomplete valence shells can interact with each other by sharing or transferring valence electrons.
- These interactions typically result in the atoms remaining close together, held by attractions called **chemical bonds.**
- The strongest chemical bonds are covalent bonds and ionic bonds.
- A **covalent bond** is formed when two atoms share a pair of valence electrons.
  - If two atoms come close enough that their unshared orbitals overlap, they can share their newly paired electrons. Each atom can count both electrons toward its goal of filling the valence shell.
  - For example, if two hydrogen atoms come close enough that their 1*s* orbitals overlap, then they can share a pair of electrons, with each atom contributing one.
- Two or more atoms held together by covalent bonds constitute a **molecule**.
- The *molecular formula* of a molecule indicates that the molecule consists of two atoms of hydrogen.
  - H_2 is the molecular formula for hydrogen gas.
- The *structural formula* uses a line for a **single bond**, a pair of shared electrons.

- H—H is the structural formula for the covalent bond between two hydrogen atoms.

- Electron sharing can be shown by an electron-distribution diagram or *Lewis dot structure*, in which element symbols are surrounded by dots representing valence electrons (H:H).
- Oxygen needs to add 2 electrons to the 6 already present to complete its valence shell.
  - Two oxygen atoms can form a molecule by sharing *two* pairs of valence electrons. These atoms form a **double covalent bond** (O=O).
- Every atom has a characteristic total number of covalent bonds that it can form, equal to the number of unpaired electrons in the outermost shell. This bonding capacity is called the atom's **valence.**
  - The valence of hydrogen is 1; oxygen is 2; nitrogen is 3; carbon is 4.
  - The situation is more complex for elements in the third row of the periodic table.
  - Phosphorus should have a valence of 3, based on its 3 unpaired electrons, but in biological molecules, it generally has a valence of 5, forming three single covalent bonds and one double bond.
- Covalent bonds can form between atoms of the same element (forming pure elements) or atoms of *different* elements (forming compounds).
  - Water (H_2O) is a compound in which two hydrogen atoms form single covalent bonds with an oxygen atom. This satisfies the valences of both elements.
  - Methane (CH_4) is a compound that satisfies the valences of both C and H.
- Atoms differ in the degree of their attraction for shared electrons. The attraction of an atom for the shared electrons of a covalent bond is called its **electronegativity**.
  - Strongly electronegative atoms strongly pull the shared electrons toward themselves.
- Electrons in a covalent bond are shared equally in a **nonpolar covalent bond**.
  - A covalent bond between two atoms of the same element is always nonpolar.
  - A covalent bond between atoms that have similar electronegativities is also nonpolar.
  - Because carbon and hydrogen do not differ greatly in electronegativities, the bonds of CH_4 are nonpolar.
- When two atoms that differ in electronegativity bond, they do not share the electron pair equally, and they form a **polar covalent bond**.
  - When oxygen and hydrogen form water, the bonds between oxygen and hydrogen are polar covalent because oxygen has a much higher electronegativity than does hydrogen.
  - Compounds with a polar covalent bond have regions of partial negative charge ($\delta-$) near the strongly electronegative atom and regions of partial positive charge ($\delta+$) near the weakly electronegative atom.
- An **ionic bond** can form if two atoms are so unequal in their attraction for valence electrons that one atom strips an electron completely from the other.
  - For example, sodium, with 1 valence electron in its third shell, transfers this electron to chlorine, with 7 valence electrons in its third shell.
  - Then sodium has a full valence shell (the second) and chlorine has a full valence shell (the third).
- After the transfer, both atoms are no longer neutral but have charges and are called **ions**.

- Atoms with positive charges are **cations**.
    - Sodium has one more proton than electrons and has a net positive charge (1+).
- Atoms with negative charges are **anions**.
    - Chlorine has one more electron than protons and has a net negative charge (1–).
- Because of differences in charge, cations and anions are attracted to each other to form an **ionic bond**.
    - Atoms in an ionic bond need not have acquired their charges by transferring electrons with each other.
- Compounds formed by ionic bonds are **ionic compounds**, or **salts**. An example is NaCl, or table salt.
    - The formula for an ionic compound indicates the ratio of elements in a crystal of that salt. NaCl is not a molecule but a salt crystal with equal numbers of Na^+ and Cl^- ions.
- Ionic compounds can have ratios of elements different from 1:1.
    - For example, the ionic compound magnesium chloride ($MgCl_2$) has two chloride atoms for each magnesium atom.
    - Magnesium needs to lose 2 electrons to drop to a full outer shell; each chlorine atom needs to gain 1 electron.
- Entire molecules that have full electrical charges are also called *ions*.
    - In the salt ammonium chloride (NH_4Cl), the anion is chloride (Cl^-) and the cation is ammonium (NH_4^+).
- The strength of ionic bonds depends on environmental conditions, such as moisture.
- Water can dissolve salts by reducing the attraction between the salt's anions and cations.

Weak chemical bonds play important roles in the chemistry of life.

- Within a cell, weak, brief bonds between molecules are important to a variety of processes.
    - Many large biological molecules are held in their functional form by weak bonds.
    - When two molecules in the cell make contact, they may adhere temporarily by weak bonds.
- The reversibility of weak bonding can be an advantage: Two molecules can come together, respond to each other in some way, and then separate.
- Weak interactions include ionic bonds between ions dissociated in water, hydrogen bonds, and van der Waals interactions.
- **Hydrogen bonds** form when a hydrogen atom that is already covalently bonded to one electronegative atom is attracted to another electronegative atom.
    - In cells, the electronegative partners are typically nitrogen or oxygen.
    - Hydrogen bonds form because a polar covalent bond leaves the hydrogen atom with a partial positive charge and the other atom with a partial negative charge.
    - The partially positive–charged hydrogen atom is attracted to regions of full or partial negative charge on molecules, atoms, or even regions of the same large molecule.
- For example, ammonia molecules and water molecules interact with weak hydrogen bonds.

  - In the ammonia molecule, the hydrogen atoms have partial positive charges, and the more electronegative nitrogen atom has a partial negative charge.
  - In the water molecule, the hydrogen atoms have partial positive charges, and the oxygen atom has a partial negative charge.
  - Areas with opposite charges are attracted to each other.
- Even molecules with nonpolar covalent bonds can have temporary regions of partial negative and positive charge.
  - Because electrons are constantly in motion, there may be times when they accumulate by chance in one area of a molecule.
  - This creates ever-changing regions of partial negative and positive charge within a molecule.
- Molecules or atoms in close proximity can be attracted by fleeting charge differences, creating **van der Waals interactions**.
  - The resulting ever-changing regions of positive and negative charge enable atoms and molecules to stick to one another.
  - van der Waals interactions between molecules on the tips of hundreds of thousands of tiny hairs on a gecko toe and the molecules of the wall's surface are so numerous that, despite their individual weakness, together they can support the gecko's body weight, allowing the animal to walk up a wall.
- Although individual bonds (ionic, hydrogen, van der Waals) are temporary and individually weak, collectively they are strong and play important biological roles.
  - The cumulative effect of individual bonds is to reinforce the three-dimensional shape of a large molecule.

A molecule's biological function is related to its shape.

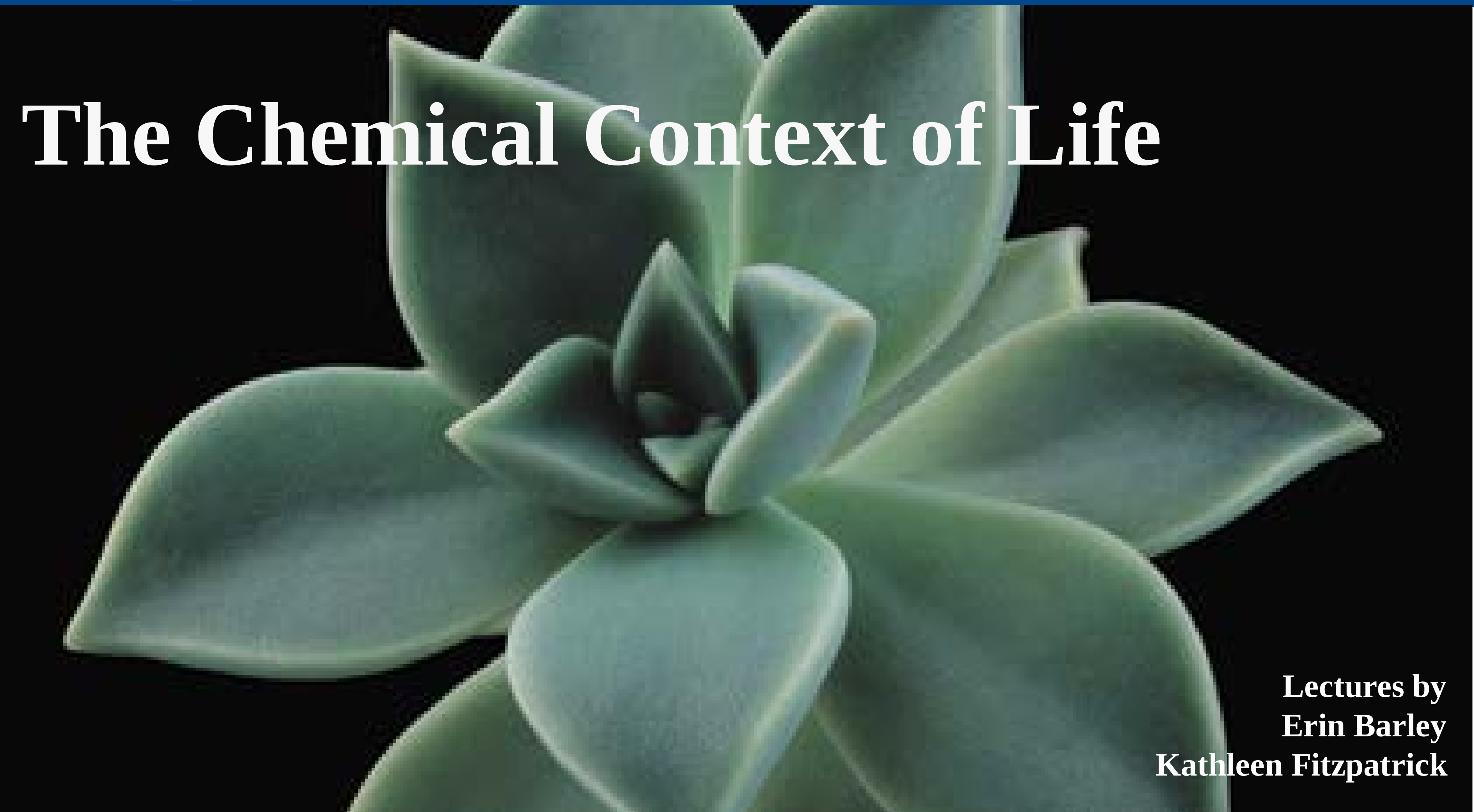
- The three-dimensional shape of a molecule is an important determinant of its function in a cell.
- A molecule with two atoms is always linear, but most molecules with more than two atoms have a more complex shape.
- The shape of a molecule is determined by the positions of the electron orbitals that are shared by the atoms involved in the bond.
  - When covalent bonds form, the orbitals in the valence shell of each atom rearrange.
- For atoms with electrons in both *s* and *p* orbitals, the formation of a covalent bond leads to hybridization of the orbitals to four new orbitals in a tetrahedral shape.
- In a water molecule, two of oxygen's four hybrid orbitals are shared with hydrogen atoms. The water molecule is shaped like a V, with its two covalent bonds spread apart at an angle of 104.5°.
- In a methane molecule (CH_4), the carbon atom shares all four of its hybrid orbitals with H atoms. The carbon nucleus is at the center of the tetrahedron, with hydrogen nuclei at the four corners.
- Large organic molecules contain many carbon atoms. In these molecules, the tetrahedral shape of carbon bonded to four other atoms is often a repeating motif.
- Biological molecules recognize and interact with one another with a specificity based on molecular shape.

- Molecules with similar shapes can have similar biological effects.
    - For example, morphine, heroin, and other opiate drugs are similar enough in shape that they can bind to the same receptors as natural signal molecules called endorphins.
    - The binding of endorphins to receptors on brain cells produces euphoria and relieves pain. Opiates mimic these natural endorphin effects.

Concept 2.4 Chemical reactions make and break chemical bonds

- In **chemical reactions**, chemical bonds are broken and reformed, leading to new arrangements of atoms.
- The starting molecules in the process are called **reactants**, and the final molecules are called **products**.
- In a chemical reaction, all of the atoms in the reactants must be present in the products.
    - The reactions must be "balanced."
    - Matter is conserved in a chemical reaction. Chemical reactions rearrange matter; they do not create or destroy matter.
    - For example, the covalent bonds of H_2 and O_2 can recombine to form the new bonds of H_2O. Two molecules of H_2 combine with one molecule of O_2 to form two molecules of H_2O.
- Photosynthesis is an important chemical reaction.
    - Humans and other animals ultimately depend on photosynthesis for food and oxygen.
    - Green plants combine carbon dioxide (CO_2) from the air and water (H_2O) from the soil to create sugar molecules, and they release molecular oxygen (O_2) as a by-product. This chemical reaction is powered by sunlight.
    - The overall process of photosynthesis is $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$.
    - This process occurs in a sequence of individual chemical reactions that rearrange the atoms of the reactants to form the products.
- All chemical reactions are reversible, with the products in the forward reaction becoming the reactants in the reverse reaction.
    - For example, in the reaction $3\ H_2 + N_2 \leftrightarrow 2\ NH_3$, hydrogen and nitrogen molecules combine to form ammonia, but ammonia can decompose to hydrogen and nitrogen molecules.
    - Initially, when reactant concentrations are high, the reactants frequently collide to create products.
    - As products accumulate, they collide to reform reactants.
- Eventually, the rate of formation of products is the same as the rate of breakdown of products (formation of reactants), and the system is at **chemical equilibrium**.
    - At equilibrium, products and reactants are continually being formed, but there is no net change in the concentrations of reactants and products.
    - At equilibrium, the concentrations of reactants and products are typically not equal, but their concentrations have stabilized at a particular ratio.
- Some chemical reactions go to completion; that is, all the reactants are converted to products.

Chapter 2



The Chemical Context of Life

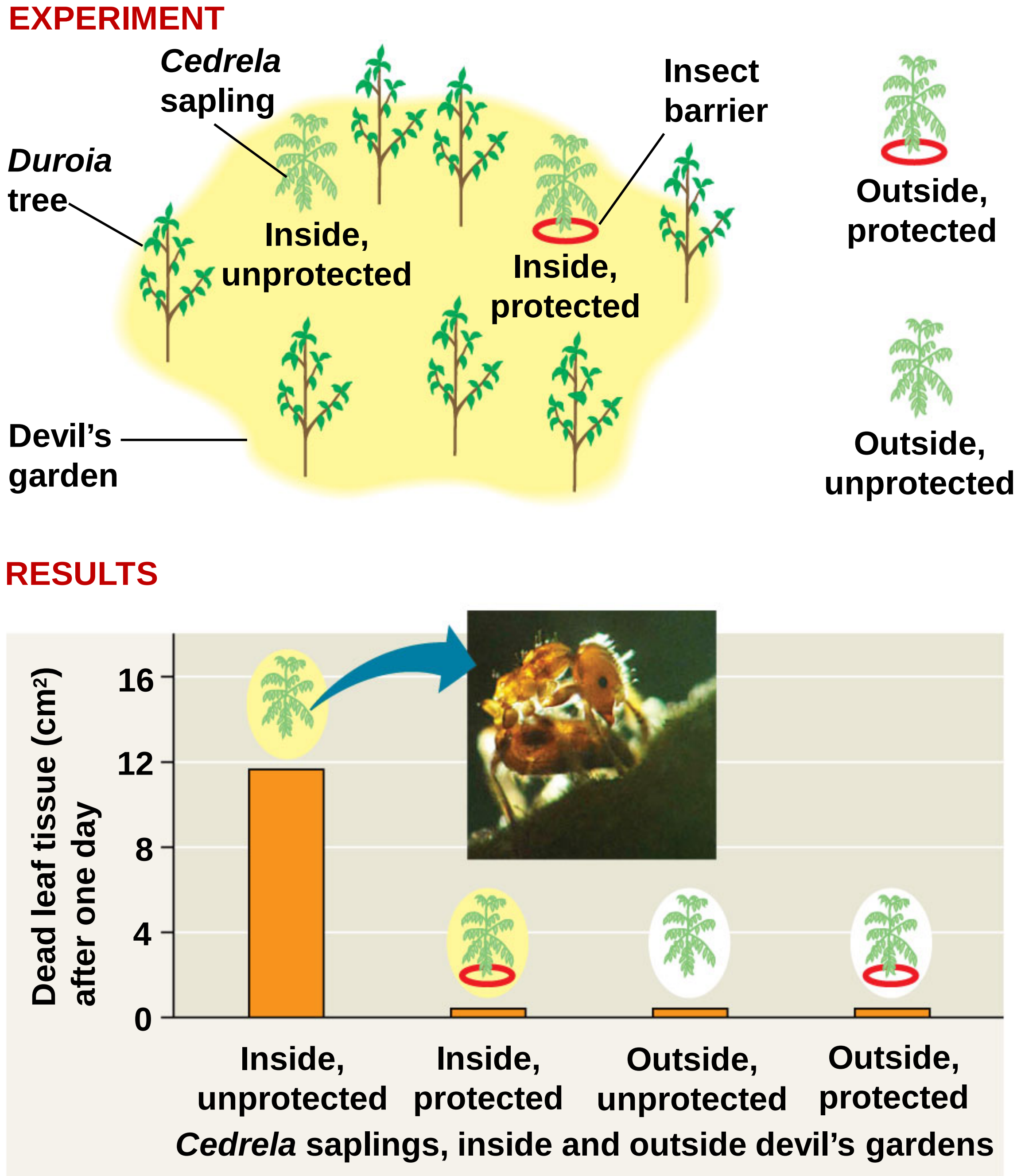
Lectures by
Erin Barley
Kathleen Fitzpatrick

Overview: A Chemical Connection to Biology

- Biology is a multidisciplinary science
- Living organisms are subject to basic laws of physics and chemistry
- One example is the use of formic acid by ants to maintain “devil’s gardens,” stands of *Duroia* trees

Figure 2.1

Figure 2.2



EXPERIMENT
Cedrela sapling
Duroia tree
Inside, unprotected
Insect barrier
Inside, protected
Outside, protected
Devil's garden
Outside, unprotected
RESULTS
Dead leaf tissue (cm²) after one day
16
12
8
4
0
Inside, unprotected
Inside, protected
Outside, unprotected
Outside, protected
Cedrela saplings, inside and outside devil's gardens

Figure 2.2a

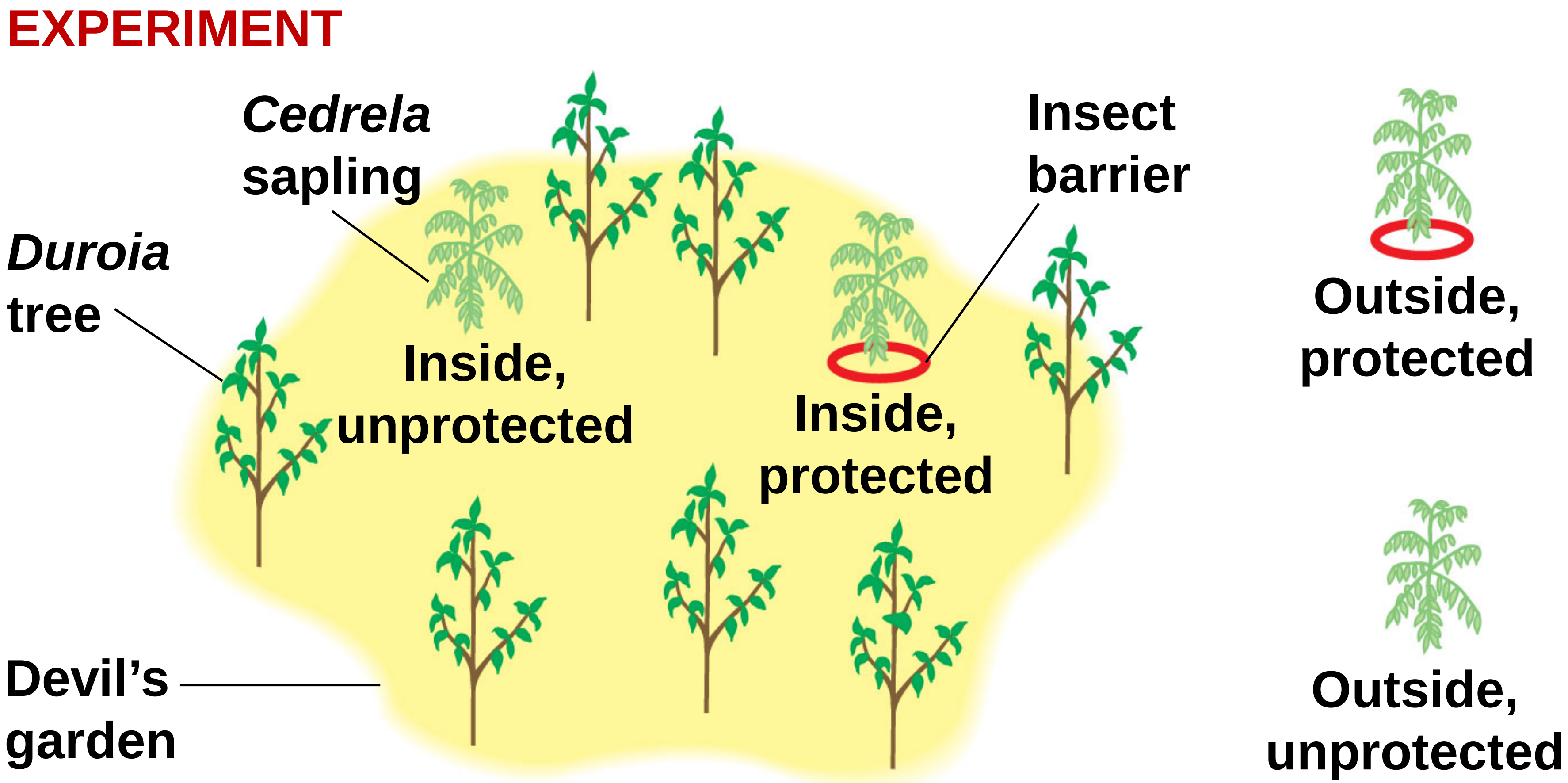
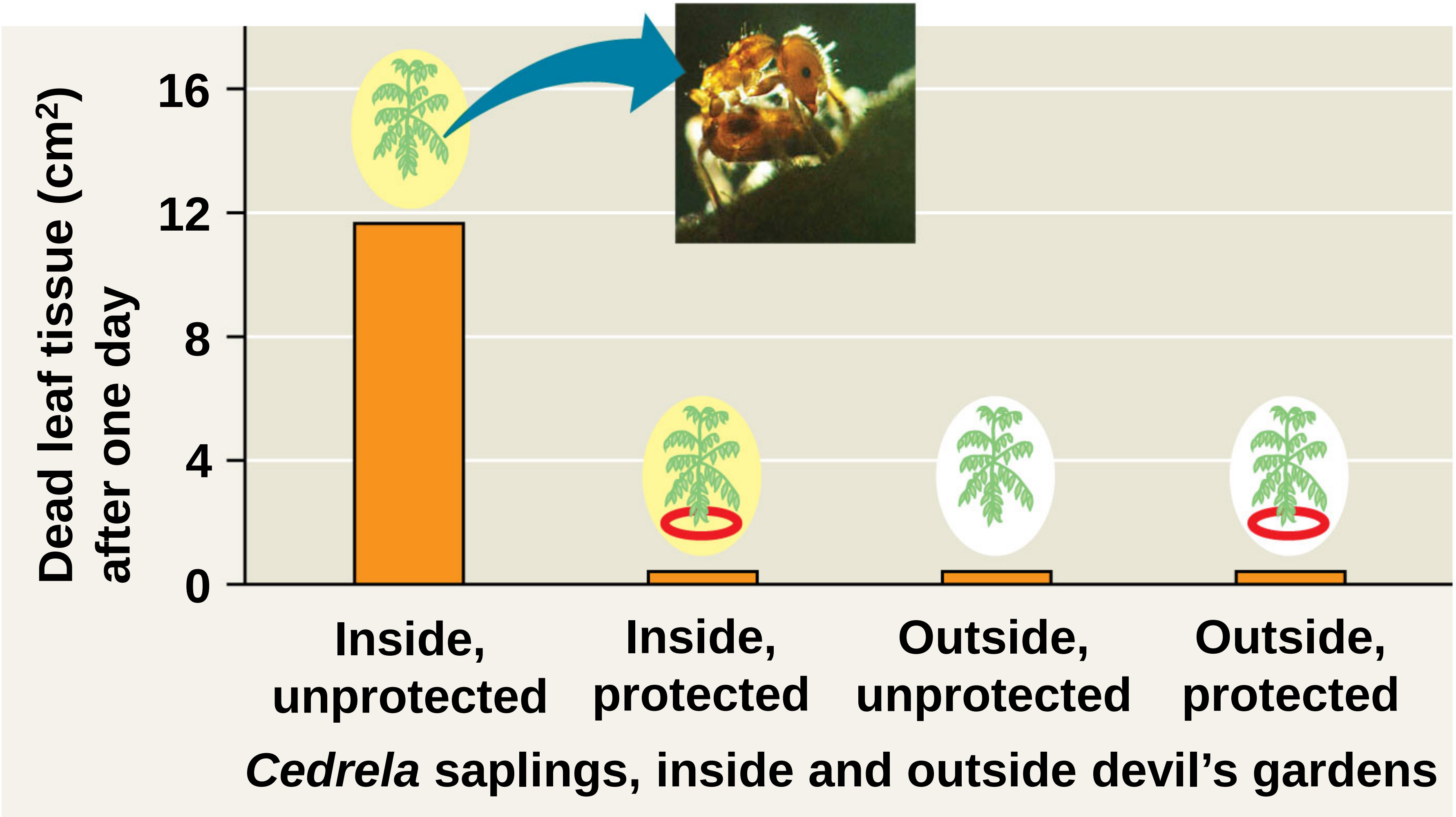

EXPERIMENT
Cedrela sapling
Duroia tree
Insect barrier
Inside, unprotected
Inside, protected
Outside, protected
Outside, unprotected
Devil's garden

Figure 2.2b

RESULTS



Concept 2.1: Matter consists of chemical elements in pure form and in combinations called compounds

- Organisms are composed of **matter**
- Matter is anything that takes up space and has mass

Elements and Compounds

- Matter is made up of elements
- An **element** is a substance that cannot be broken down to other substances by chemical reactions
- A **compound** is a substance consisting of two or more elements in a fixed ratio
- A compound has characteristics different from those of its elements

Figure 2.3

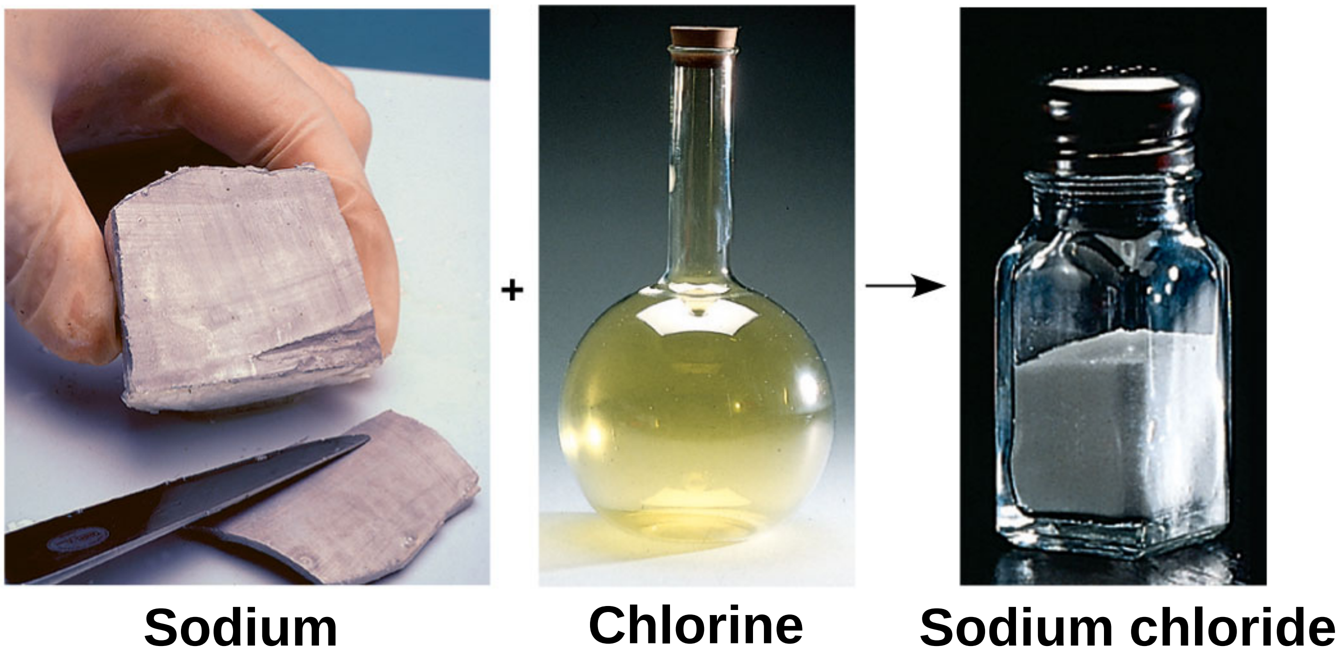


Figure 2.3a

Sodium

Figure 2.3b

Chlorine

Figure 2.3c

Sodium chloride

The Elements of Life

- About 20–25% of the 92 elements are essential to life
- Carbon, hydrogen, oxygen, and nitrogen make up 96% of living matter
- Most of the remaining 4% consists of calcium, phosphorus, potassium, and sulfur
- **Trace elements** are those required by an organism in minute quantities

Table 2.1

Table 2.1 Elements in the Human Body

Element	Symbol	Percentage of Body Mass (including water)	
Oxygen	O	65.0%	96.3%
Carbon	C	18.5%	
Hydrogen	H	9.5%	
Nitrogen	N	3.3%	
Calcium	Ca	1.5%	3.7%
Phosphorus	P	1.0%	
Potassium	K	0.4%	
Sulfur	S	0.3%	
Sodium	Na	0.2%	
Chlorine	Cl	0.2%	
Magnesium	Mg	0.1%	

Trace elements (less than 0.01% of mass): Boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), zinc (Zn)

Case Study: Evolution of Tolerance to Toxic Elements

- Some elements can be toxic, for example, arsenic
- Some species can become adapted to environments containing toxic elements
  - For example, some plant communities are adapted to serpentine

Figure 2.4

Figure 2.4a

Figure 2.4b

Figure 2.4c

Concept 2.2: An element's properties depend on the structure of its atoms

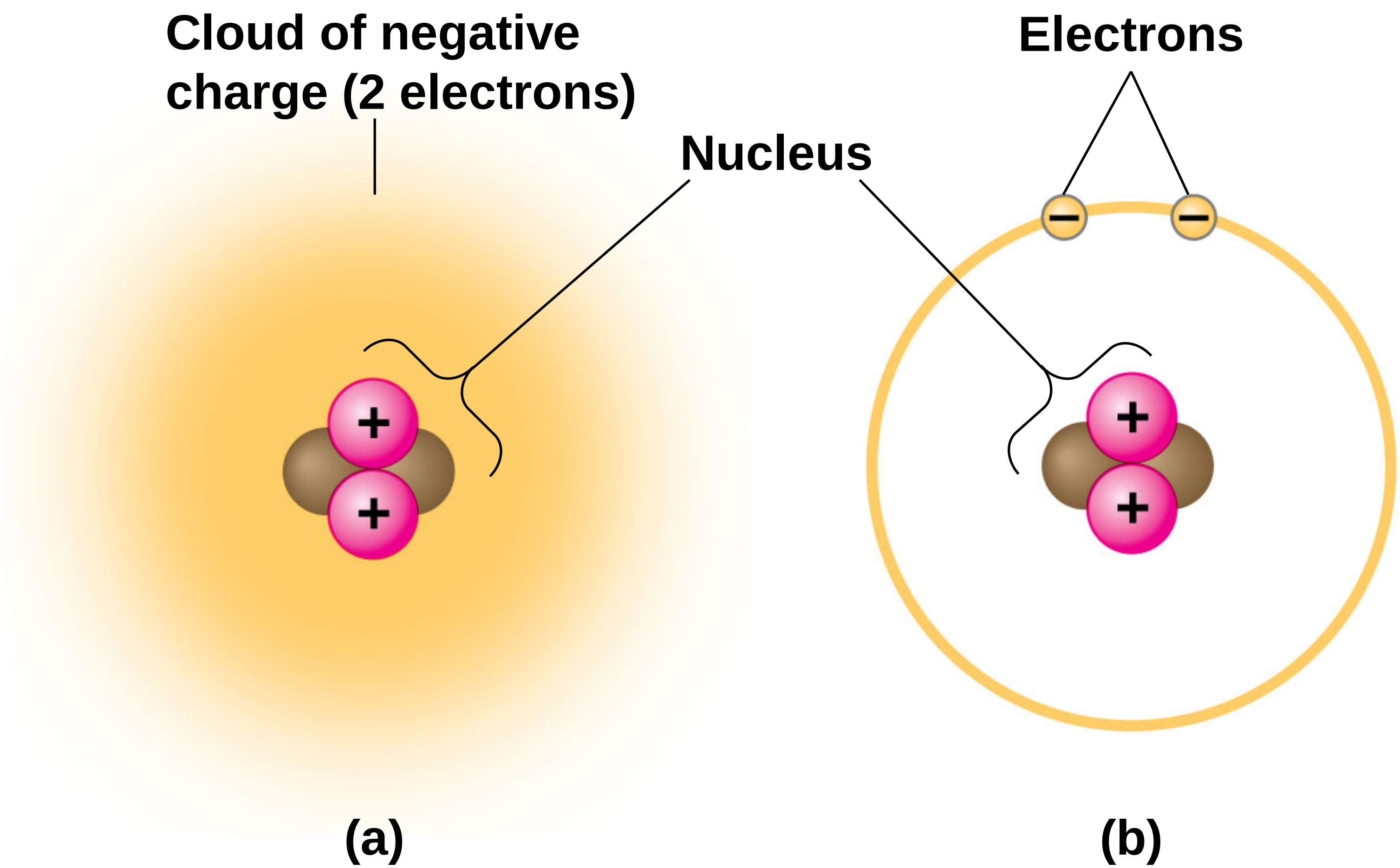
- Each element consists of unique atoms
- An **atom** is the smallest unit of matter that still retains the properties of an element

Subatomic Particles

- Atoms are composed of subatomic particles
- Relevant subatomic particles include
  - **Neutrons** (no electrical charge)
  - **Protons** (positive charge)
  - **Electrons** (negative charge)

- Neutrons and protons form the **atomic nucleus**
- Electrons form a cloud around the nucleus
- Neutron mass and proton mass are almost identical and are measured in **daltons**

Figure 2.5



Atomic Number and Atomic Mass

- Atoms of the various elements differ in number of subatomic particles
- An element's **atomic number** is the number of protons in its nucleus
- An element's **mass number** is the sum of protons plus neutrons in the nucleus
- **Atomic mass**, the atom's total mass, can be approximated by the mass number

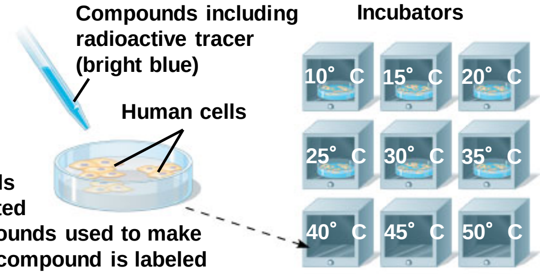
Isotopes

- All atoms of an element have the same number of protons but may differ in number of neutrons
- **Isotopes** are two atoms of an element that differ in number of neutrons
- **Radioactive isotopes** decay spontaneously, giving off particles and energy

- Some applications of radioactive isotopes in biological research are
  - Dating fossils
  - Tracing atoms through metabolic processes
  - Diagnosing medical disorders

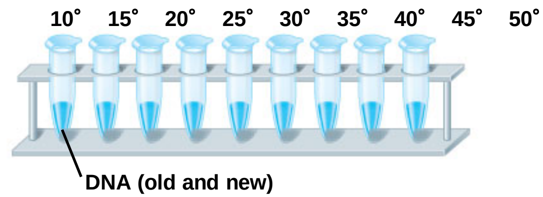
Figure 2.6

TECHNIQUE



1 Human cells are incubated with compounds used to make DNA. One compound is labeled with ^{3}H.

2 Cells from each incubator are placed in tubes; their DNA is isolated; and unused labeled compounds are removed.



3 The test tubes are placed in a scintillation counter.

RESULTS

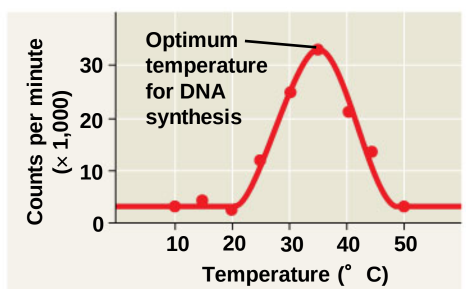
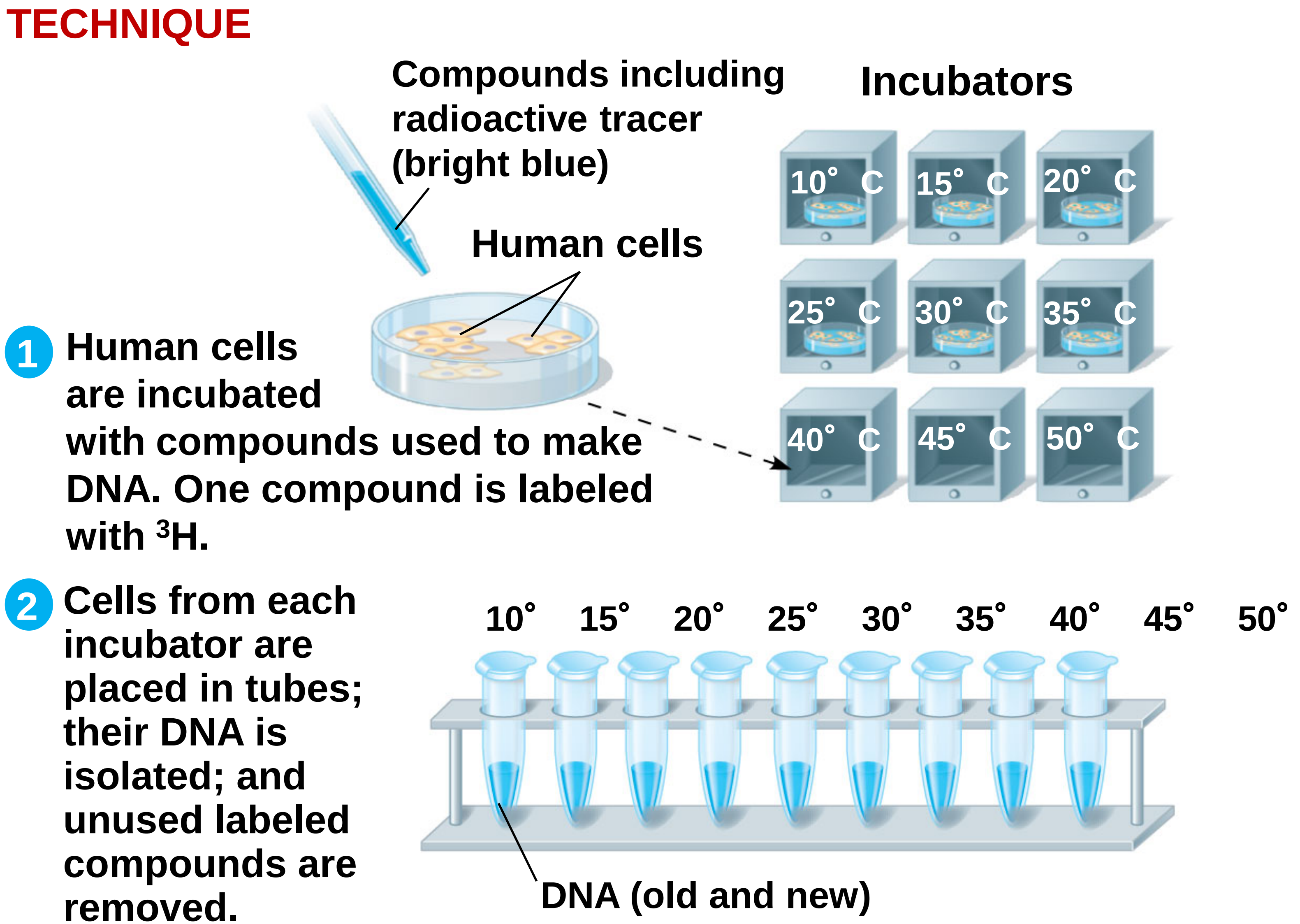


Figure 2.6a



TECHNIQUE
Compounds including radioactive tracer (bright blue)
Incubators
10° C
15° C
20° C
25° C
30° C
35° C
40° C
45° C
50° C
Human cells
1 Human cells are incubated with compounds used to make DNA. One compound is labeled with ^{3}H.
2 Cells from each incubator are placed in tubes; their DNA is isolated; and unused labeled compounds are removed.
10°
15°
20°
25°
30°
35°
40°
45°
50°
DNA (old and new)

Figure 2.6b

TECHNIQUE

3 **The test tubes are placed in a scintillation counter.**

Figure 2.6c

RESULTS

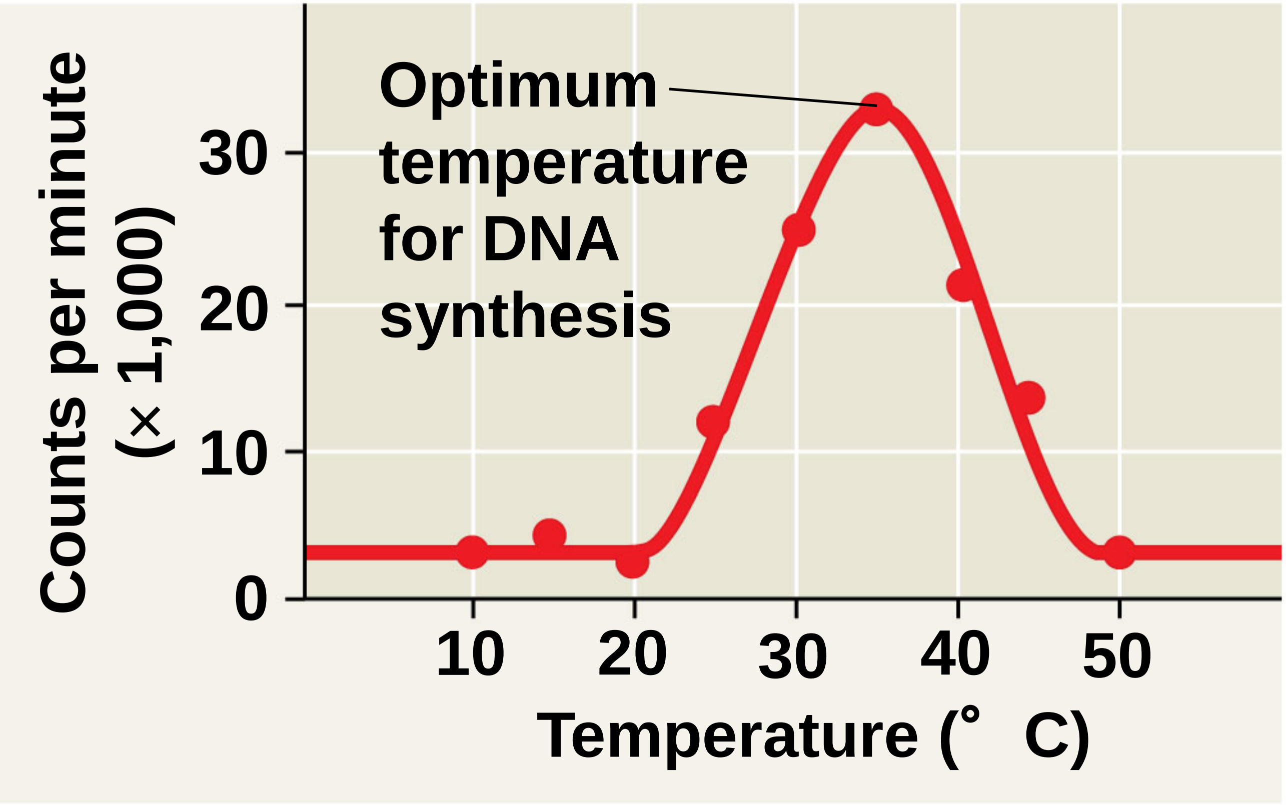
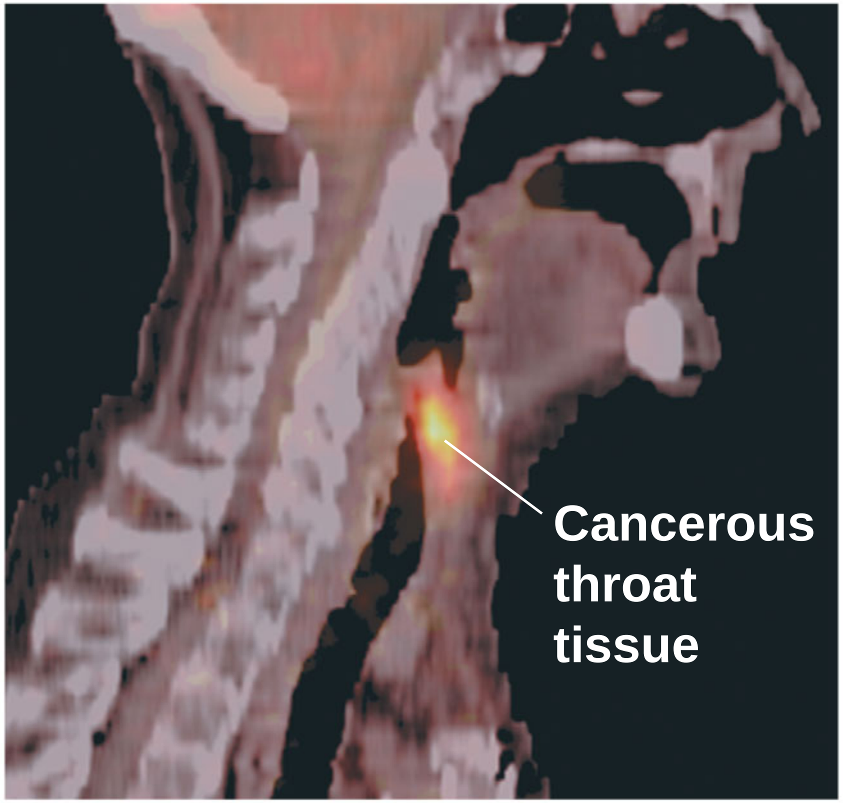


Figure 2.7

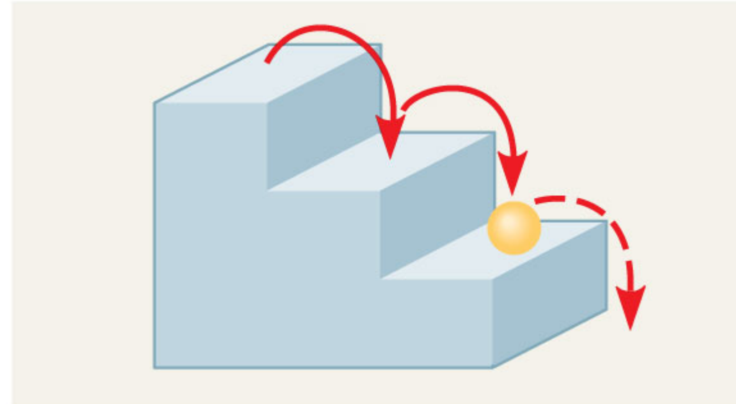


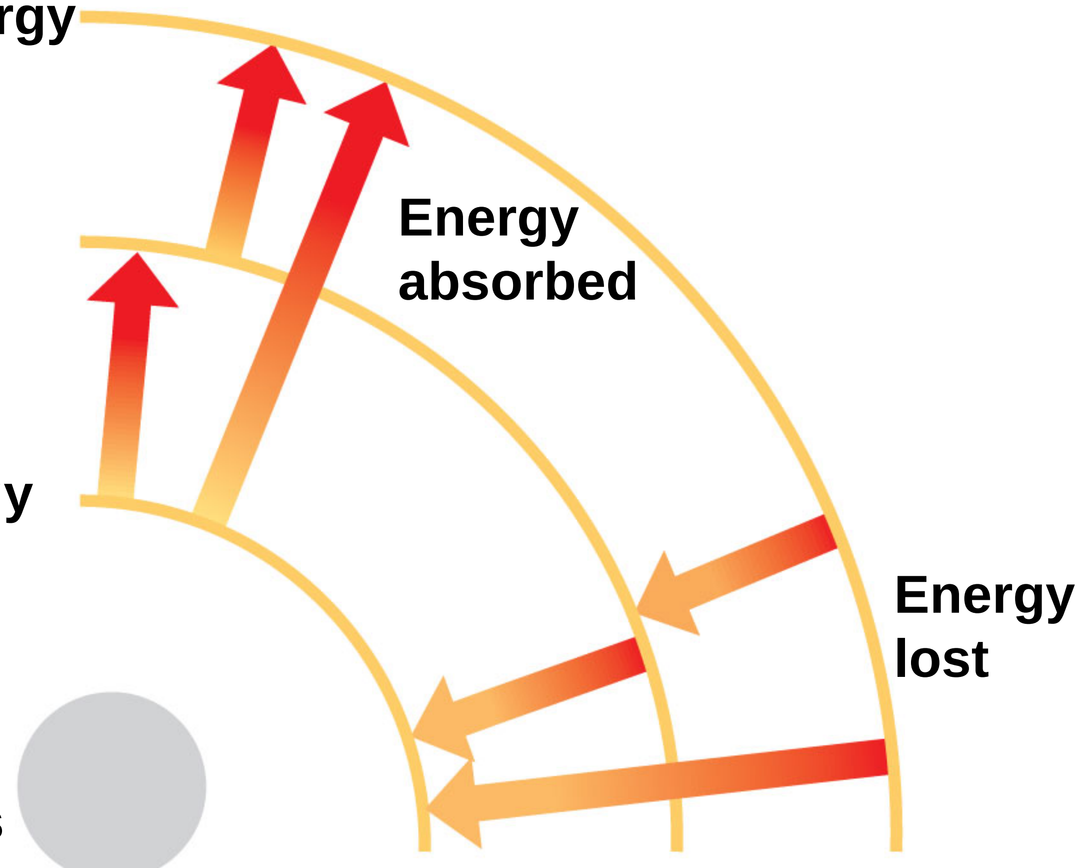
The Energy Levels of Electrons

- **Energy** is the capacity to cause change
- **Potential energy** is the energy that matter has because of its location or structure
- The electrons of an atom differ in their amounts of potential energy
- An electron's state of potential energy is called its energy level, or **electron shell**

Figure 2.8

(a) A ball bouncing down a flight of stairs provides an analogy for energy levels of electrons.



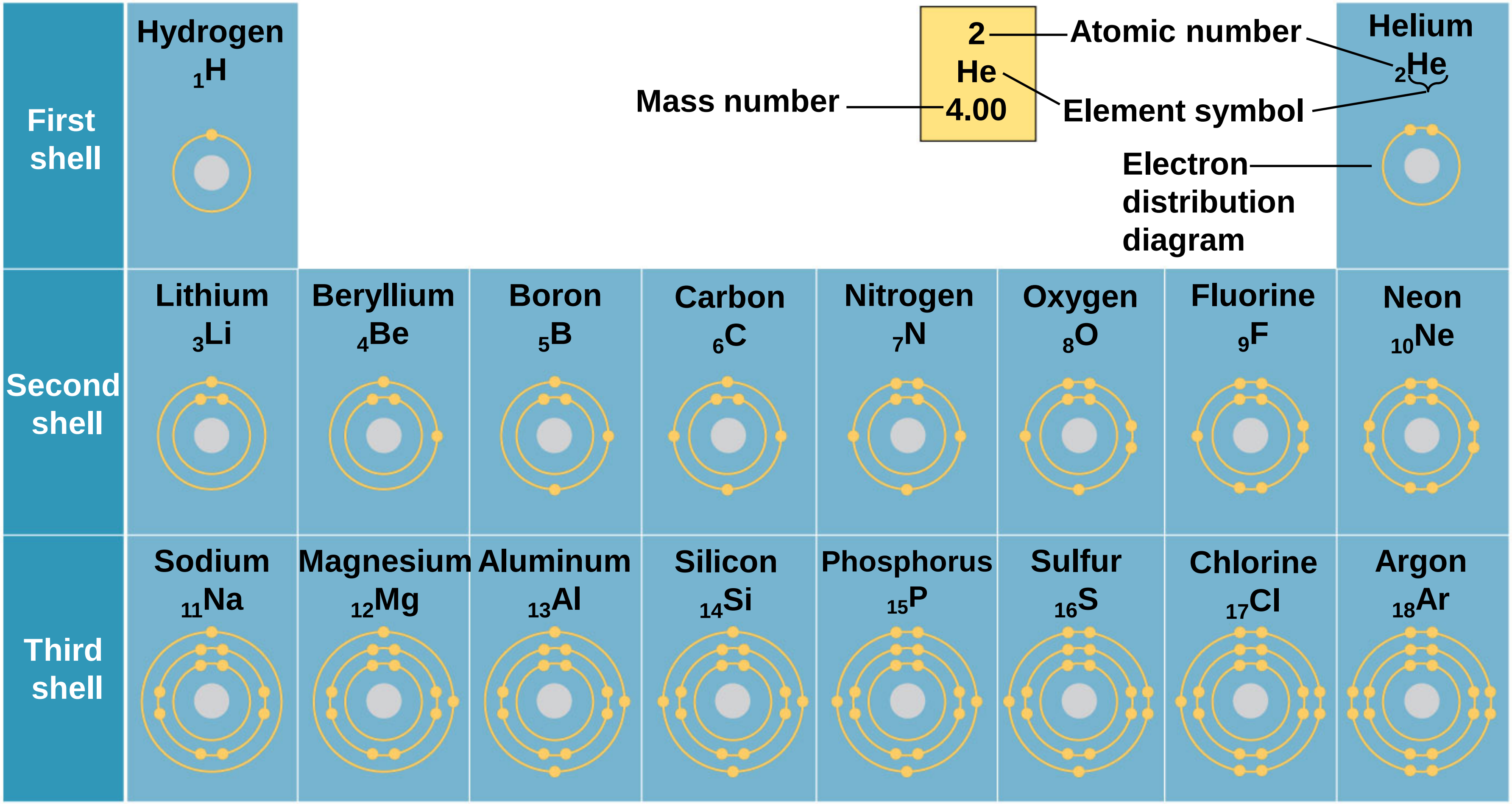


(b)

Electron Distribution and Chemical Properties

- The chemical behavior of an atom is determined by the distribution of electrons in electron shells
- The periodic table of the elements shows the electron distribution for each element

Figure 2.9



First shell
Hydrogen
1H
2
He
4.00
Atomic number
Mass number
Element symbol
Electron distribution diagram
Helium
2He
Second shell
Lithium
3Li
Beryllium
4Be
Boron
5B
Carbon
6C
Nitrogen
7N
Oxygen
8O
Fluorine
9F
Neon
10Ne
Third shell
Sodium
11Na
Magnesium
12Mg
Aluminum
13Al
Silicon
14Si
Phosphorus
15P
Sulfur
16S
Chlorine
17Cl
Argon
18Ar

- **Valence electrons** are those in the outermost shell, or **valence shell**
- The chemical behavior of an atom is mostly determined by the valence electrons
- Elements with a full valence shell are chemically inert

Electron Orbitals

- An **orbital** is the three-dimensional space where an electron is found 90% of the time
- Each electron shell consists of a specific number of orbitals

Figure 2.10

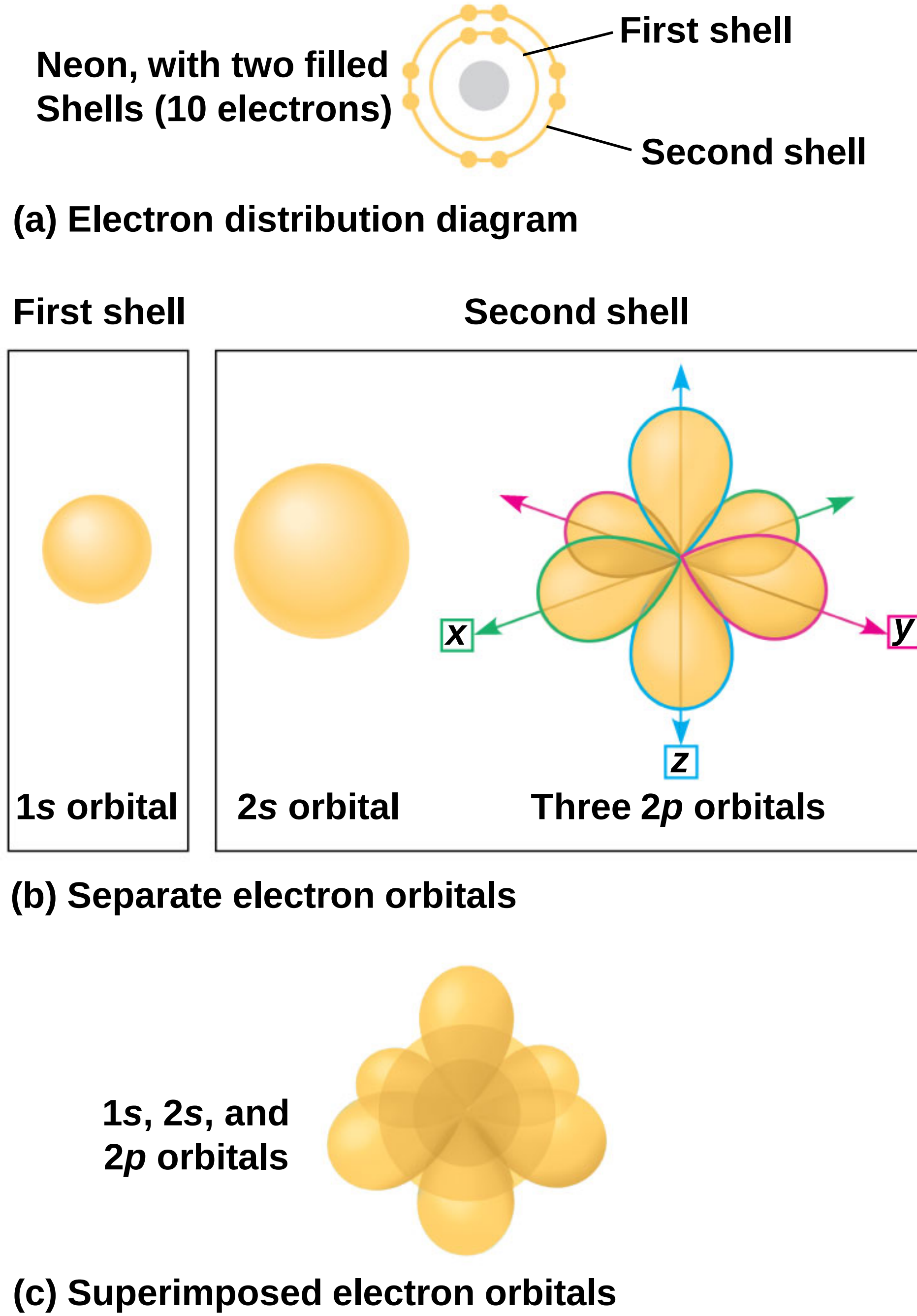
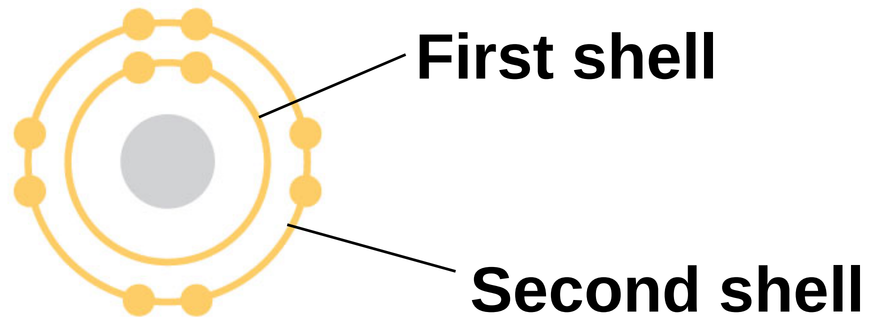

Neon, with two filled Shells (10 electrons)
First shell
Second shell
(a) Electron distribution diagram
First shell
Second shell
1s orbital
2s orbital
x
y
z
Three 2p orbitals
(b) Separate electron orbitals
1s, 2s, and 2p orbitals
(c) Superimposed electron orbitals

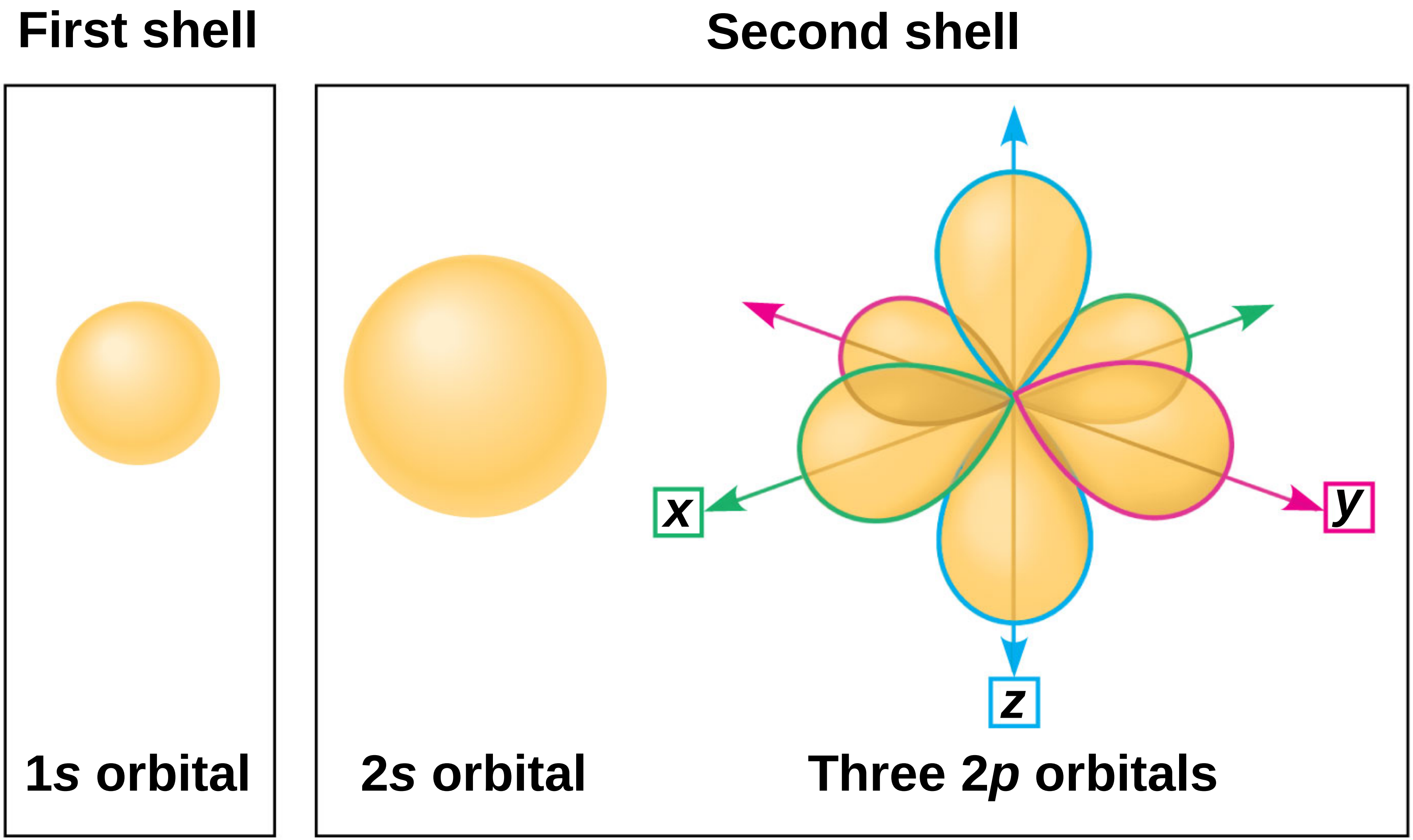
Figure 2.10a

Neon, with two filled
Shells (10 electrons)



(a) Electron distribution diagram

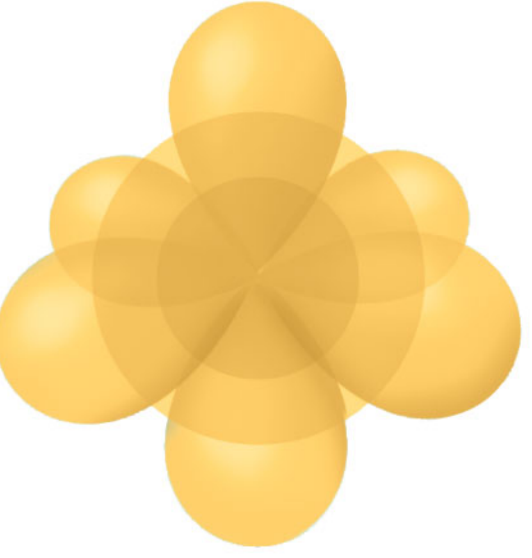
Figure 2.10b



(b) Separate electron orbitals

Figure 2.10c

1*s*, 2*s*, and 2*p* orbitals



(c) Superimposed electron orbitals

Concept 2.3: The formation and function of molecules depend on chemical bonding between atoms

- Atoms with incomplete valence shells can share or transfer valence electrons with certain other atoms
- These interactions usually result in atoms staying close together, held by attractions called **chemical bonds**

Covalent Bonds

- A **covalent bond** is the sharing of a pair of valence electrons by two atoms
- In a covalent bond, the shared electrons count as part of each atom's valence shell

Figure 2.11-1

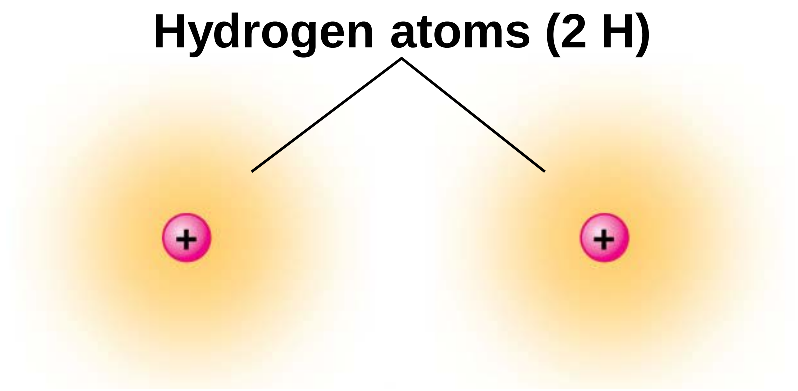


Figure 2.11-2

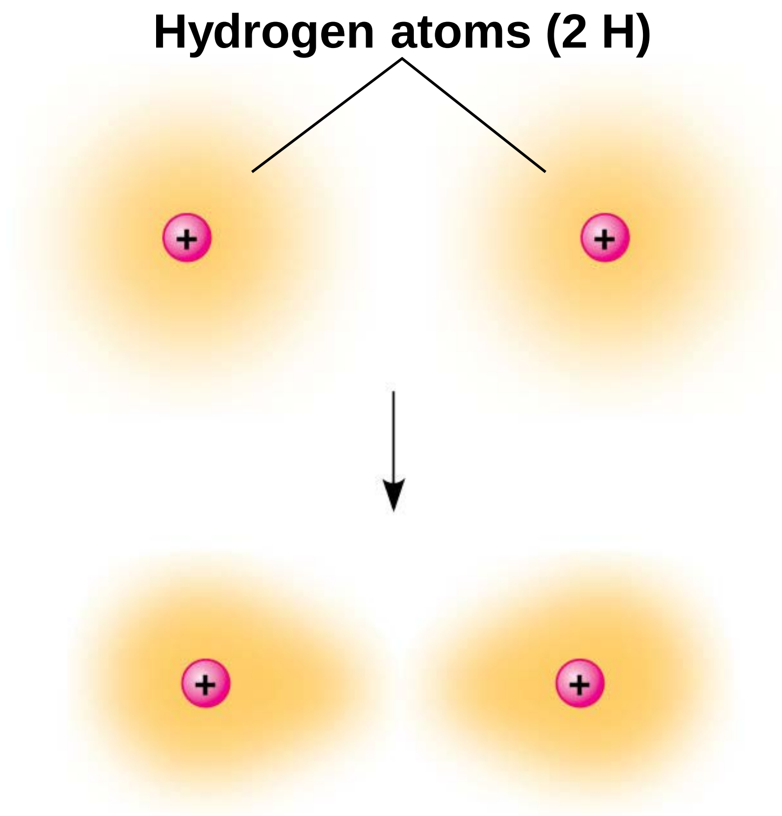
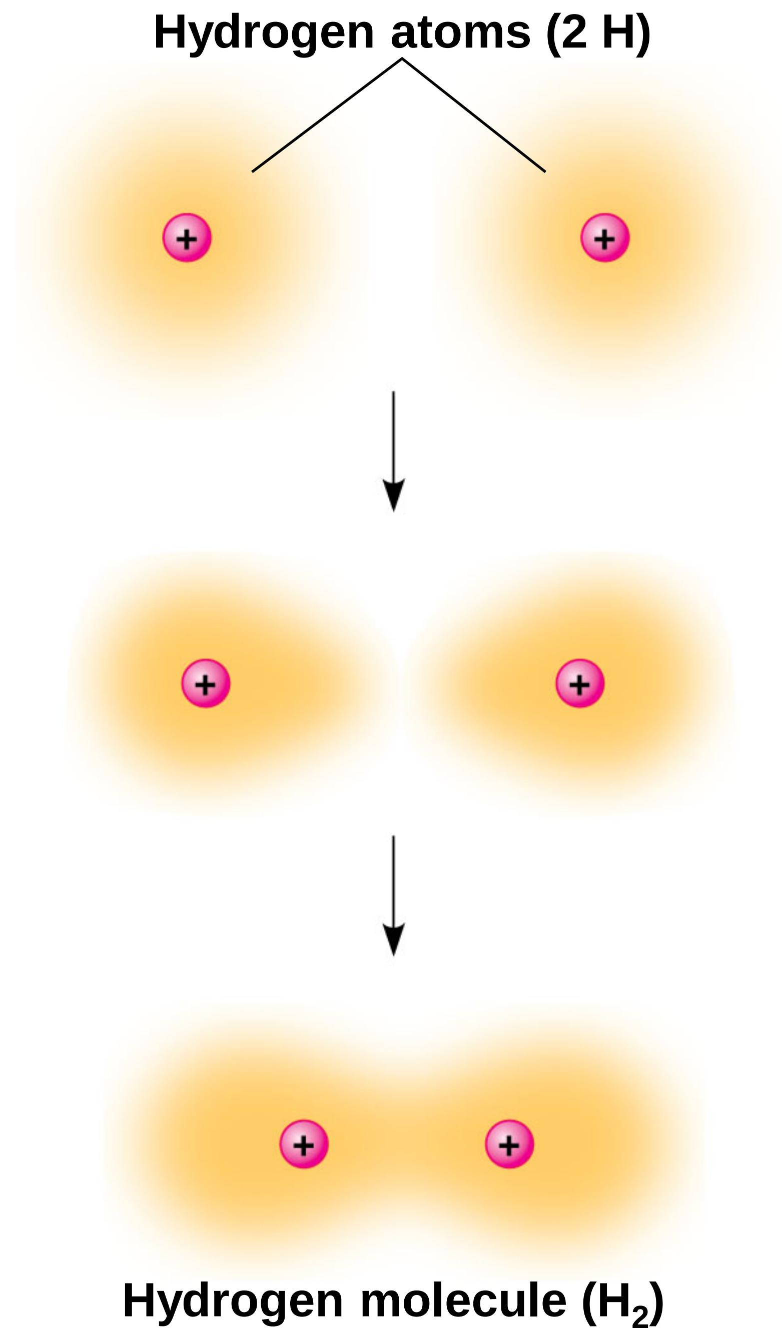


Figure 2.11-3



- A **molecule** consists of two or more atoms held together by covalent bonds
- A single covalent bond, or **single bond**, is the sharing of one pair of valence electrons
- A double covalent bond, or **double bond**, is the sharing of two pairs of valence electrons

- The notation used to represent atoms and bonding is called a **structural formula**
  - For example, H—H
- This can be abbreviated further with a **molecular formula**
  - For example, H_2

PLAY Animation: Covalent Bonds

Figure 2.12

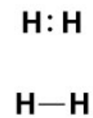
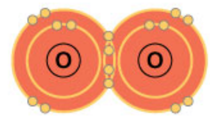
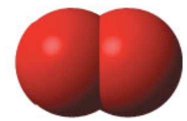
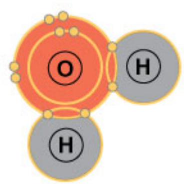
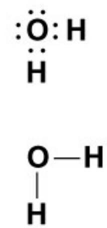
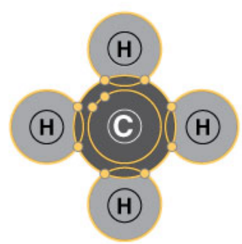
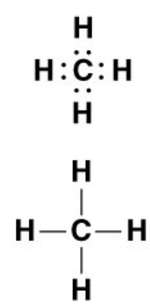
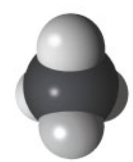
Name and Molecular Formula	Electron Distribution Diagram	Lewis Dot Structure and Structural Formula	Space-Filling Model
(a) Hydrogen (H_2)			
(b) Oxygen (O_2)			
(c) Water (H_2O)			
(d) Methane (CH_4)			

Figure 2.12a

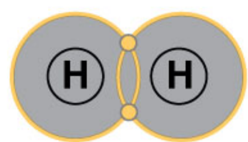
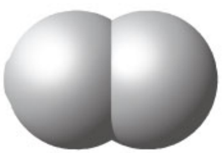
Name and Molecular Formula	Electron Distribution Diagram	Lewis Dot Structure and Structural Formula	Space-Filling Model
(a) Hydrogen (H_2)		**H : H** **H—H**	

Figure 2.12b

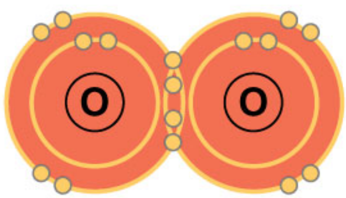
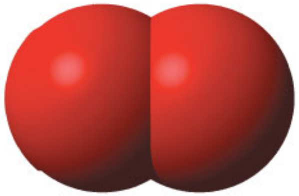
Name and Molecular Formula	Electron Distribution Diagram	Lewis Dot Structure and Structural Formula	Space-Filling Model
(b) Oxygen (O_2)		 $O{=}O$	

Figure 2.12c

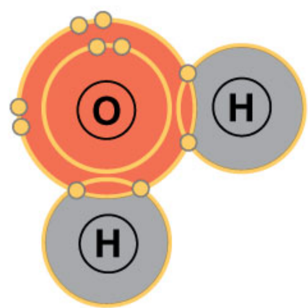
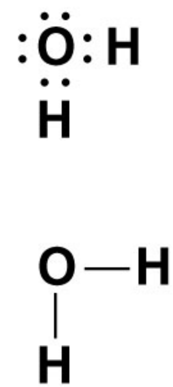
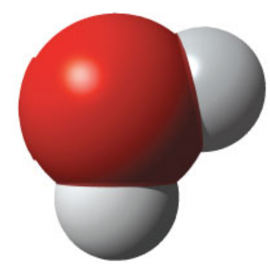
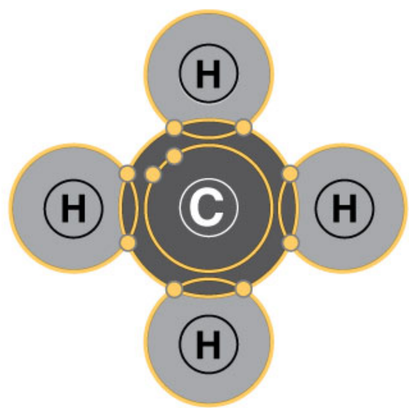
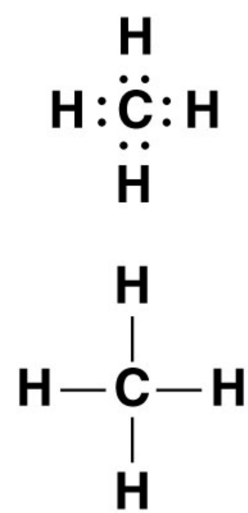
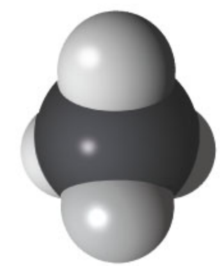
Name and Molecular Formula	Electron Distribution Diagram	Lewis Dot Structure and Structural Formula	Space-Filling Model
(c) Water (H_2O)			

Figure 2.12d

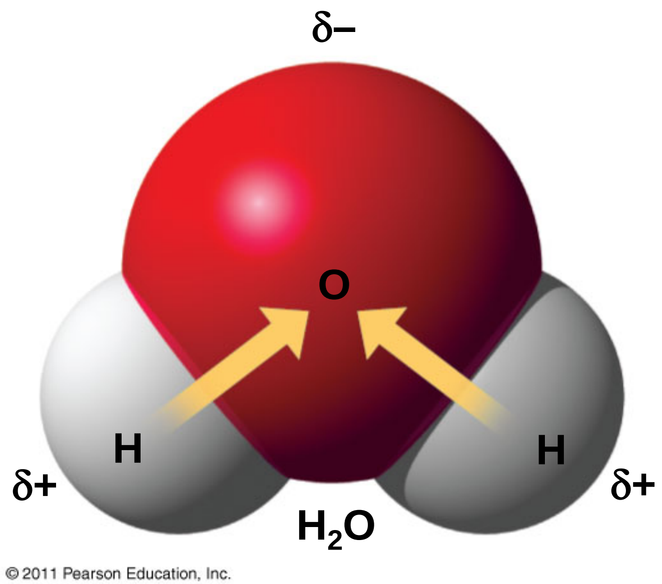
Name and Molecular Formula	Electron Distribution Diagram	Lewis Dot Structure and Structural Formula	Space-Filling Model
(d) Methane (CH_4)			

- Covalent bonds can form between atoms of the same element or atoms of different elements
- A compound is a combination of two or more different elements
- Bonding capacity is called the atom's **valence**

- Atoms in a molecule attract electrons to varying degrees
- **Electronegativity** is an atom’s attraction for the electrons in a covalent bond
- The more electronegative an atom, the more strongly it pulls shared electrons toward itself

- In a **nonpolar covalent bond**, the atoms share the electron equally
- In a **polar covalent bond**, one atom is more electronegative, and the atoms do not share the electron equally
- Unequal sharing of electrons causes a partial positive or negative charge for each atom or molecule

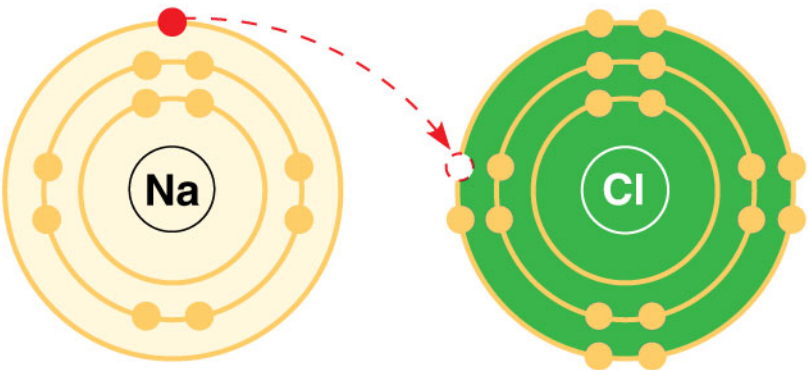
Figure 2.13



Ionic Bonds

- Atoms sometimes strip electrons from their bonding partners
- An example is the transfer of an electron from sodium to chlorine
- After the transfer of an electron, both atoms have charges
- A charged atom (or molecule) is called an **ion**

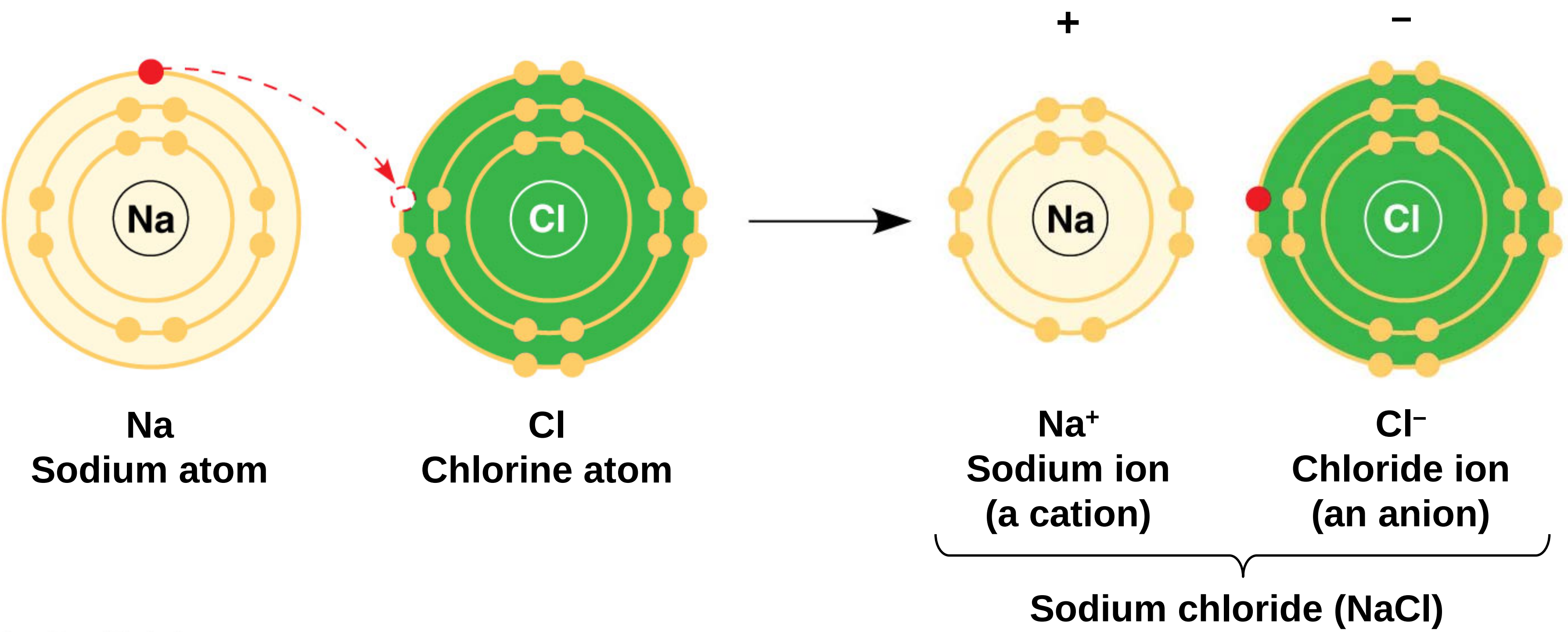
Figure 2.14-1



Na
Sodium atom

Cl
Chlorine atom

Figure 2.14-2


+
−
Na
Cl
Na
Cl
Na
Sodium atom
Cl
Chlorine atom
Na^+
Sodium ion
(a cation)
Cl^-
Chloride ion
(an anion)
Sodium chloride (NaCl)

- A **cation** is a positively charged ion
- An **anion** is a negatively charged ion
- An **ionic bond** is an attraction between an anion and a cation

PLAY Animation: Ionic Bonds

- Compounds formed by ionic bonds are called **ionic compounds**, or **salts**
- Salts, such as sodium chloride (table salt), are often found in nature as crystals

Figure 2.15

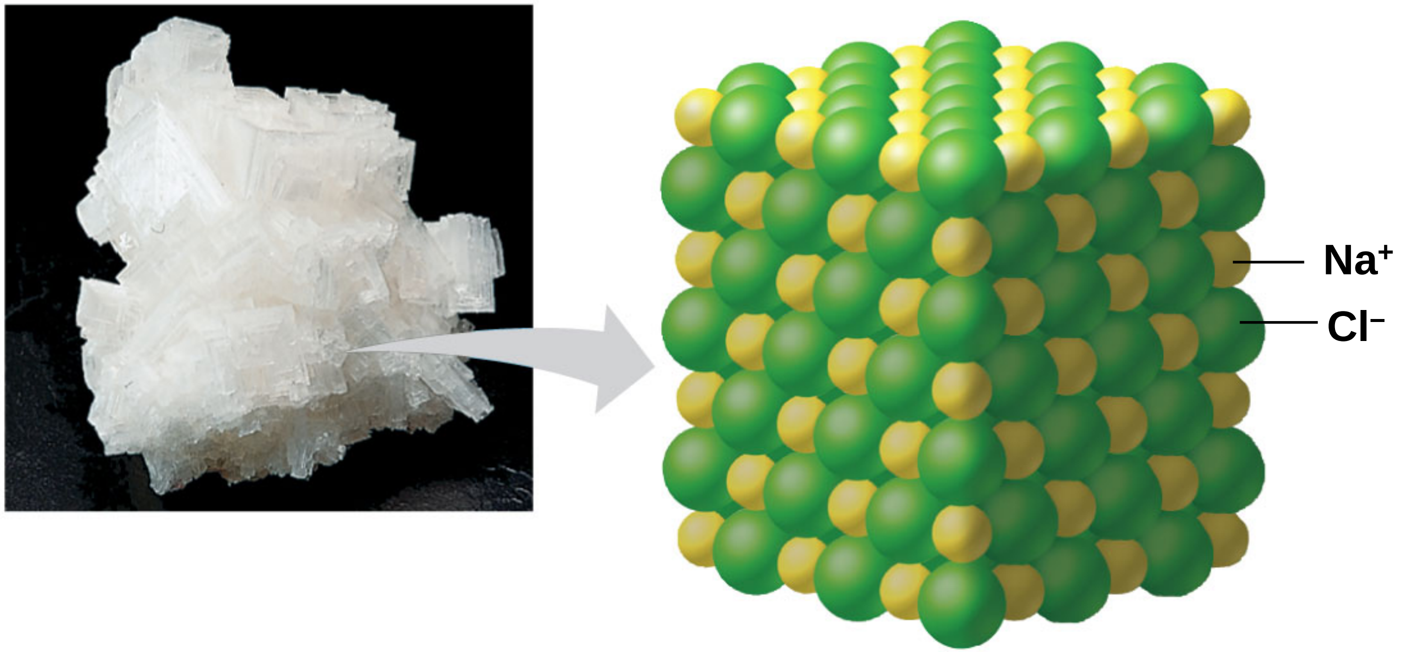
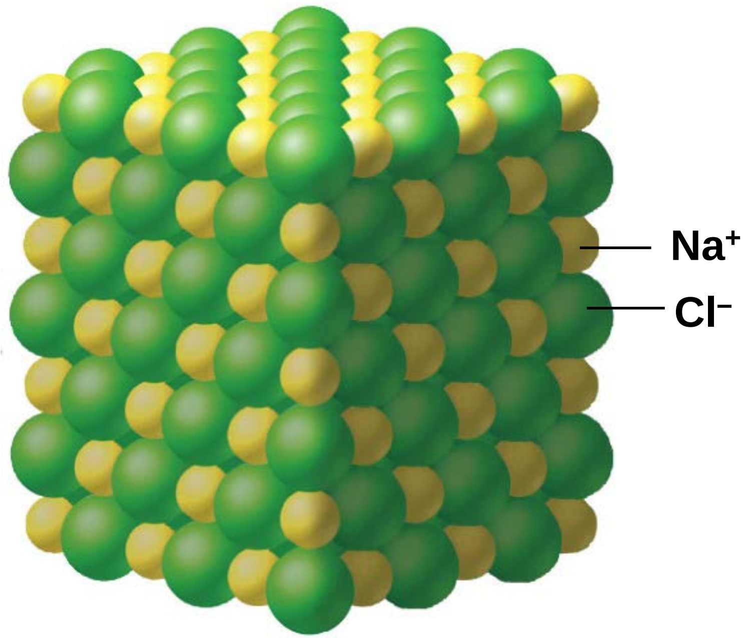


Figure 2.15a

Figure 2.15



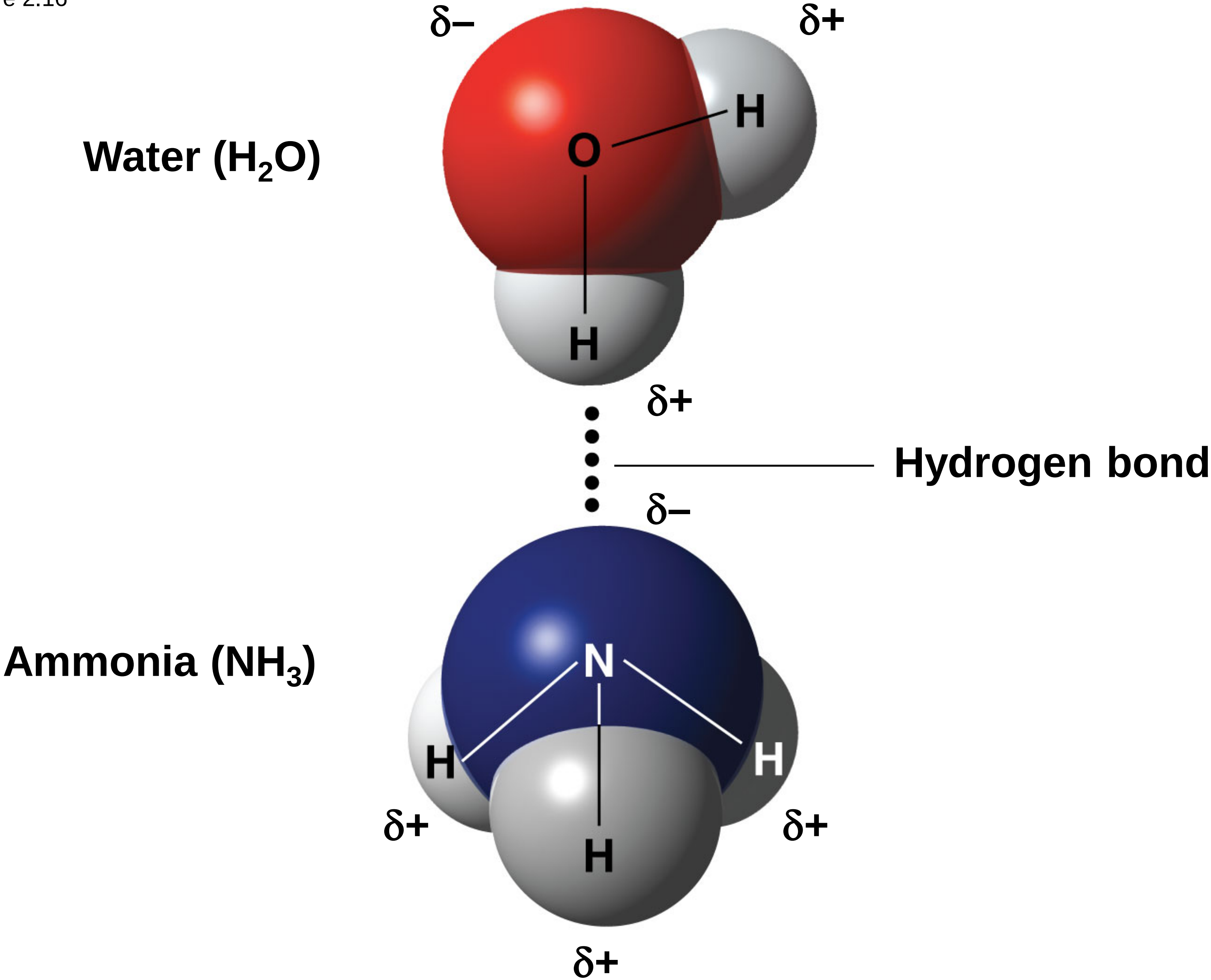
Weak Chemical Bonds

- Most of the strongest bonds in organisms are covalent bonds that form a cell's molecules
- Weak chemical bonds, such as ionic bonds and hydrogen bonds, are also important
- Weak chemical bonds reinforce shapes of large molecules and help molecules adhere to each other

Hydrogen Bonds

- A **hydrogen bond** forms when a hydrogen atom covalently bonded to one electronegative atom is also attracted to another electronegative atom
- In living cells, the electronegative partners are usually oxygen or nitrogen atoms

Figure 2.16

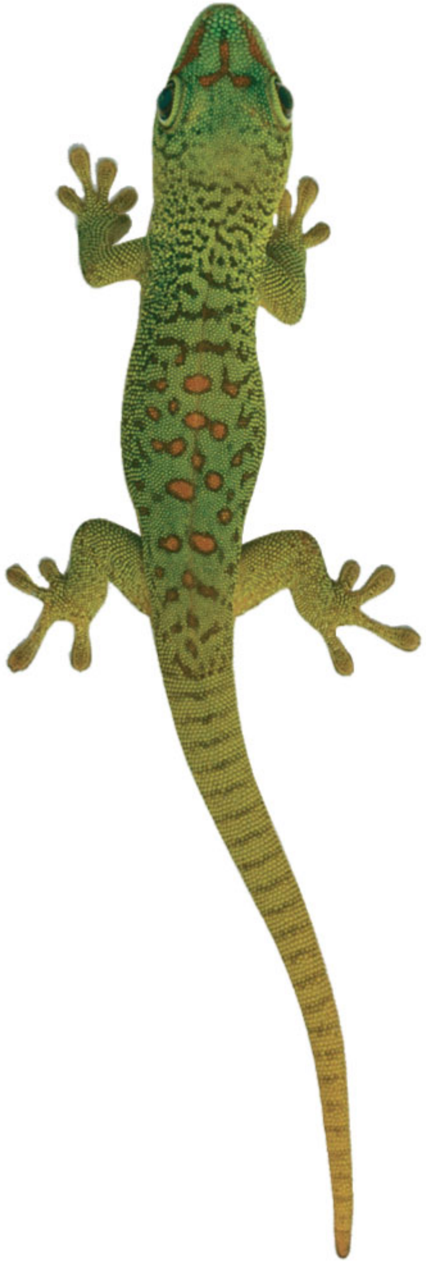


Van der Waals Interactions

- If electrons are distributed asymmetrically in molecules or atoms, they can result in “hot spots” of positive or negative charge
- **Van der Waals interactions** are attractions between molecules that are close together as a result of these charges

- Collectively, such interactions can be strong, as between molecules of a gecko’s toe hairs and a wall surface

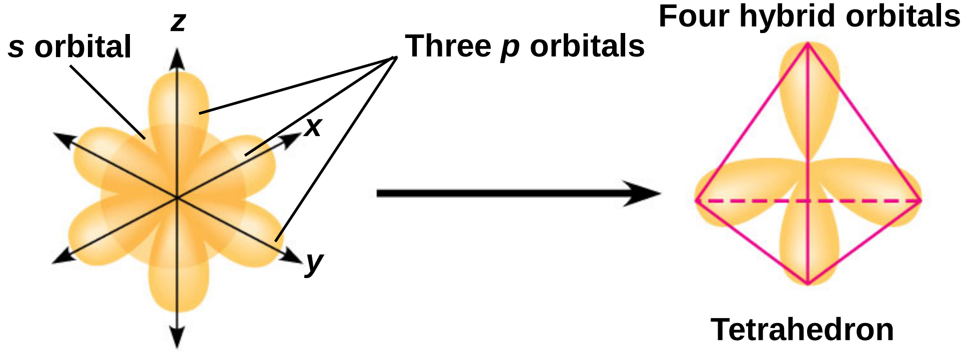
Figure 2.UN01



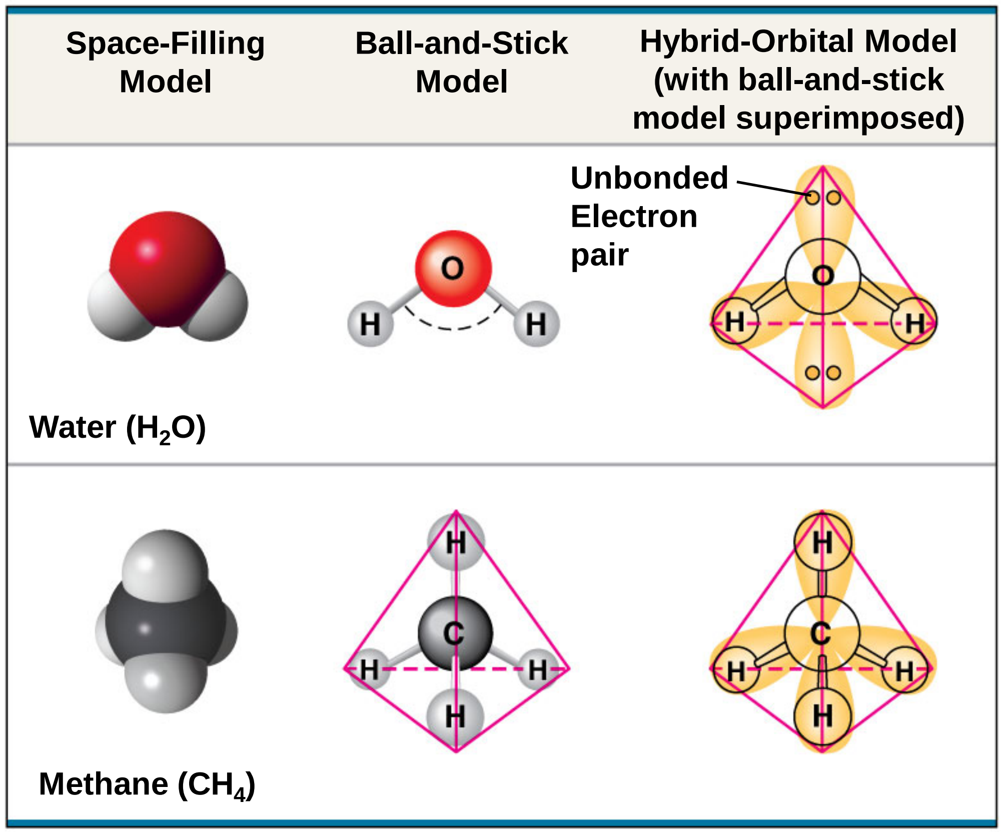
Molecular Shape and Function

- A molecule's shape is usually very important to its function
- A molecule's shape is determined by the positions of its atoms' valence orbitals
- In a covalent bond, the *s* and *p* orbitals may hybridize, creating specific molecular shapes

Figure 2.17

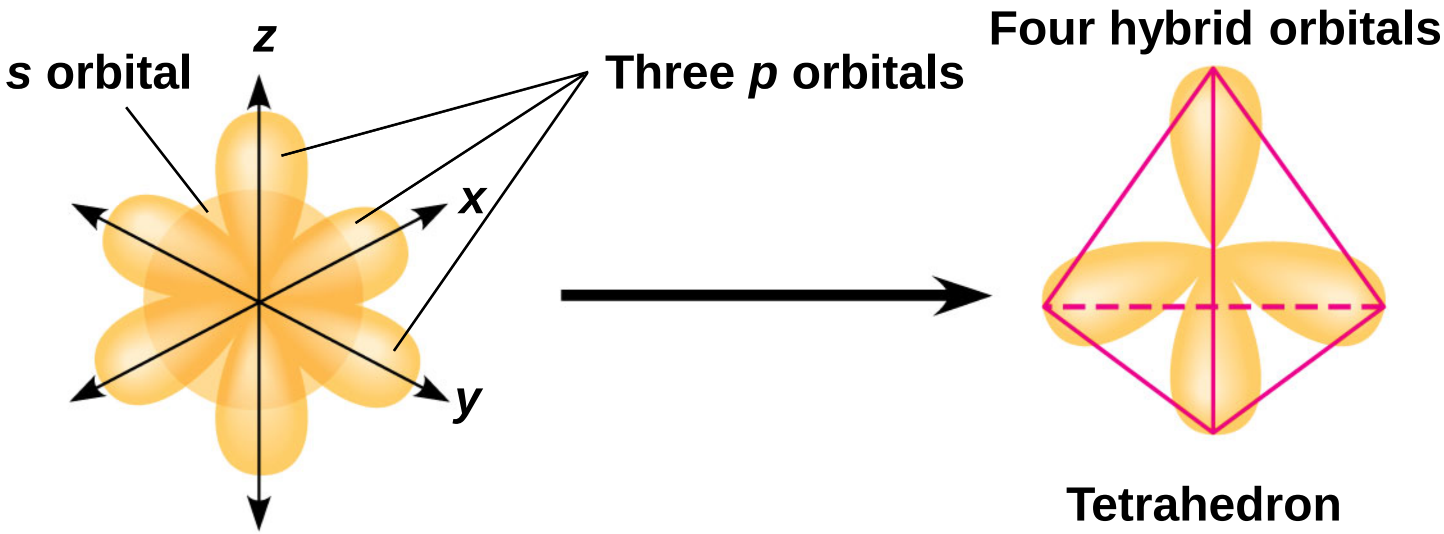


(a) Hybridization of orbitals



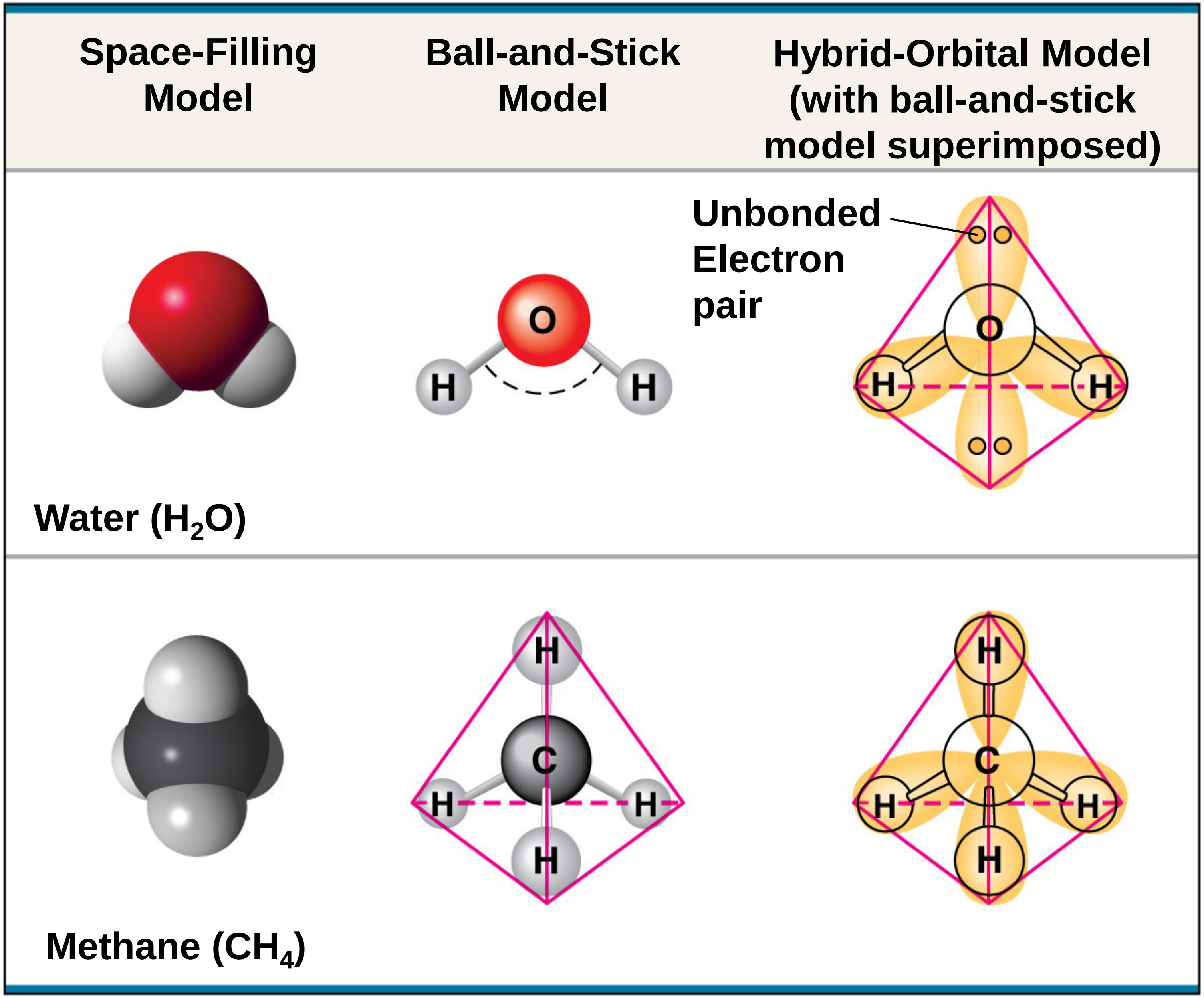
(b) Molecular-shape models

Figure 2.17a



(a) Hybridization of orbitals

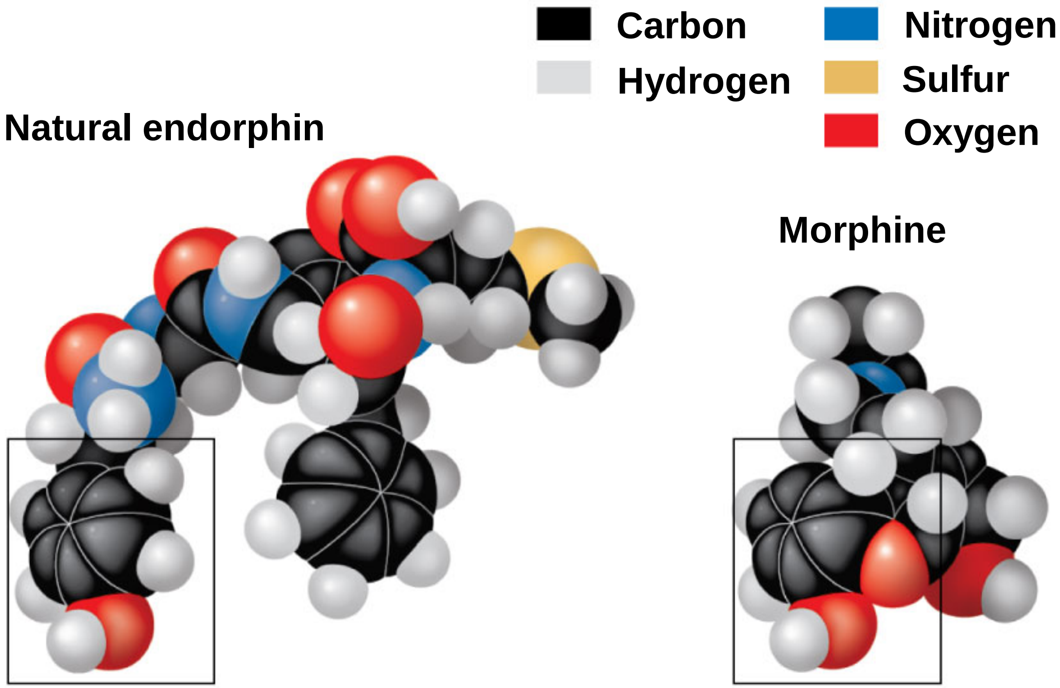
Figure 2.17b



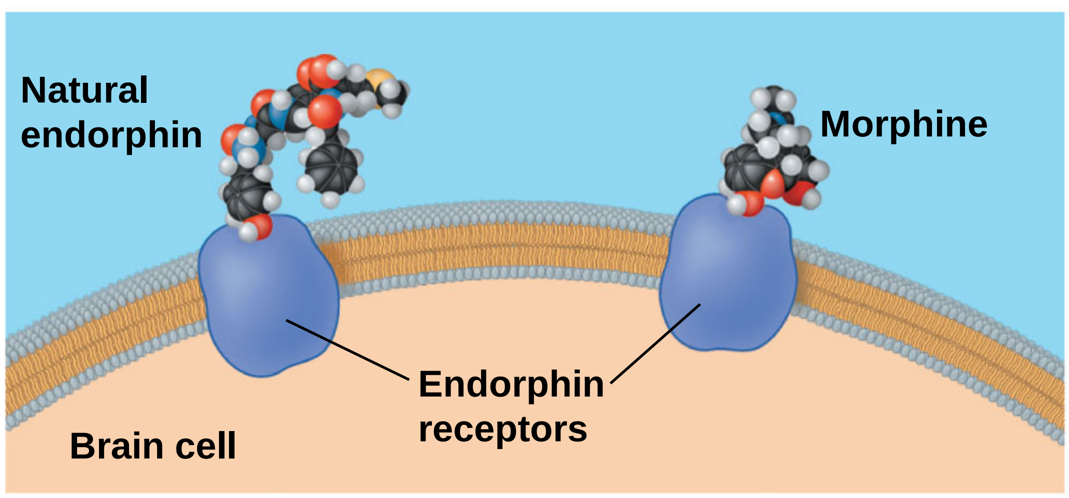
(b) Molecular-shape models

- Biological molecules recognize and interact with each other with a specificity based on molecular shape
- Molecules with similar shapes can have similar biological effects

Figure 2.18

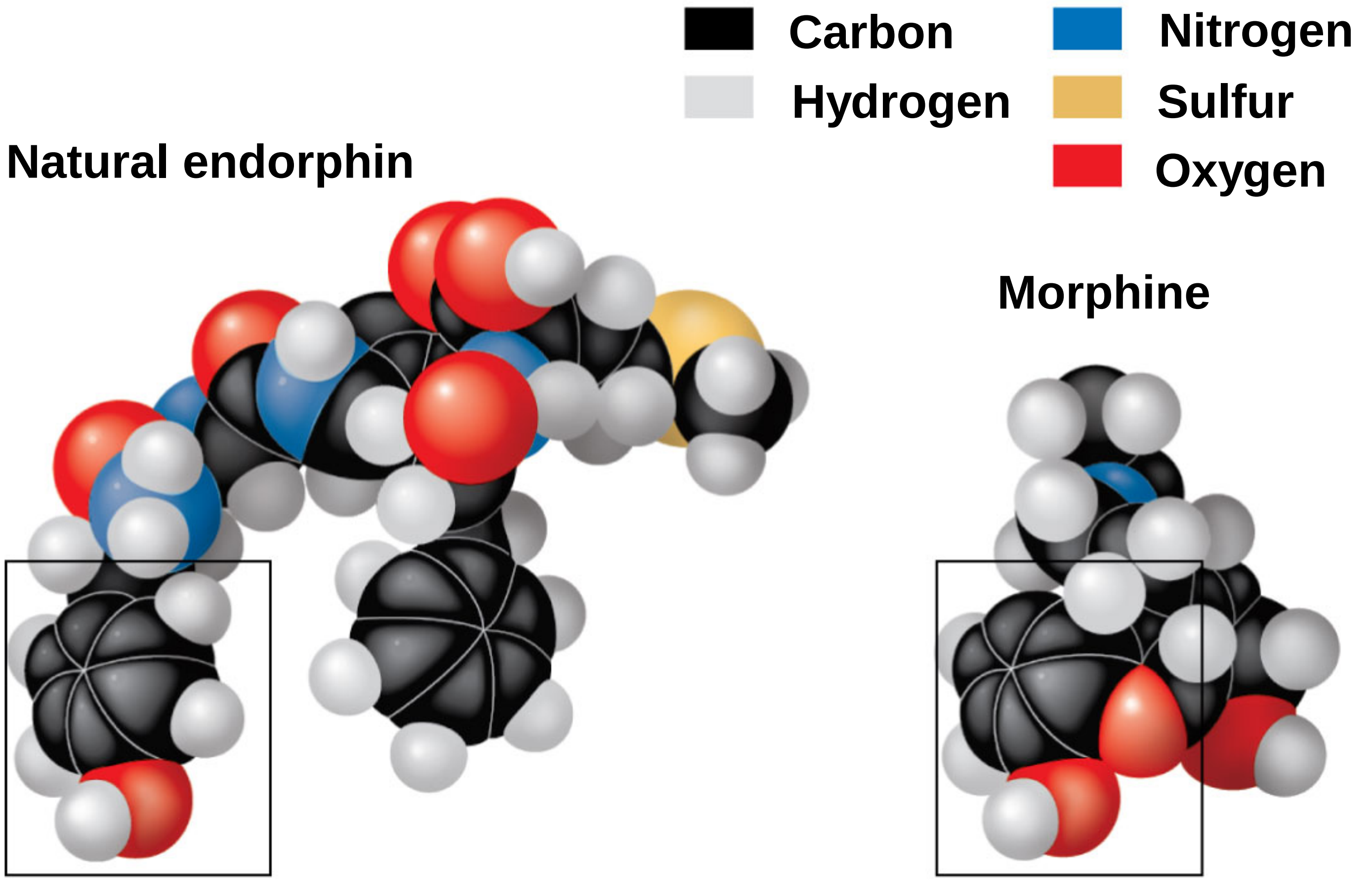


(a) Structures of endorphin and morphine



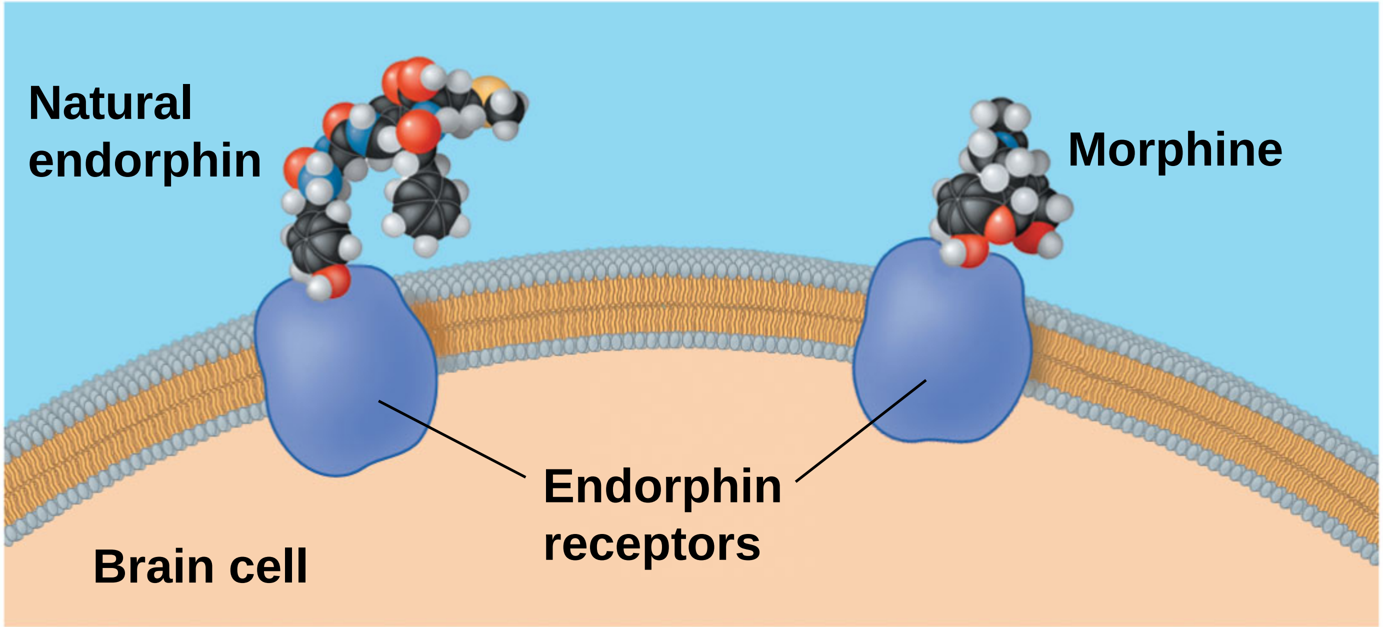
(b) Binding to endorphin receptors

Figure 2.18a



(a) Structures of endorphin and morphine

Figure 2.18b

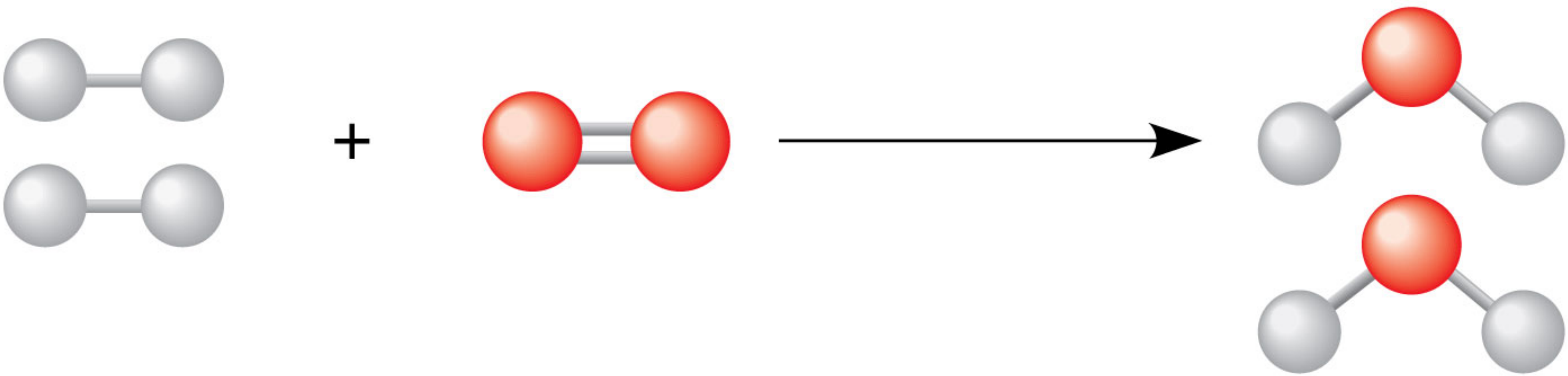


(b) Binding to endorphin receptors

Concept 2.4: Chemical reactions make and break chemical bonds

- **Chemical reactions** are the making and breaking of chemical bonds
- The starting molecules of a chemical reaction are called **reactants**
- The final molecules of a chemical reaction are called **products**

Figure 2.UN02



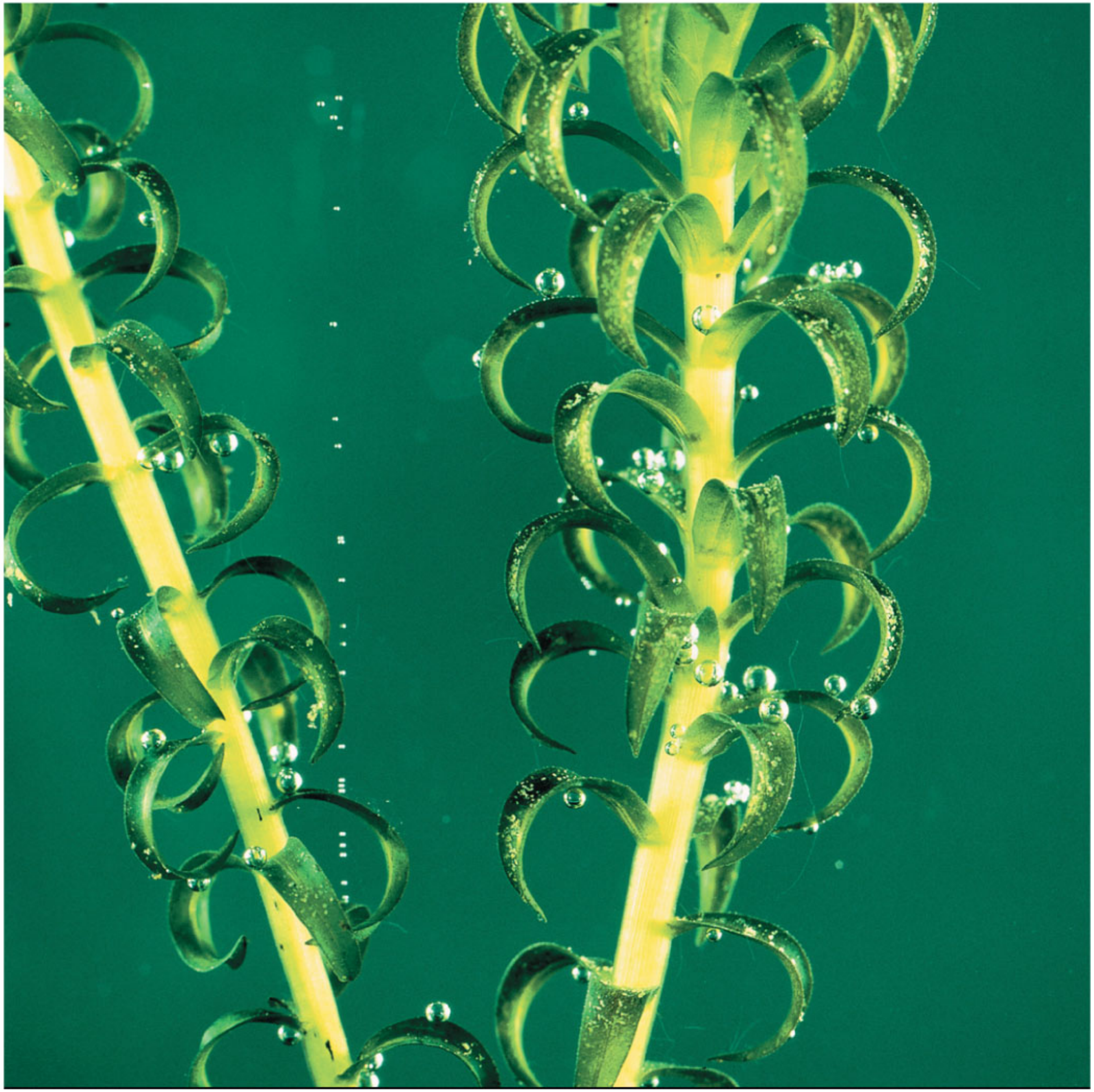
$$2\,H_2 + O_2 \longrightarrow 2\,H_2O$$

Reactants Reaction Products

- Photosynthesis is an important chemical reaction
- Sunlight powers the conversion of carbon dioxide and water to glucose and oxygen

$$6\ CO_2 + 6\ H_20 \rightarrow C_6H_{12}O_6 + 6\ O_2$$

Figure 2.19



- All chemical reactions are reversible: products of the forward reaction become reactants for the reverse reaction
- **Chemical equilibrium** is reached when the forward and reverse reaction rates are equal

Figure 2.UN03

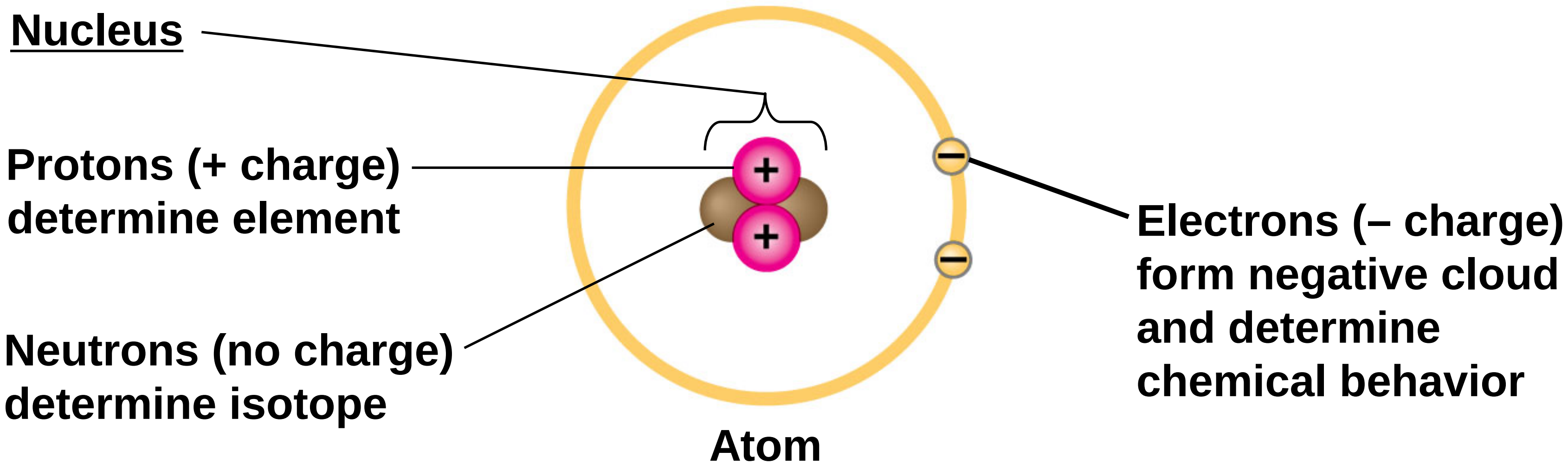
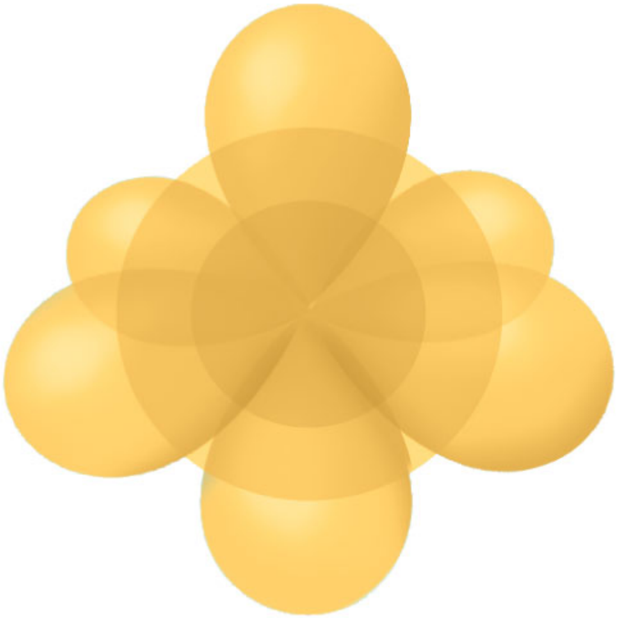


Figure 2.UN04



Electron orbitals

Figure 2.UN05

Figure 2.UN06

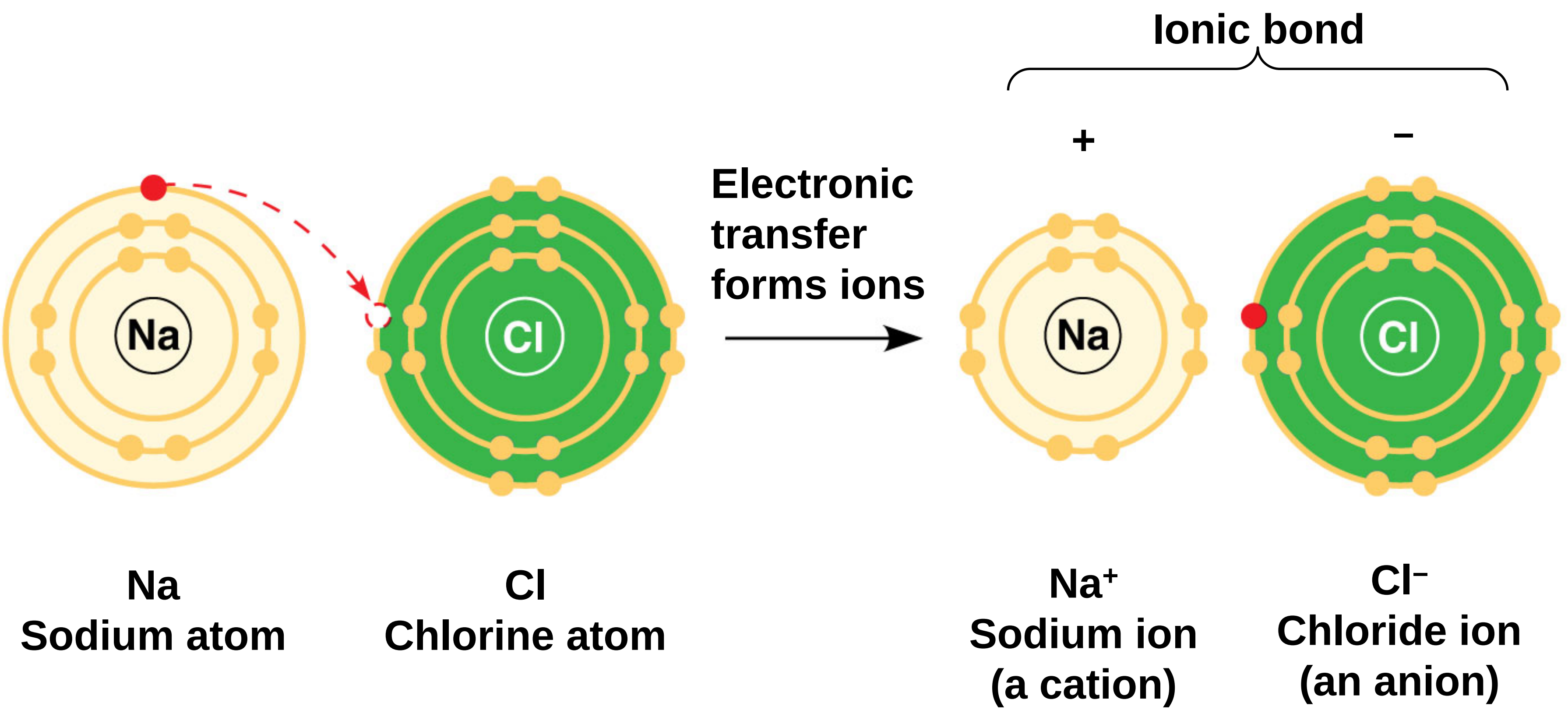
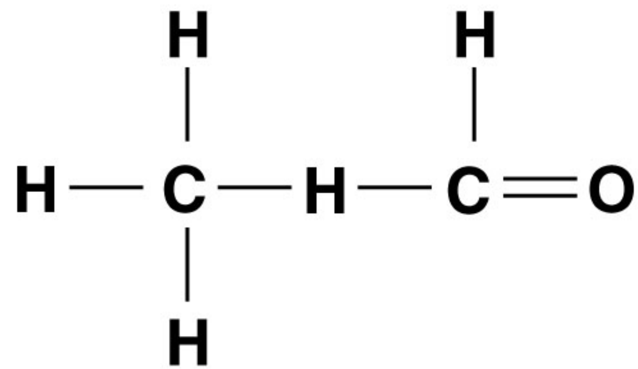
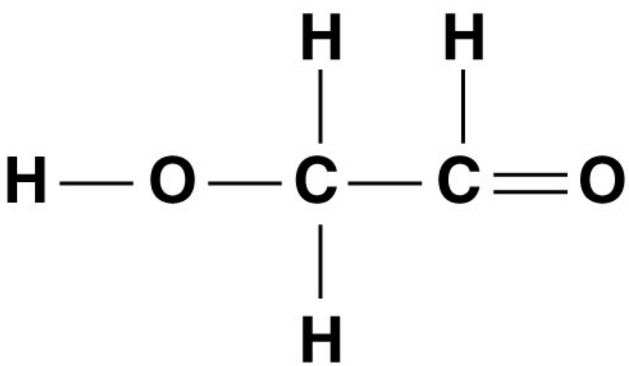


Figure 2.UN07

(a)

(c)





(b)

(d)

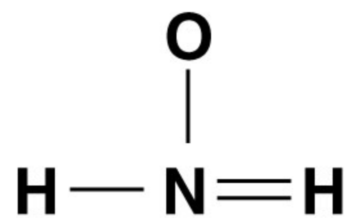


Figure 2.UN08

Figure 2.UN09

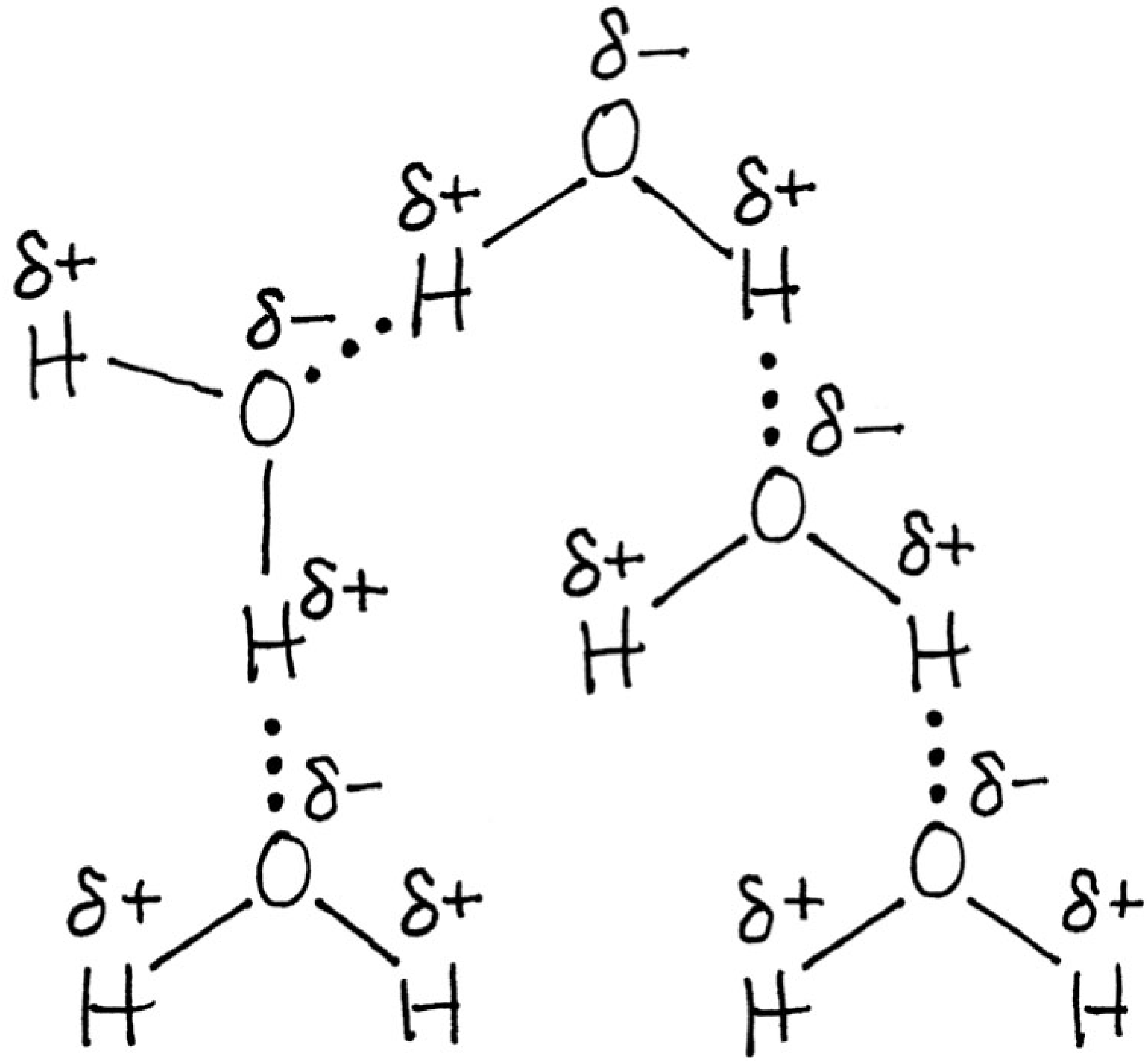


Figure 2.UN10

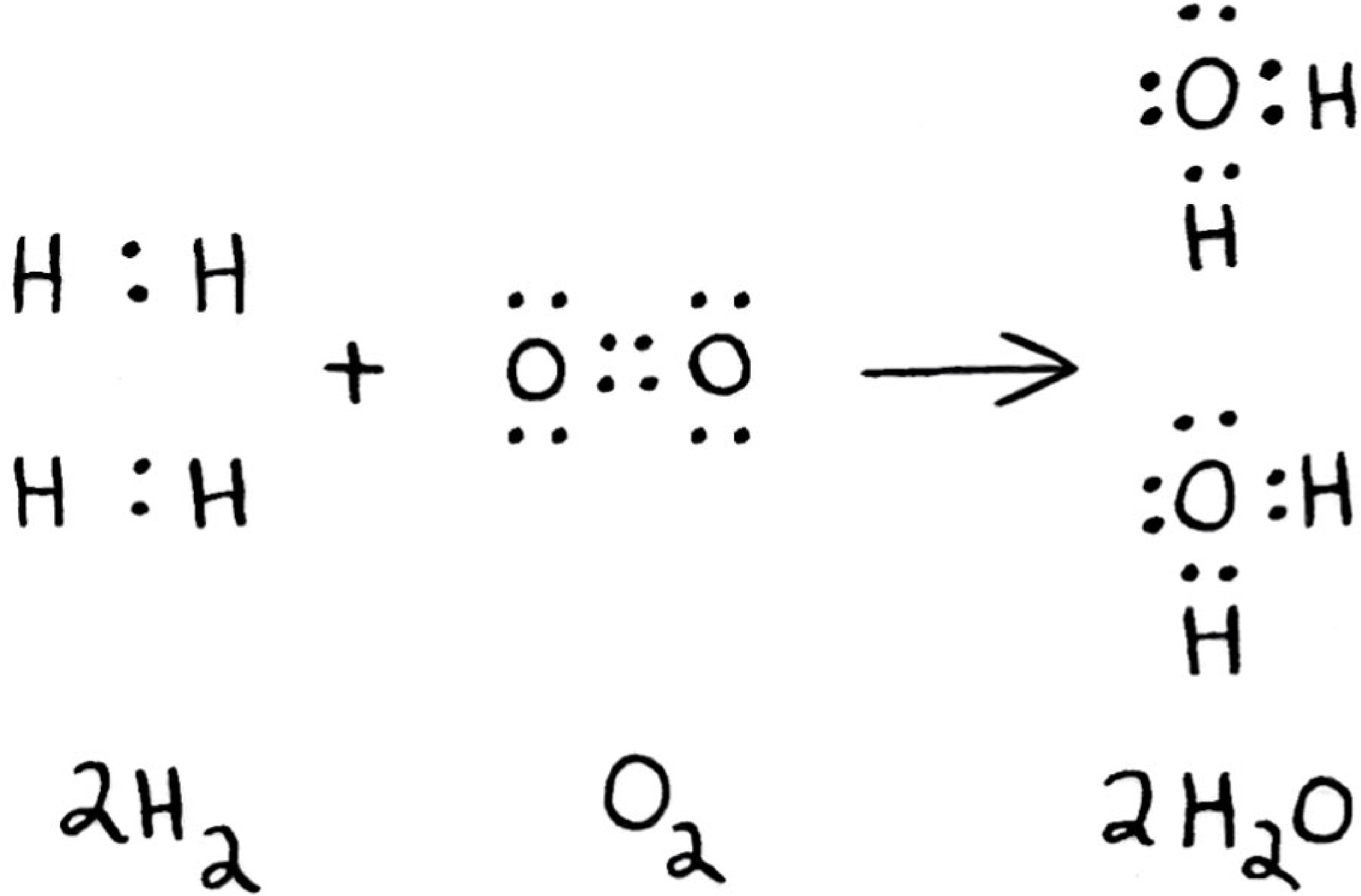


Figure 2.UN11

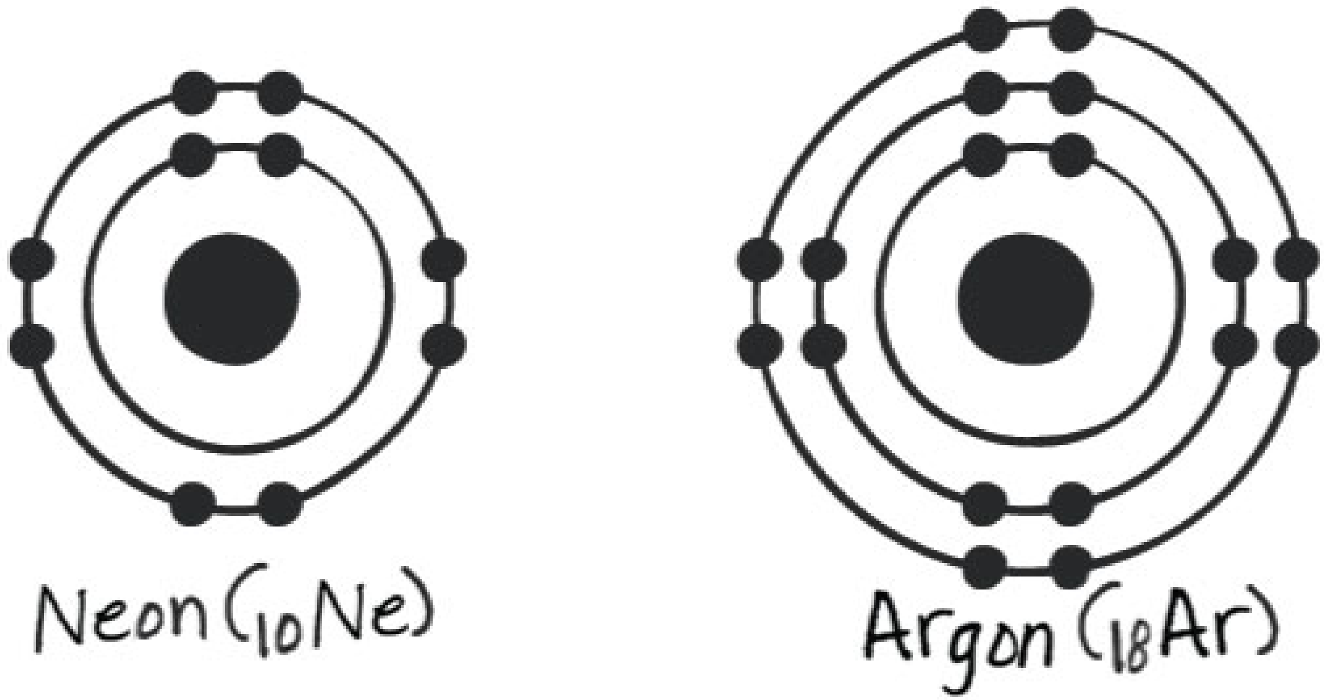
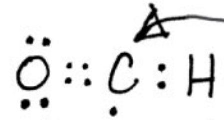
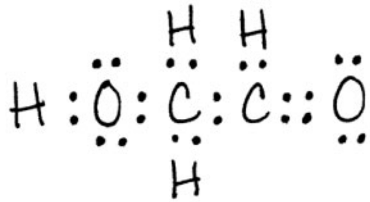
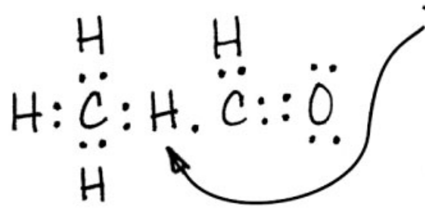


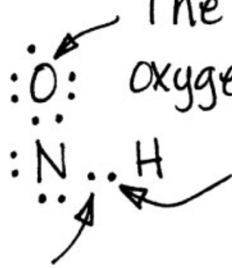
Figure 2.UN12

a.  This structure doesn't make sense because the valence shell of carbon is incomplete; carbon can form 4 bonds.

b.  This structure makes sense because all valence shells are complete, and all bonds have the correct number of electrons.

c.  This structure doesn't make sense because H has only 1 electron to share, so it cannot form bonds with 2 atoms.

d. This structure doesn't make sense for several reasons:



The valence shell of oxygen is incomplete; oxygen can form 2 bonds.

H has only 1 electron to share, so it cannot form a double bond.

Nitrogen usually makes only 3 bonds. It does not have enough electrons to make 2 single bonds, make a double bond, and complete its valence shell.

Name______________________Period__________

Chapter 2: The Chemical Context of Life

This chapter covers the basics that you may have learned in your chemistry class. Whether your teacher goes over this chapter, or assigns it for you do review on your own, the questions that follow should help you focus on the most important points.

Concept 2.1 Matter consists of chemical elements in pure form and in combinations called compounds

1. Define and give an example of the following terms:
   matter

   element

   compound

2. What four elements make up 96% of all living matter?

3. What is the difference between an *essential element* and a *trace element*?
   essential element

   trace element

Concept 2.2 An element's properties depend on the structure of its atoms

4. Sketch a model of an atom of helium, showing the electrons, protons, neutrons, and atomic nucleus.

5. What is the atomic number of helium? _________ Its atomic mass? ________

6. Here are some more terms that you should firmly grasp. Define each term.
   neutron

   proton

   electron

   atomic number

atomic mass

isotope

electron shells

energy

7. Consider this entry in the periodic table for carbon.

What is the atomic mass? ______ atomic number? _______

How many electrons does carbon have? _______ neutrons? _______

6 **C** 12

8. Which is the only subatomic particle that is directly involved in the chemical reactions between atoms?

9. What is *potential energy*?

10. Explain which has more potential energy in each pair:

a. boy at the top of a slide/boy at the bottom

b. electron in the first energy shell/electron in the third energy shell

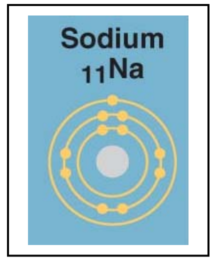
c. water/glucose

11. What determines the chemical behavior of an atom?

12. Here is an electron distribution diagram for sodium:

a. How many valence electrons does it have? ______ Circle the valence electron(s).

b. How many protons does it have? ______



Concept 2.3 The formation and function of molecules depend on chemical bonding between atoms

13. Define *molecule*.

14. Now, refer back to your definition of a *compound* and fill in the following chart:

	Molecule? (y/n)	Compound? (y/n)	Molecular Formula	Structural Formula
Water				
Carbon dioxide				
Methane				
O_2			O_2	

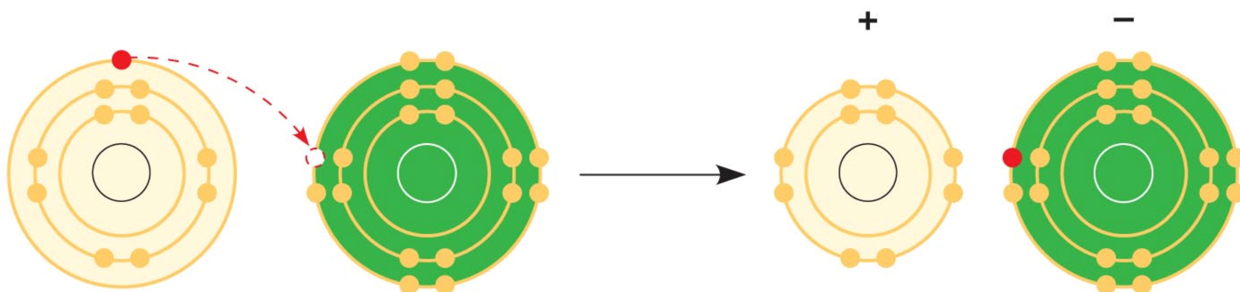
15. What type of bond is seen in O_2? Explain what this means.

16. What is meant by *electronegativity*?

17. Explain the difference between a *nonpolar covalent bond* and a *polar covalent bond*.

18. Make an electron distribution diagram of water. Which element is most electronegative? Why is water considered a *polar* molecule? Label the regions that are more positive or more negative. (This is a very important concept. Spend some time with this one!)

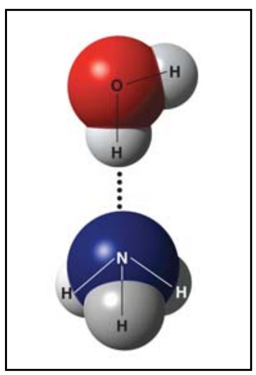
19. Another bond type is the *ionic bond*. Explain what is happening in the figure below (2.14):



20. What two elements are involved above?

21. Define *anion* and *cation*. In the preceding example, which is the anion?

22. What is a *hydrogen bond*? Indicate where the hydrogen bond occurs in this figure.



23. Explain *van der Waals interactions*. Though they represent very weak attractions, when these interactions are numerous they can stick a gecko to the ceiling!

24. Here is a list of the types of bonds and interactions discussed in this section. Place them in order from the strongest to the weakest: hydrogen bonds, van der Waals interactions, covalent bonds, ionic bonds.

STRONG

WEAK

25. Use morphine and endorphins as examples to explain why molecular shape is crucial in biology.

Concept 2.4 Chemical reactions make and break chemical bonds

26. Write the chemical shorthand equation for photosynthesis. Label the *reactants* and the *products*.

27. For the equation you just wrote, how many molecules of carbon dioxide are there? _____

How many molecules of glucose? _________ How many elements in glucose? _________

28. What is meant by *dynamic equilibrium*? Does this imply equal concentrations of each reactant and product?

Testing Your Knowledge: Self-Quiz Answers
Now you should be ready to test your knowledge. Place your answers here:

1._______ 2._______ 3._______ 4._______ 5._______ 6._______ 7._______ 8._______

The King's Academy
AP Biology
Mrs. Carruthers
Test – Chapter 2

THE CHEMICAL CONTEXT OF LIFE

Multiple Choice: Identify the choice that best completes the statement or answers the question.

1) Which of the following statements is false?
A) Carbon, hydrogen, oxygen, and nitrogen are the most abundant elements of living matter.
B) Some trace elements are very abundant on Earth.
C) Virtually all organisms require the same elements in the same quantities.
D) Iron is an example of an element needed by all organisms.
E) Other than some trace elements, animals are mostly made up of the same elements as plants, in similar proportions.

2) What factors are most important in determining which elements are most common in living matter?
A) the relative abundances of the elements in Earth's crust and atmosphere
B) the emergent properties of the simple compounds made from these elements
C) the reactivity of the elements with water
D) the chemical stability of the elements
E) both the relative abundances of the elements and the emergent properties of the compounds made from these elements

3) Knowing just the atomic mass of an element allows inferences about which of the following?
A) the chemical properties of the element
B) the number of protons in the element
C) the number of neutrons in the element
D) the number of protons plus neutrons in the element
E) both the number of protons and the chemical properties ofthe element

4) In what way are elements in the same column of the periodic table the same?
A) They have the same number of protons.
B) They have the same number of neutrons.
C) They have the same number of electrons.
D) They have the same number of electrons in their valence shell.
E) They have the same number of electron shells.

5) Carbon-12 is the most common isotope of carbon, and has an atomic mass of 12 daltons. A mole of carbon in naturally occurring coal, however, weighs slightly more than 12 grams. Why?
A) The atomic mass does not include the mass of electrons.
B) Some carbon atoms in nature have an extra proton.
C) Some carbon atoms in nature have more neutrons.
D) Some carbon atoms in nature have a different valence electron distribution.
E) Some carbon atoms in nature have undergone radioactive decay.

6) Electrons exist only at fixed levels of potential energy. However, if an atom absorbs sufficient energy, a possible result is that
A) an electron may move to an electron shell farther away from the nucleus.
B) an electron may move to an electron shell closer to the nucleus.
C) the atom may become a radioactive isotope.
D) the atom would become a positively charged ion, or cation, and become a radioactive isotope.
E) the atom would become a negatively charged ion, or anion.

7) The atomic number of each atom is given to the left of each of the elements below. Which of the atoms has the same valence as carbon ($^{12}_{6}C$)?
A) $_7N$ nitrogen
B) $_9F$ flourine
C) $_{10}Ne$ neon
D) $_{12}Mg$ magnesium
E) $_{14}Si$ silicon

8) Two atoms appear to have the same mass number. These atoms
A) must have the same atomic number.
B) must have the same number of electrons.
C) must have the same chemical properties.
D) must have the same number of protons + neutrons.
E) must have the same atomic number, the same number of protons + neutrons, the same number of electrons, and the same chemical properties.

-continue-

9) The organic molecules in living organisms have a measurably lower ratio of carbon-13/carbon-12, two stable isotopes of carbon that comprise approximately 1.1% and 98.9% of atmospheric carbon, respectively. What is a reasonable explanation for this phenomenon?
A) Photosynthesis preferentially uses carbon dioxide molecules with carbon-12, and the lower carbon-13/carbon-12 ratio propagates through the food chain.
B) Carbon dioxide molecules with carbon-13 stay in the upper atmosphere and are less available to terrestrial plants and algae.
C) Carbon-13 has a different valence electron configuration and is therefore less chemically reactive than carbon-12.
D) Oxygen atoms preferentially react with carbon-13, thereby enriching the atmosphere with carbon dioxide molecules containing carbon-13 atoms.
E) Carbon dioxide molecules containing carbon-13 are heavier and sink into the ocean depths, making them less available to living organisms.

10) Phosphorus-32, a radioactive isotope of phosphorus-31 (atomic number 15), undergoes a form of radioactive decay whereby a neutron turns into a proton and emits radiation in the form of an electron. What is the product of such radioactive decay of phosphorus-32?
A) phosphorus-31
B) a positively charged phosphorus-31 ion
C) a negatively charged phosphorus-32 ion
D) sulfur-32 (atomic number 16)
E) the conversion of the phosphorus-32 atom into pure energy

11) An atom with atomic number 12 would have what type of chemical behavior in bonding with other elements?
A) It would form ions with a +1 charge.
B) It would form ions with a +2 charge.
C) It would form ions with a -1 charge.
D) It would form ions with a -2 charge.
E) It would form two covalent bonds with other atoms.

12) If a salamander relied on hydrogen bonds to cling to surfaces, what type of surface would cause the most problems for this animal?
A) a surface coated with a thin film of water
B) a surface made with carbon and hydrogen atoms covalently bonded together
C) a surface made with carbon, hydrogen, and oxygen atoms covalently bonded together
D) a surface made with carbon, hydrogen, nitrogen, and oxygen atoms covalently bonded together
E) a surface made with silicon and oxygen atoms covalently bonded together

-continue-

13) What is the maximum number of covalent bonds an element with atomic number 8 can make with hydrogen?
A) 1
B) 2
C) 3
D) 4
E) 6

14) Nitrogen (N) is much more electronegative than hydrogen (H). Which of the following statements is correct about the atoms in ammonia (NH_3)?
A) Each hydrogen atom has a partial positive charge; the nitrogen atom has a partial negative charge.
B) The nitrogen atom has a strong positive charge; each hydrogen atom has a strong positive charge.
C) Each hydrogen atom has a slight negative charge; the nitrogen atom has a strong positive charge.
D) The nitrogen atom has a slight positive charge; each hydrogen atom has a slight negative charge.
E) There are covalent bonds between the hydrogen atoms and polar bonds between each hydrogen atom and the nitrogen atom.

15) When two atoms are equally electronegative, they will interact to form
A) hydrogen bonds.
B) van der Waals interactions.
C) polar covalent bonds.
D) nonpolar covalent bonds.
E) ionic bonds.

16) What results from an unequal sharing of electrons between atoms?
A) a nonpolar covalent bond
B) a polar covalent bond
C) an ionic bond
D) a hydrogen bond
E) a hydrophobic interaction

17) A covalent bond is likely to be polar when
A) one of the atoms sharing electrons is much more electronegative than the other atom.
B) the two atoms sharing electrons are equally electronegative.
C) oxygen is one of the two atoms sharing electrons.
D) one of the atoms has absorbed more energy than the other atom.
E) the two atoms sharing electrons are different elements.

18) Which of the following molecules contains the most polar covalent bond?
A) H_2
B) O_2
C) CO_2
D) H_2O
E) CH_4

19) In comparing covalent bonds and ionic bonds, which of the following would you expect?
A) An atom can form covalent bonds with multiple partner atoms, but only a single ionic bond with a single partner atom.
B) Covalent bonds and ionic bonds occupy opposite ends of a continuous spectrum, from nearly equal to completely unequal sharing of electrons.
C) Both involve electrical attraction between the electrons of one atom and the nucleus of the other atom.
D) Ionic interactions remain when covalent bonds are broken in water. Ionic bonds are much stronger than covalent bonds.

20) How many electron pairs are shared between carbon atoms in a molecule that has the formula C_2H_4?
A) 0
B) 1
C) 2
D) 3
E) 4

21) Which bond or interaction would be difficult to disrupt when compounds are put into water?
A) covalent bond
B) hydrogen bond
C) van der Waals interaction
D) ionic bond
E) either covalent bonds or ionic bonds

22) Which of the following explains most specifically the attraction of water molecules to one another?
A) nonpolar covalent bond
B) polar covalent bond
C) ionic bond
D) hydrogen bond
E) hydrophobic interaction

-continue-

23) What bonding or interaction is most likely to occur among a broad array of molecules of various types (polar, nonpolar, hydrophilic, hydrophobic)?
A) covalent bonding
B) polar covalent bonding
C) ionic bonding
D) hydrogen bonding
E) van der Waals interactions

24) Which of the following is not considered to be a weak molecular interaction?
A) a covalent bond
B) a van der Waals interaction
C) an ionic bond in the presence of water
D) a hydrogen bond
E) both a hydrogen bond and a covalent bond

25) What is the maximum number of hydrogen atoms that can be covalently bonded in a molecule containing two carbon atoms?
A) 2
B) 3
C) 4
D) 6
E) 8

26) Which of the following is true for this reaction?

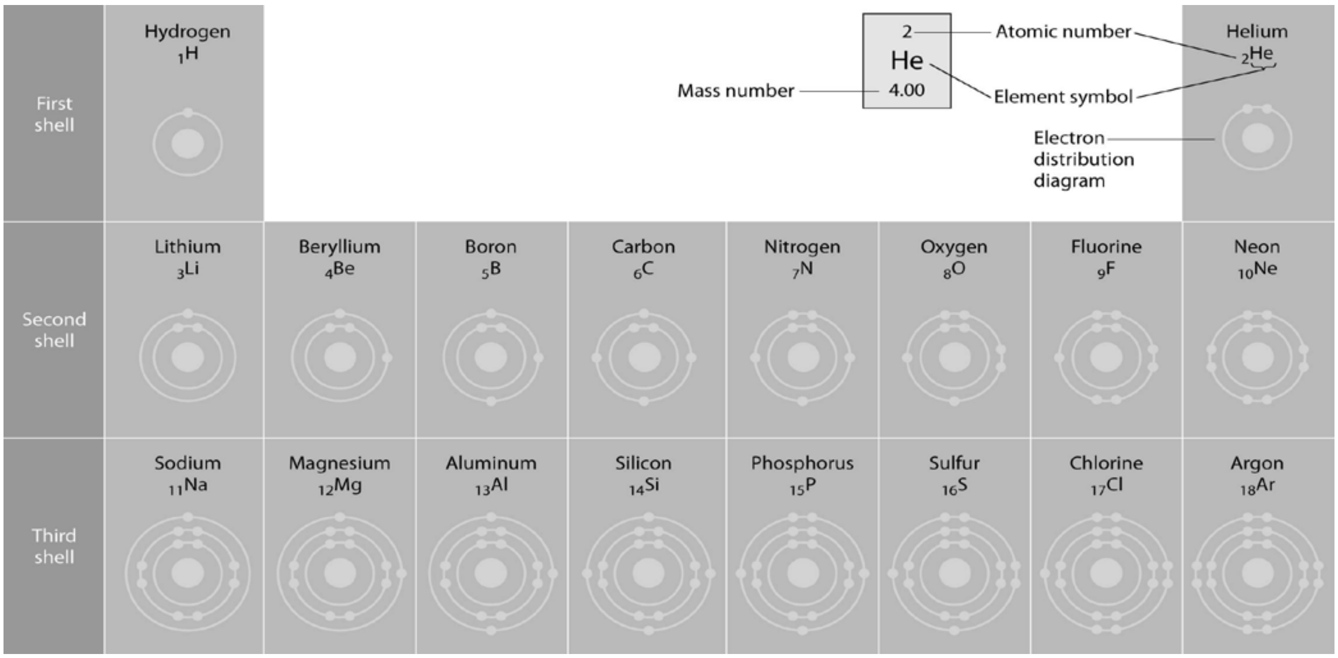
$3\ H_2 + N_2 \leftrightarrow 2\ NH_3$

A) The reaction is nonreversible.
B) Hydrogen and nitrogen are the reactants of the reverse reaction.
C) Hydrogen and nitrogen are the products of the forward reaction.
D) Ammonia is being formed and decomposed.
E) Hydrogen and nitrogen are being decomposed.

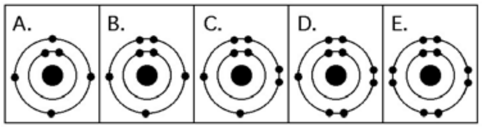
27) Which of the following correctly describes any reaction that has reached chemical equilibrium?
A) The concentration of the reactants equals the concentration of the products.
B) The rate of the forward reaction is equal to the rate of the reverse reaction.
C) All of the reactants have been converted to the products of the reaction.
D) All of the products have been converted to the reactants of the reaction.
E) Both the forward and the reverse reactions have stopped with no net effect on the concentration of the reactants and the products.

-continue-

28) Which of these systems is least likely to be at chemical equilibrium?
A) a test tube of living cells
B) a test tube of organic molecules, kept in the freezer
C) a test tube of dry organic molecules, kept at room temperature
D) a test tube of organic molecules dissolved in water, kept at room temperature
E) a test tube of dead cells in water, kept at room temperature



29) Refer to the figure above (first three rows of the periodic table). If life arose on a planet where carbon is absent, which element might fill the role of carbon?
A) boron
B) silicon
C) nitrogen
D) aluminum
E) phosphorus



30) Which drawing in the figure above depicts the electron configuration of an element with chemical properties most similar to Helium ($_2He$)?
A) A
B) B
C) C
D) D
E) E

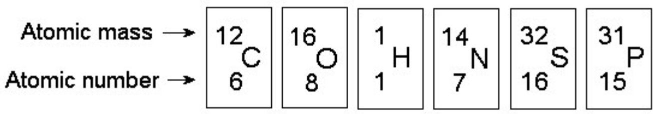
31) Which drawing in the figure above depicts the electron configuration of an atom that can form covalent bonds with two hydrogen atoms?
A) A
B) B
C) C
D) D
E) E

32) Which drawing in the figure above depicts the electron configuration of an atom capable of forming three covalent bonds with other atoms?
A) A
B) B
C) C
D) D
E) E

33) Which drawing in the figure above is of the electron configuration of a sodium $_{11}Na^+$ ion?
A) A
B) B
C) C
D) D
E) E

34) Which drawing in the figure above depicts the most electronegative atom?
A) A
B) B
C) C
D) D
E) E

35) Which drawing in the figure above depicts an atom with a valence of 3?
A) A
B) B
C) C
D) D
E) E



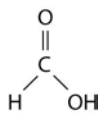
36) In the figure above, how many electrons does nitrogen have in its valence shell?
A) 2
B) 5
C) 7
D) 8
E) 14

37) In the figure above, how many unpaired electrons does phosphorus have in its valence shell?
A) 15
B) 2
C) 3
D) 7
E) 5

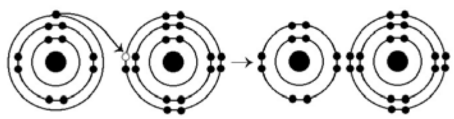
38) How many neutrons are present in the nucleus of a phosphorus-32 (^{32}P) atom (see the figure above)?
A) 5
B) 15
C) 16
D) 17
E) 32

39) Based on electron configuration, which of these elements in the figure above would exhibit a chemical behavior most like that of oxygen?
A) carbon
B) hydrogen
C) nitrogen
D) sulfur
E) phosphorus

-continue-



40) The illustration above shows a representation of formic acid. A formic acid molecule
A) will form hydrogen bonds with water molecules.
B) has a tetrahedral configuration of hybrid electron orbitals for the carbon atom.
C) consists of largely nonpolar covalent bonds.
D) is held together by hydrogen bonds.
E) has a tetrahedral shape and will form hydrogen bonds with water molecules.

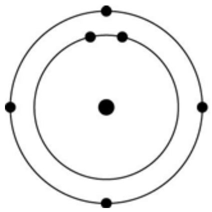
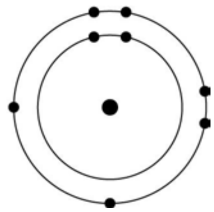


41) What results from the chemical reaction illustrated above?
A) a cation with a net charge of +1
B) a cation with a net charge of -1
C) an anion with a net charge of +1
D) an anion with a net charge of -1
E) a cation with a net charge of +1 and an anion with a net charge of -1

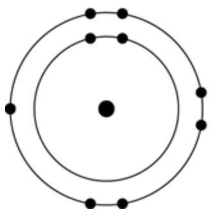
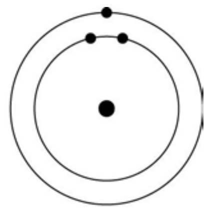
42) What is the atomic number of the cation formed in the reaction illustrated above?
A) 1
B) 8
C) 10
D) 11
E) 16

43) Which of the following pairs of atoms would be most likely to form a polar covalent bond?

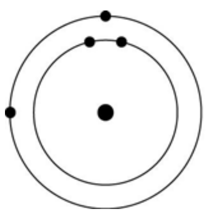
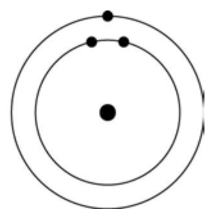
A)

 and 

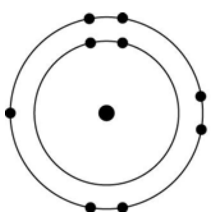
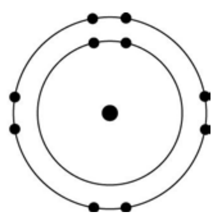
B)

 and 

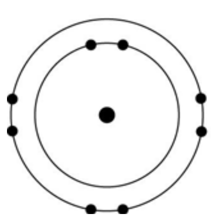
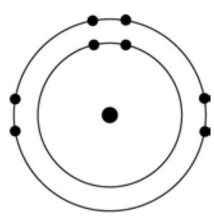
C)

 and 

D)

 and 

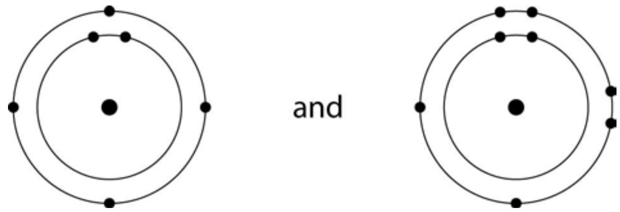
E)

 and 

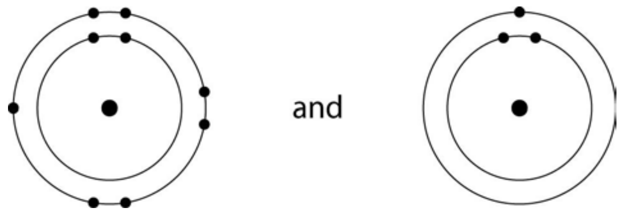
-continue-

44) Which of the following pairs of atoms would be most likely to form an ionic bond?

A)

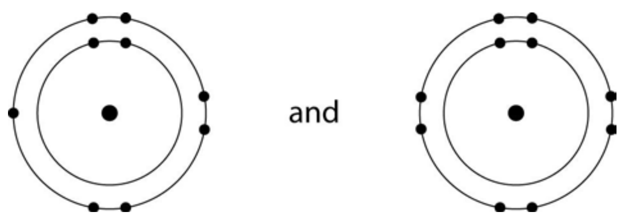


B)

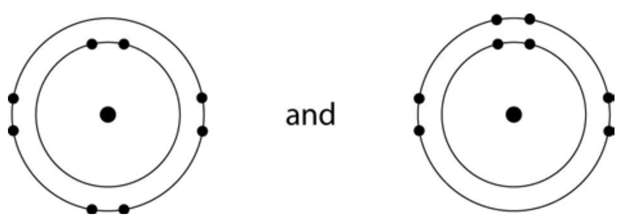


C)

D)



E)



45) A group of molecular biologists is trying to synthesize a new artificial compound to mimic the effects of a known hormone that influences sexual behavior. They have turned to you for advice. Which of the following compounds is most likely to mimic the effects of the hormone?

A) a compound with the same number of carbon atoms as the hormone

B) a compound with the same molecular mass (measured in daltons) as the hormone

C) a compound with the same three-dimensional shape as part of the hormone

D) a compound with the same number of orbital electrons as the hormone

E) a compound with the same number of hydrogen and nitrogen atoms as the hormone

-continue-

Short Answer Essay: Thoroughly answer each question using complete sentences. Diagrams may be used to help clarify but should not be used alone without explanation.

1. Female silkworm moths (*Bombyx mori*) attract males by emitting chemical signals that spread through the air. A male hundreds of meters away can detect these molecules and fly toward their source. The sensory organs responsible for this behavior are comblike antennae. Each filament of an antenna is equipped with thousands of receptor cells that detect the sex attractant.

a. **Propose** a hypothesis to account for the ability of the male moth to detect a specific molecule in the presence of many other molecules in the air.

b. **Design** an experiment to test your hypothesis.

c. **Predict** the outcome of your experiment if your hypothesis is supported and **justify** your prediction.

WATER AND THE FITNESS OF THE ENVIRONMENT

CHAPTER 3

Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce and to maintain dynamic homeostasis.

Enduring understanding 2.A: Growth, reproduction and maintenance of the organization of living systems require free energy and matter.

Essential knowledge 2.A.3: Organisms must exchange matter with the environment to grow, reproduce and maintain organization.

a. Molecules and atoms from the environment are necessary to build new molecules.

Evidence of student learning is a demonstrated understanding of each of the following:

3. Living systems depend on properties of water that result from its polarity and hydrogen bonding.

To foster student understanding of this concept, instructors can choose an illustrative example such as:

- Cohesion
- Adhesion
- High specific heat capacity
- Universal solvent supports reactions
- Heat of vaporization
- Heat of fusion
- Water's thermal conductivity

Learning Objectives:

LO 2.8 The student is able to justify the selection of data regarding the types of molecules that an animal, plant or bacterium will take up as necessary building blocks and excrete as waste products. [See **SP 4.1**]

LO 2.9 The student is able to represent graphically or model quantitatively the exchange of molecules between an organism and its environment, and the subsequent use of these molecules to build new molecules that facilitate dynamic homeostasis, growth and reproduction. [See **SP 1.1, 1.4**]

Chapter 3

Water and Life

Lecture Outline

Overview: The Molecule That Supports All of Life

- Because water is the substance that makes life possible on Earth, astronomers hope to find evidence of water on newly discovered planets orbiting distant stars.
    - Water is the substance that makes life on Earth possible.
    - All organisms are made mostly of water and live in an environment dominated by water.
    - Water is the only common substance in the natural environment that exists in all three physical states of matter: solid, liquid, and gas.
    - Water is also unusual in that the solid state (ice) floats on the liquid state (water). This rare and important property emerges from the chemistry of water.
- Three-quarters of Earth’s surface is covered by water.
- Life on Earth began in water and evolved there for 3 billion years before colonizing land.
- Even terrestrial organisms are tied to water.
    - Most cells are surrounded by water.
    - Cells are 70–95% water.
    - Water is a reactant in many of the chemical reactions of life.

Concept 3.1 Polar covalent bonds in water molecules result in hydrogen bonding

- A water molecule is shaped like a wide V, with two hydrogen atoms joined to an oxygen atom by single polar covalent bonds.
- Because oxygen is more electronegative than hydrogen, a water molecule is a **polar molecule** in which opposite ends of the molecule have opposite charges.
    - The oxygen region of the molecule has a partial negative charge (δ^-), and the hydrogen regions have a partial positive charge (δ^+).
- Water has a variety of unusual properties because of the attraction between polar water molecules.
    - The slightly negative regions of one water molecule are attracted to the slightly positive regions of nearby water molecules, forming hydrogen bonds.
    - Each water molecule can form hydrogen bonds with as many as four neighbors.

- When water is in its liquid form, its hydrogen bonds are very fragile, about one-twentieth as strong as covalent bonds.
- Hydrogen bonds form, break, and re-form with great frequency.
- Each hydrogen bond lasts only a few trillionths of a second, but the molecules continuously form new hydrogen bonds with a succession of partners.
- At any given instant, a substantial percentage of all water molecules are hydrogen-bonded to their neighbors.

Concept 3.2 Four emergent properties of water contribute to Earth's suitability for life

Organisms depend on the cohesion of water molecules.

- Collectively, hydrogen bonds hold water together, a phenomenon called **cohesion**.
- Cohesion among water molecules plays a key role in transporting water and dissolved nutrients against gravity in plants.
    - Water molecules move up from the roots to the leaves of a plant through water-conducting vessels.
    - As water molecules evaporate from a leaf, other water molecules from vessels in the leaf replace them.
    - Hydrogen bonds cause water molecules leaving the vessels to tug on molecules farther down.
    - This upward pull is transmitted down to the roots.
    - **Adhesion**, the clinging of one substance to another, also contributes, as water adheres to the walls of the vessels.
- **Surface tension**, a measure of the force necessary to stretch or break the surface of a liquid, is related to cohesion.
    - Water has a greater surface tension than most other liquids because hydrogen bonds among surface water molecules resist stretching or breaking the surface.
    - Water behaves as if covered by an invisible film.
    - Some animals can stand, walk, or run on water without breaking the surface.

Water moderates temperatures on Earth.

- Water moderates air temperatures by absorbing heat from warmer air and releasing the stored heat to cooler air.
- Water can absorb or release relatively large amounts of heat with only a slight change in its own temperature.
- Atoms and molecules have **kinetic energy**, the energy of motion, because they are always moving.
    - The faster a molecule moves, the more kinetic energy it has.

- **Heat** is a measure of the *total* quantity of kinetic energy due to molecular motion in a body of matter.
- **Temperature** measures the intensity of heat in a body of matter due to the *average* kinetic energy of molecules.
    - As the average speed of molecules increases, a thermometer records an increase in temperature.
- Heat and temperature are related but not identical.
    - Heat depends in part on the matter's volume, while temperature is the average kinetic energy of molecules, regardless of volume.
- When two objects of different temperatures come together, heat passes from the warmer object to the cooler object until the two are the same temperature.
    - Molecules in the cooler object speed up at the expense of the kinetic energy of the warmer object.
    - Ice cubes cool a glass of soda by absorbing heat from the soda as the ice melts.
- In most biological settings, temperature is measured on the **Celsius scale** (°C).
    - At sea level, water freezes at 0°C and boils at 100°C.
    - Human body temperature is typically 37°C.
- Although there are several ways to measure heat energy, one convenient unit is the **calorie (cal)**.
    - One calorie is the amount of heat energy necessary to raise the temperature of 1 gram of water by 1°C.
    - A calorie is released when 1 g of water cools by 1°C.
- In many biological processes, the **kilocalorie (kcal)** is a more convenient unit.
    - One kilocalorie is the amount of heat energy necessary to raise the temperature of 1000 g (1 kg) of water by 1°C.
- Another common energy unit, the **joule (J)**, is equivalent to 0.239 cal.

Water has a high specific heat.

- Water stabilizes temperature because it has a high specific heat.
- The **specific heat** of a substance is the amount of heat that must be absorbed or lost for 1 g of that substance to change its temperature by 1°C.
    - By definition, the specific heat of water is 1 cal per gram per degree Celsius, or 1 cal/g/°C.
- Water has an unusually high specific heat compared to other substances.
    - For example, ethyl alcohol has a specific heat of 0.6 cal/g/°C.
    - The specific heat of iron is one-tenth that of water.
- Water resists changes in temperature because of its high specific heat.
    - In other words, water absorbs or releases a relatively large quantity of heat for each degree of temperature change.
- Water's high specific heat is due to hydrogen bonding.

- Heat must be absorbed to break hydrogen bonds, and heat is released when hydrogen bonds form.
- The investment of 1 calorie of heat causes relatively little change in the temperature of water because much of the energy is used to disrupt hydrogen bonds, not speed up the movement of water molecules.

- Water's high specific heat affects Earth as a whole as well as individual organisms.
  - A large body of water can absorb a large amount of heat from the sun during the daytime in the summer and yet warm only a few degrees.
  - At night and during the winter, the warm water heats the cooler air.
  - Therefore, the oceans and coastal land areas have more stable temperatures than inland areas.
  - Living things are made of primarily water, so they resist changes in temperature better than they would if composed of a liquid with a lower specific heat.

Water's high heat of vaporization has many effects.

- The transformation of a molecule from a liquid to a gas is called vaporization, or *evaporation*.
  - Vaporization occurs when a molecule moves fast enough to overcome the attraction of other molecules in the liquid.
  - The speed of molecular movement varies; temperature is the *average* kinetic energy of molecules.
  - Even in a low-temperature liquid (with low average kinetic energy), some molecules move fast enough to evaporate.
  - Heating a liquid increases the average kinetic energy and increases the rate of evaporation.
- **Heat of vaporization** is the quantity of heat that a liquid must absorb for 1 g of it to be converted from liquid to gas.
  - Water has a relatively high heat of vaporization, with about 580 cal of heat required to evaporate 1 g of water at room temperature.
  - This is double the amount of heat required to vaporize the same quantity of alcohol or ammonia.
  - The heat of vaporization is high because hydrogen bonds must be broken before a water molecule can evaporate from the liquid.
- The large amount of energy required to vaporize water has a wide range of effects.
  - Water's high heat of vaporization moderates climate.
  - Much of the sun's heat absorbed by tropical oceans is used for the evaporation of surface water.
  - As moist tropical air moves to the poles, water vapor condenses to form rain, releasing heat.
- At the level of the organism, water's high heat of vaporization accounts for the severity of steam burns.

- Steam burns are caused by the heat energy released when steam condenses to liquid on the skin.

- As a liquid evaporates, the surface of the liquid that remains behind cools, a phenomenon called **evaporative cooling**.
    - The most energetic molecules are the most likely to evaporate, leaving the lower–kinetic energy molecules behind.
    - Evaporative cooling moderates temperature in lakes and ponds.
- Evaporation of sweat in mammals or evaporation of water from the leaves of plants removes excess heat and prevents terrestrial organisms from overheating.

Oceans and lakes don't freeze solid because ice floats on water.

- Water is unusual because it is less dense as a solid than as a cold liquid.
    - Most materials contract as they solidify, but water expands.
    - At temperatures higher than 4°C, water behaves like other liquids, expanding as it warms and contracting as it cools.
- Water begins to freeze when its molecules are no longer moving vigorously enough to break their hydrogen bonds.
- When water reaches 0°C, it becomes locked into a crystalline lattice, with each water molecule bonded to four partners.
- As ice starts to melt, some of the hydrogen bonds break, and water molecules can slip closer together than they can while in the ice state.
- Ice is about 10% less dense than water at 4°C. Therefore, ice floats on the cool water below.
- Ice floating on water has important consequences for life.
    - If ice sank, eventually all ponds, lakes, and even oceans would freeze solid.
    - During the summer, only the upper few centimeters of oceans would thaw.
    - Instead, the surface layer of ice insulates the liquid water below, preventing it from freezing and allowing life to exist under the frozen surface.
    - Ice also provides solid habitat for Arctic animals like polar bears and seals.
- Global warming is affecting icy environments around the globe.
    - In northern Alaska and Canada, the average air temperature has risen 1.4^{0}C since 1961.
    - As a result, ice forms later, melts earlier, and covers a smaller area of the Arctic, threatening animals that depend on ice for survival.

Water is the solvent of life.

- A liquid that is a completely homogeneous mixture of two or more substances is called a **solution**.
    - A sugar cube in a glass of water eventually dissolves to form a uniform solution of sugar and water.

- The dissolving agent is the **solvent**, and the substance that is dissolved is the **solute**.
    - In our example, water is the solvent and sugar is the solute.
- In an **aqueous solution**, water is the solvent.
- Water is not a universal solvent, but it is very versatile because of the polarity of water molecules.
    - Water is an effective solvent because it readily forms hydrogen bonds with charged and polar covalent molecules.
    - For example, when a crystal of salt (NaCl) is placed in water, the Na^+ cations interact with the partial negative charges of the oxygen regions of water molecules.
    - The Cl^- anions interact with the partial positive charges of the hydrogen regions of water molecules.
    - Each dissolved ion is surrounded by a sphere of water molecules, a **hydration shell**.
    - Eventually, water dissolves all the ions, resulting in a solution with two solutes: sodium and chloride ions.
- Polar molecules are soluble in water because they form hydrogen bonds with water.
- Even large molecules, like proteins, can dissolve in water if they have ionic and polar regions.
- A substance that has an affinity for water is **hydrophilic** *(water-loving)*.
    - Hydrophilic substances are dominated by ionic or polar bonds.
- Some hydrophilic substances do not dissolve because their molecules are too large.
    - For example, cotton is hydrophilic because cellulose, its major constituent, has numerous polar covalent bonds. However, its giant cellulose molecules are too large to dissolve in water.
    - Water molecules form hydrogen bonds with the cellulose fibers of cotton. When you dry yourself with a cotton towel, the water is pulled into the towel.
- Substances that have no affinity for water are **hydrophobic** *(water-fearing)*.
    - Hydrophobic substances are nonionic and have nonpolar covalent bonds.
    - Because no regions consistently have partial or full charges, water molecules cannot form hydrogen bonds with hydrophobic molecules.
    - Oils such as vegetable oil are hydrophobic because the dominant bonds, carbon-carbon and carbon-hydrogen, share electrons equally.
    - Hydrophobic molecules are major ingredients of cell membranes.
- Biological chemistry is “wet” chemistry, with most reactions involving solutes dissolved in water.
- Chemical reactions depend on collisions of molecules and therefore on the concentrations of solutes in aqueous solution.

- When carrying out experiments, we use mass to calculate the number of molecules.
  - We know the mass of each atom in a given molecule, so we can calculate its **molecular mass**, which is the sum of the masses of all the atoms in a molecule.
  - We measure the number of molecules in units called moles**.**
- The actual number of molecules in a mole is called Avogadro's number, 6.02×10^{23}.
  - A **mole (mol)** is equal to the molecular weight of a substance but scaled up from *daltons* to grams.
- To illustrate, how can we measure 1 mole of table sugar—sucrose ($C_{12}H_{22}O_{11}$)?
  - A carbon atom weighs 12 daltons, hydrogen 1 dalton, and oxygen 16 daltons.
  - One molecule of sucrose weighs 342 daltons, the sum of the weights of all the atoms in sucrose, or the **molecular weight** of sucrose.
  - To get 1 mole of sucrose, we would weigh out 342 g.
- The advantage of using a mole as a unit of measure is that a mole of one substance has the same number of molecules as a mole of any other substance.
  - If substance A has a molecular weight of 10 daltons and substance B has a molecular weight of 100 daltons, then we know that 10 g of substance A has the same number of molecules as 100 g of substance B.
  - A mole of sucrose contains 6.02×10^{23} molecules and weighs 342 g, while a mole of ethyl alcohol (C_2H_6O) also contains 6.02×10^{23} molecules but weighs only 46 g because the molecules are smaller.
  - Measuring in moles allows scientists to combine substances in fixed ratios of molecules.
- In "wet" chemistry, we typically combine solutions or measure the quantities of materials in aqueous solutions.
  - The concentration of a material in solution is called its **molarity**.
  - A one-molar (1 *M*) solution has 1 mole of a substance dissolved in 1 liter of a solvent, typically water.
  - To make a 1 *M* solution of sucrose, we would slowly add water to 342 g of sucrose until the total volume was 1 liter and all the sugar was dissolved.
- Because water is essential to life on Earth, astrobiologists seeking extraterrestrial life have concentrated on planets that may have water.
  - Over 200 planets have been found outside our solar system, and there is evidence for the presence of water vapor on one or two of them.
  - Mars, like Earth, has an ice cap at both poles. In 2008, the robotic spacecraft Phoenix landed on Mars and found ice under the Martian surface and water vapor in the Martian atmosphere.
  - This exciting finding has reinvigorated the search for signs of past or present life on Mars and other planets.

Concept 3.3 Acidic and basic conditions affect living organisms

- Occasionally, a hydrogen atom participating in a hydrogen bond between two water molecules shifts from one molecule to the other.
  - The hydrogen atom leaves its electron behind and is transferred as a single proton—a **hydrogen ion** (H^+).
  - The water molecule that lost the proton is now a **hydroxide ion** ($OH^–$).
  - The water molecule with the extra proton is now a **hydronium ion** (H_3O^+).
- A simplified way to view this process is to say that a water molecule dissociates into a hydrogen ion and a hydroxide ion: $H_2O \Leftrightarrow H^+ + OH^–$.
  - This reaction is reversible.
- At equilibrium, the concentration of water molecules greatly exceeds the concentration of H^+ and $OH^–$.
  - In pure water, only one water molecule in every 554 million is dissociated.
  - At equilibrium, the concentration of H^+ or $OH^–$ is $10^{–7}$ *M* (at 25°C).
  - There is only one ten-millionth of a mole of hydrogen ions per liter of pure water and an equal number of hydroxide ions.
- Although the dissociation of water is reversible and statistically rare, it is very important in the chemistry of life.
  - Because hydrogen and hydroxide ions are very reactive, changes in their concentrations can drastically affect the chemistry of a cell.
- Adding certain solutes, called acids and bases, disrupts the equilibrium and modifies the concentrations of hydrogen and hydroxide ions.
- The pH scale is used to describe how acidic or basic a solution is.
- An **acid** is a substance that increases the hydrogen ion concentration in a solution.
  - When hydrochloric acid is added to water, hydrogen ions dissociate from chloride ions: $HCl \rightarrow H^+ + Cl^–$. This produces an acidic solution.
- Any substance that reduces the hydrogen ion concentration in a solution is a **base**.
- Some bases reduce the H^+ concentration directly by accepting hydrogen ions.
  - Ammonia (NH_3) acts as a base when the nitrogen’s unshared electron pair attracts a hydrogen ion from the solution, creating an ammonium ion (NH_4^+): $NH_3 + H^+ \Leftrightarrow NH_4^+$.
- Other bases reduce the H^+ concentration indirectly by dissociating to $OH^–$, which then combines with H^+ to form water.
  - $NaOH \rightarrow Na^+ + OH^–$
  - $OH^– + H^+ \rightarrow H_2O$
- HCl and NaOH dissociate completely when mixed with water.
  - Hydrochloric acid is a strong acid, and sodium hydroxide is a strong base.
- In contrast, ammonia is a relatively weak base.

- The double arrows in the reaction for ammonia indicate that the binding and release of hydrogen ions are reversible reactions.
- At equilibrium, there is a fixed ratio of NH_4^+ to NH_3.

- Carbonic acid is a weak acid, which reversibly releases and accepts hydrogen ions.
    - $H_2CO_3 \Leftrightarrow HCO_3^- + H^+$
      Carbonic acid Bicarbonate ion Hydrogen ion

The pH scale measures the H⁺ concentration of a solution.

- In any aqueous solution at 25°C, the *product* of the H^+ and OH^- concentrations is constant at 10^{-14}.
- Brackets ($[H^+]$ and $[OH^–]$) indicate the molar concentration of the enclosed substance.
    - $[H^+] [OH^–] = 10^{–14}$
    - In a neutral solution at room temperature, $[H^+] = 10^{–7}$ *M* and $[OH^–] = 10^{–7}$ *M*.
- Solutions with more $OH^–$ than H^+ are basic solutions; solutions with more H^+ than OH^- are acidic; solutions in which the concentrations of OH^- and H^+ are equal are neutral.
- Adding an acid to a solution shifts the balance between H^+ and $OH^–$ toward H^+ and leads to a decrease in the $OH^–$ concentration.
    - If $[H^+] = 10^{–5}$ *M*, then $[OH^–] = 10^{–9}$ *M*.
    - Hydroxide concentrations decrease because some of the additional acid combines with hydroxide to form water.
- Adding a base does the opposite, increasing the $OH^–$ concentration and lowering the H^+ concentration.
- The H^+ and $OH^–$ concentrations of solutions can vary by a factor of 100 trillion or more.
- To express this variation more conveniently, the H^+ and $OH^–$ concentrations are typically expressed with the pH scale.
    - The pH scale, ranging from 1 to 14, compresses the range of concentrations by employing logarithms.
    - The **pH** of a solution is defined as the negative logarithm (base 10) of the hydrogen ion concentration.
    - $pH = -\log [H^+]$ or $[H^+] = 10^{-pH}$
    - In a neutral solution, $[H^+] = 10^{–7}$ *M* and pH = 7.
- The pH *decreases* as the H^+ concentration *increases*.
- Although the pH scale is based on $[H^+]$, values for $[OH^–]$ can be easily calculated from the product relationship.
- The pH of a neutral solution is 7.
- Acidic solutions have pH values less than 7, and basic solutions have pH values greater than 7.
- Most biological fluids have pH values in the range 6–8.

- However, the human stomach has strongly acidic digestive juice with a pH of about 2.

- Each pH unit represents a tenfold difference in H^+ and $OH^–$ concentrations.
    - A small change in pH indicates a substantial change in H^+ and $OH^–$ concentrations.
    - A solution of pH 3 is not twice as acidic as a solution of pH 6 but a thousand times more acidic.

Organisms are sensitive to changes in pH.

- The chemical processes in the cell can be disrupted by changes in the H^+ and $OH^–$ concentrations away from their normal values, usually near pH 7.
    - The pH of human blood is close to 7.4. A person cannot survive for more than a few minutes if the blood pH drops to 7 or rises to 7.8.
- To maintain cellular pH values at a constant level, biological fluids have buffers.
- **Buffers** resist changes in the pH of a solution when H^+ or $OH^–$ is added to the solution.
    - Buffers accept hydrogen ions from the solution when they are in excess and donate hydrogen ions when they have been depleted.
    - Buffers typically consist of a weak acid and its corresponding base.
    - One important buffer in human blood and other biological solutions is carbonic acid (H_2CO_3), formed when CO_2 reacts with water in blood plasma.
        - Carbonic acid dissociates to yield a bicarbonate ion (HCO_3^-) and a hydrogen ion (H^+).
        - The chemical equilibrium between carbonic acid and bicarbonate acts as a pH regulator.
        - The equilibrium shifts left or right as other metabolic processes add or remove H^+ from the solution.

Acidification of rivers, lakes, seas, and rain threatens the environment.

- Human activities threaten water quality.
- The burning of fossil fuels releases gaseous compounds into the atmosphere, which react with water to increases the acidity of the water.
    - Decreasing pH may alter the delicate balance of conditions for life on Earth.
- About 25% of human-generated CO_2 is absorbed by the oceans.
    - In spite of the huge volume of water in the oceans, scientists worry that this absorption of so much CO_2 will harm marine life and ecosystems.
- When CO_2 dissolves in seawater, it can react with water (H_20) to form carbonic acid (H_2CO_3).
    - This weak acid lowers the pH of seawater, a process known as **ocean acidification**.
    - Based on measurements of CO_2 levels in air bubbles trapped in ice over thousands of years, scientists calculate that the pH of the oceans is 0.1 pH units lower now than any time in the past 420,000 years.

- Recent studies predict it will drop another 0.3-0.5 pH units by 2100.

- As seawater acidifies, the extra hydrogen ions combine with carbonate ions (CO_3^{2-}) to form bicarbonate ions (HCO_3^-).
  - Scientists predict that ocean acidification will cause carbonate concentrations in the oceans to decrease by 40% over this century.
- Calcification, the production of calcium carbonate ($CaCO_3$) by corals and other organisms, is directly affected by the concentration of CO_3^{2-}.
- The burning of fossil fuels is also a major source of sulfur oxides and nitrous oxides.
  - These oxides react with water to form strong acids, which fall to Earth with rain or snow.
- **Acid precipitation** is rain, snow, or fog with a pH below 5.2.
  - Acid precipitation can damage aquatic life and also adversely affects land plants by changing soil chemistry.
  - The United States passed the Clean Air Act in 1990, mandating improved industrial technologies to reduce the release of harmful chemical pollutants.

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Chapter 3

Water and Life

Lectures by
Erin Barley
Kathleen Fitzpatrick

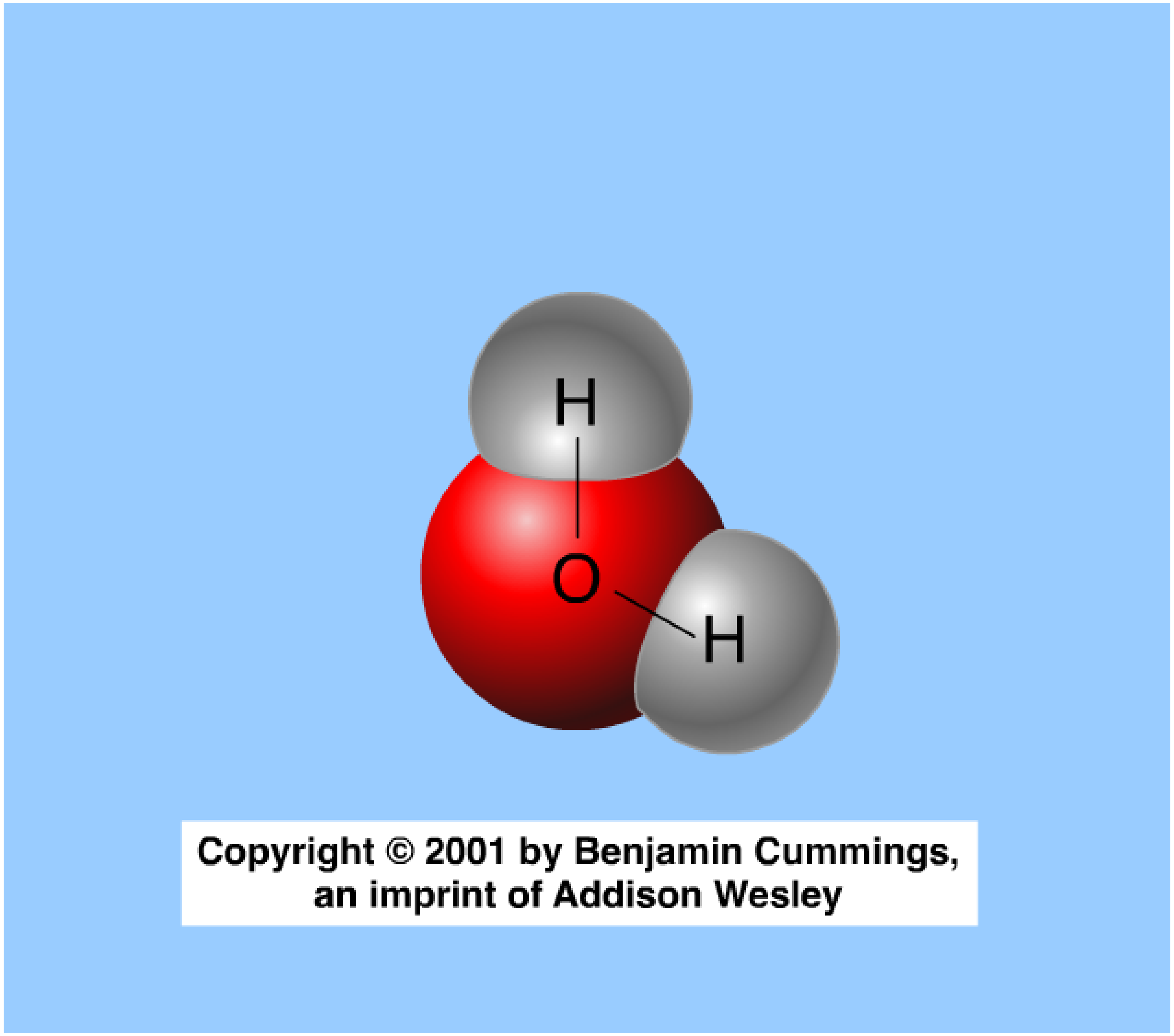
Overview: The Molecule That Supports All of Life

- Water is the biological medium on Earth
- All living organisms require water more than any other substance
- Most cells are surrounded by water, and cells themselves are about 70–95% water
- The abundance of water is the main reason the Earth is habitable

Figure 3.1

Concept 3.1: Polar covalent bonds in water molecules result in hydrogen bonding

- The water molecule is a **polar molecule**: the opposite ends have opposite charges
- Polarity allows water molecules to form hydrogen bonds with each other



Animation: Water Structure

Right-click slide/select “Play”

Figure 3.2

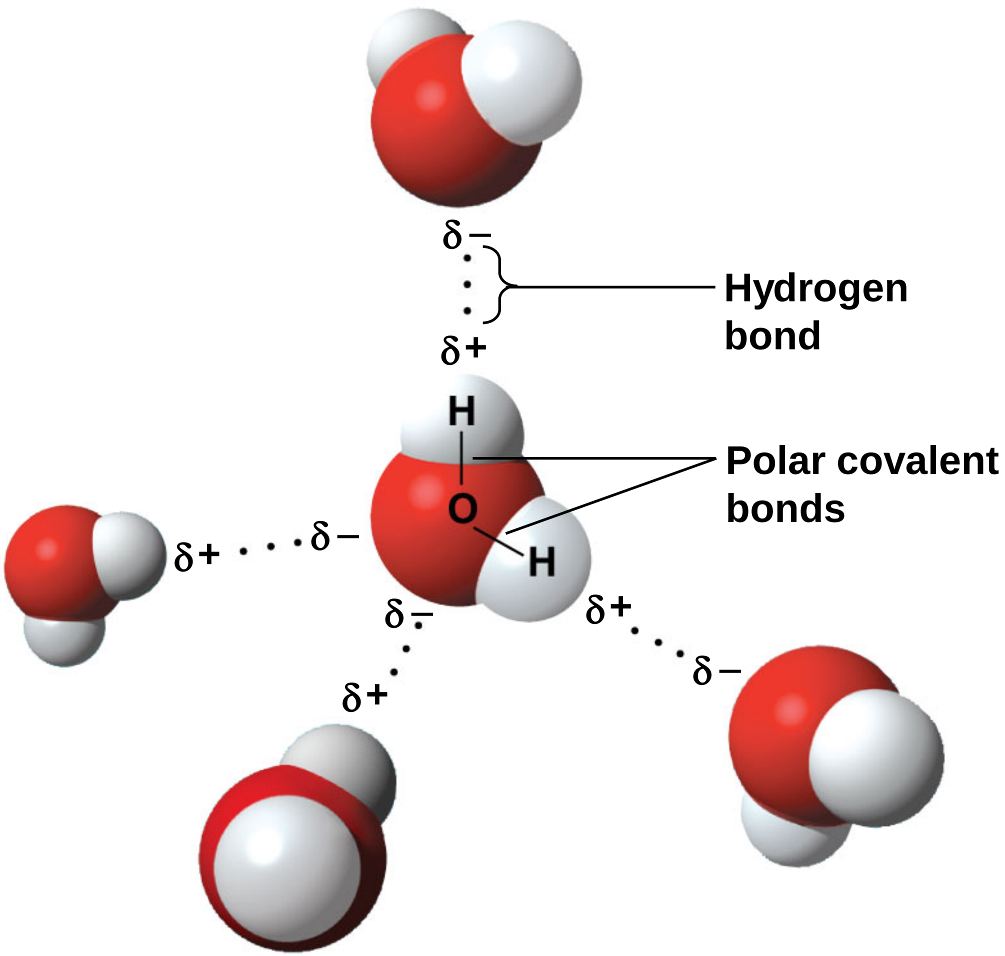
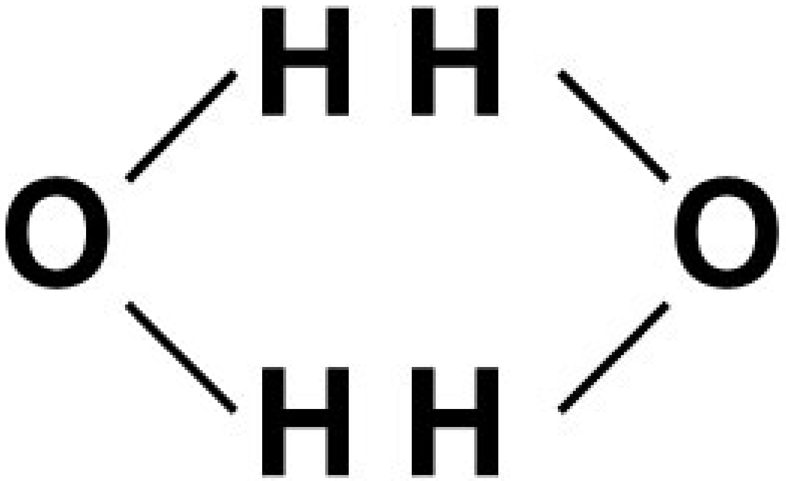


Figure 3.UN01

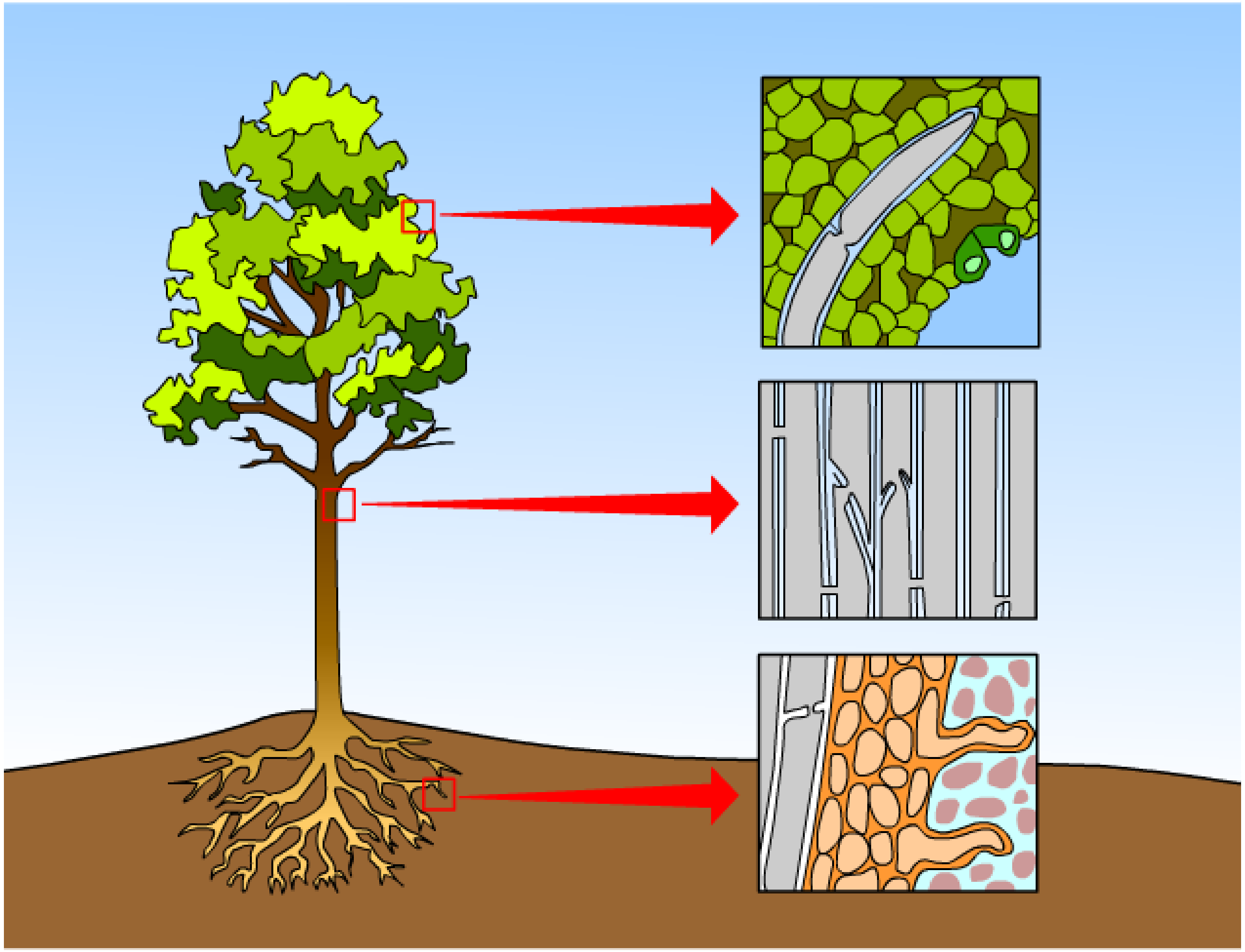


Concept 3.2: Four emergent properties of water contribute to Earth's suitability for life

- Four of water's properties that facilitate an environment for life are
  - Cohesive behavior
  - Ability to moderate temperature
  - Expansion upon freezing
  - Versatility as a solvent

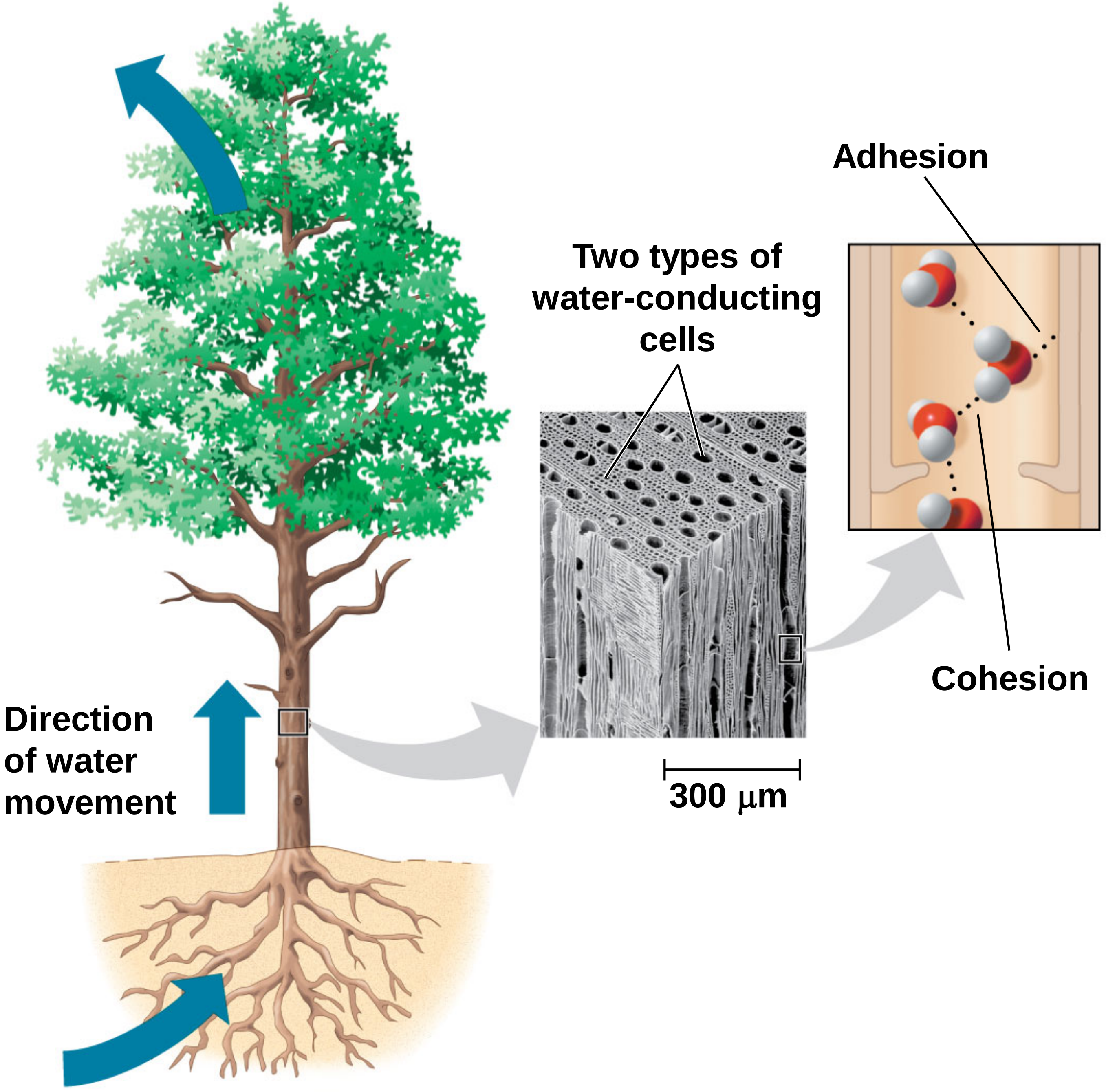
Cohesion of Water Molecules

- Collectively, hydrogen bonds hold water molecules together, a phenomenon called **cohesion**
- Cohesion helps the transport of water against gravity in plants
- **Adhesion** is an attraction between different substances, for example, between water and plant cell walls



Animation: Water Transport
Right-click slide/select “Play”

Figure 3.3



Adhesion
Two types of water-conducting cells
Cohesion
Direction of water movement
300 μm

Figure 3.3a

- **Surface tension** is a measure of how hard it is to break the surface of a liquid
- Surface tension is related to cohesion

Figure 3.4

Moderation of Temperature by Water

- Water absorbs heat from warmer air and releases stored heat to cooler air
- Water can absorb or release a large amount of heat with only a slight change in its own temperature

Heat and Temperature

- **Kinetic energy** is the energy of motion
- **Heat** is a measure of the total amount of kinetic energy due to molecular motion
- **Temperature** measures the intensity of heat due to the average kinetic energy of molecules

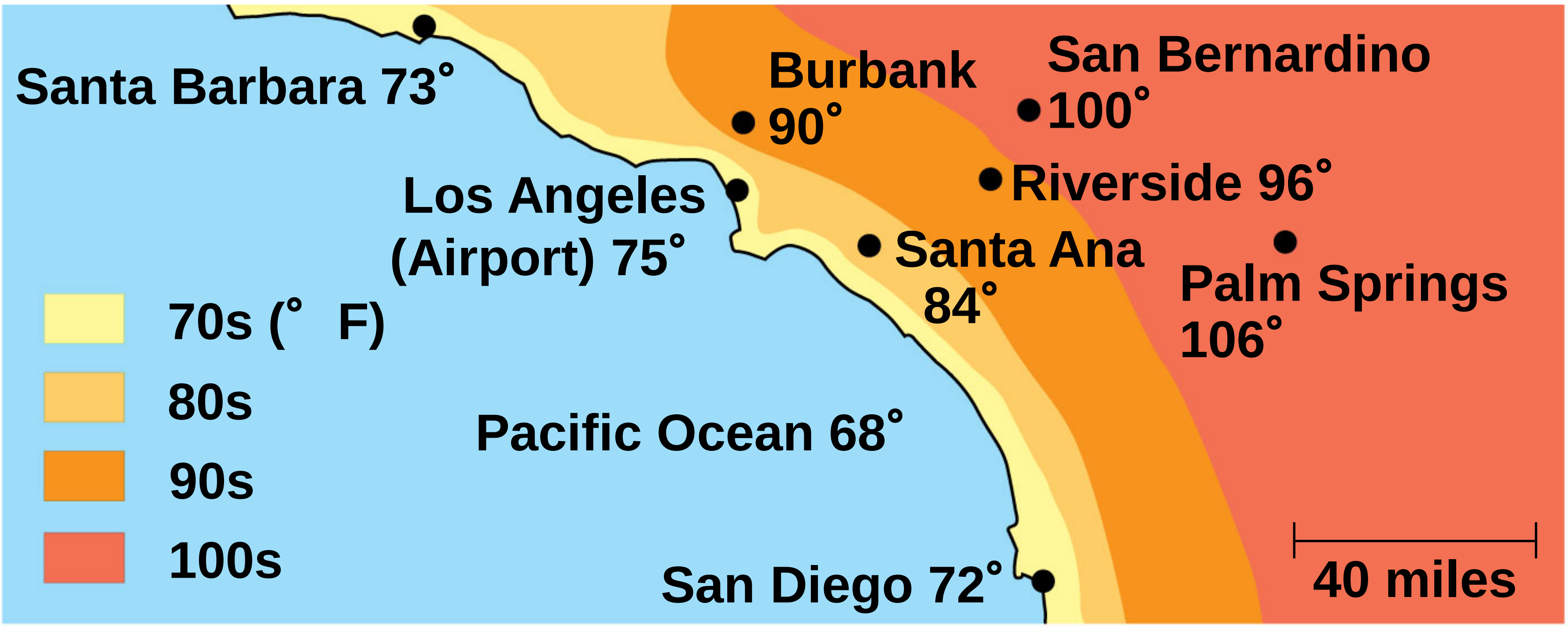
- The **Celsius scale** is a measure of temperature using Celsius degrees (°C)
- A **calorie (cal)** is the amount of heat required to raise the temperature of 1 g of water by 1°C
- The “calories” on food packages are actually **kilocalories (kcal)**, where 1 kcal = 1,000 cal
- The **joule (J)** is another unit of energy where 1 J = 0.239 cal, or 1 cal = 4.184 J

Water's High Specific Heat

- The **specific heat** of a substance is the amount of heat that must be absorbed or lost for 1 g of that substance to change its temperature by 1ºC
- The specific heat of water is 1 cal/g/ºC
- Water resists changing its temperature because of its high specific heat

- Water’s high specific heat can be traced to hydrogen bonding
  - Heat is absorbed when hydrogen bonds break
  - Heat is released when hydrogen bonds form
- The high specific heat of water minimizes temperature fluctuations to within limits that permit life

Figure 3.5



Santa Barbara 73°
Burbank 90°
San Bernardino 100°
Los Angeles (Airport) 75°
Riverside 96°
Santa Ana 84°
Palm Springs 106°
70s (° F)
80s
90s
100s
Pacific Ocean 68°
San Diego 72°
40 miles

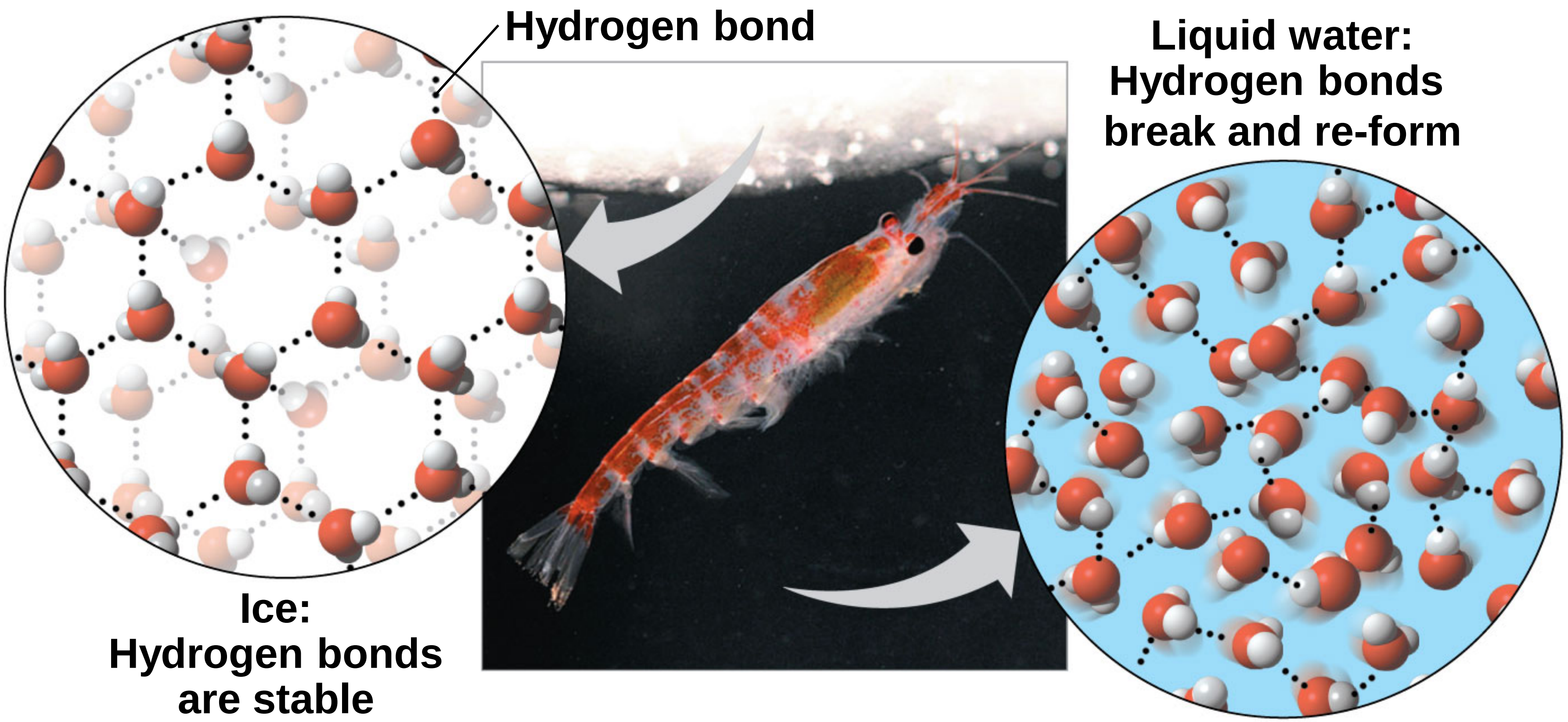
Evaporative Cooling

- Evaporation is transformation of a substance from liquid to gas
- **Heat of vaporization** is the heat a liquid must absorb for 1 g to be converted to gas
- As a liquid evaporates, its remaining surface cools, a process called **evaporative cooling**
- Evaporative cooling of water helps stabilize temperatures in organisms and bodies of water

Floating of Ice on Liquid Water

- Ice floats in liquid water because hydrogen bonds in ice are more “ordered,” making ice less dense
- Water reaches its greatest density at 4°C
- If ice sank, all bodies of water would eventually freeze solid, making life impossible on Earth

Figure 3.6



Hydrogen bond
Liquid water:
Hydrogen bonds
break and re-form
Ice:
Hydrogen bonds
are stable

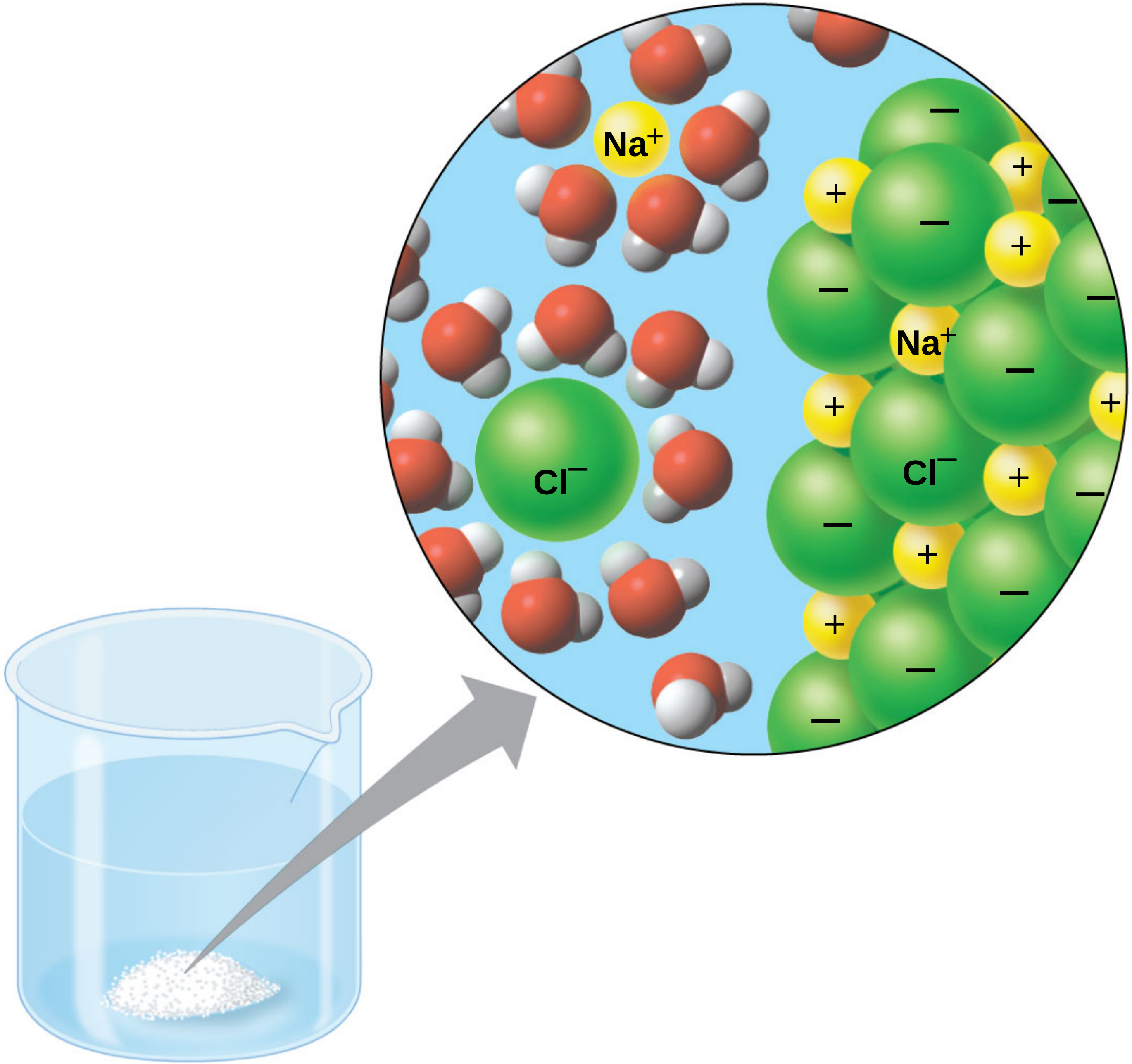
Figure 3.6a

Water: The Solvent of Life

- A **solution** is a liquid that is a homogeneous mixture of substances
- A **solvent** is the dissolving agent of a solution
- The **solute** is the substance that is dissolved
- An **aqueous solution** is one in which water is the solvent

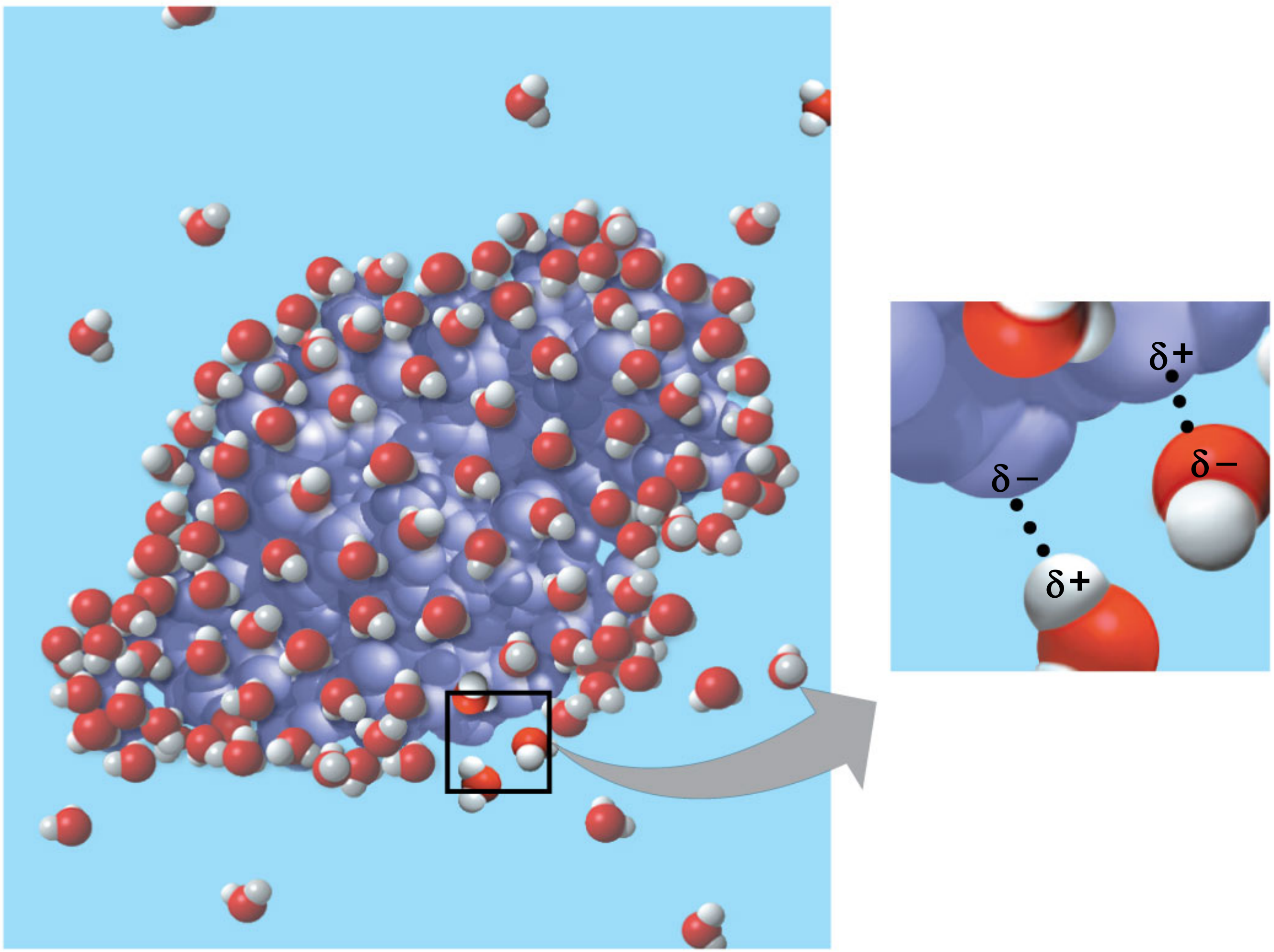
- Water is a versatile solvent due to its polarity, which allows it to form hydrogen bonds easily
- When an ionic compound is dissolved in water, each ion is surrounded by a sphere of water molecules called a **hydration shell**

Figure 3.7



- Water can also dissolve compounds made of nonionic polar molecules
- Even large polar molecules such as proteins can dissolve in water if they have ionic and polar regions

Figure 3.8



Hydrophilic and Hydrophobic Substances

- A **hydrophilic** substance is one that has an affinity for water
- A **hydrophobic** substance is one that does not have an affinity for water
- Oil molecules are hydrophobic because they have relatively nonpolar bonds
- A **colloid** is a stable suspension of fine particles in a liquid

Solute Concentration in Aqueous Solutions

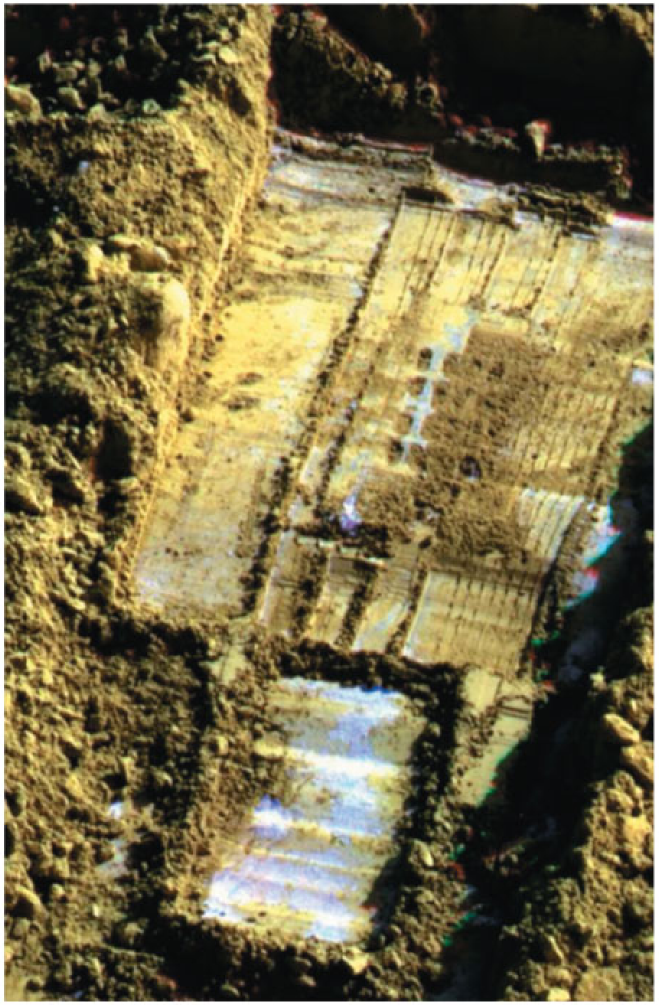
- Most biochemical reactions occur in water
- Chemical reactions depend on collisions of molecules and therefore on the concentration of solutes in an aqueous solution

- **Molecular mass** is the sum of all masses of all atoms in a molecule
- Numbers of molecules are usually measured in moles, where 1 **mole (mol)** = 6.02×10^{23} molecules
- Avogadro's number and the unit *dalton* were defined such that 6.02×10^{23} daltons = 1 g
- **Molarity (*M*)** is the number of moles of solute per liter of solution

Possible Evolution of Life on Other Planets with Water

- The remarkable properties of water support life on Earth in many ways
- Astrobiologists seeking life on other planets are concentrating their search on planets with water
- To date, more than 200 planets have been found outside our solar system; one or two of them contain water
- In our solar system, Mars has been found to have water

Figure 3.9

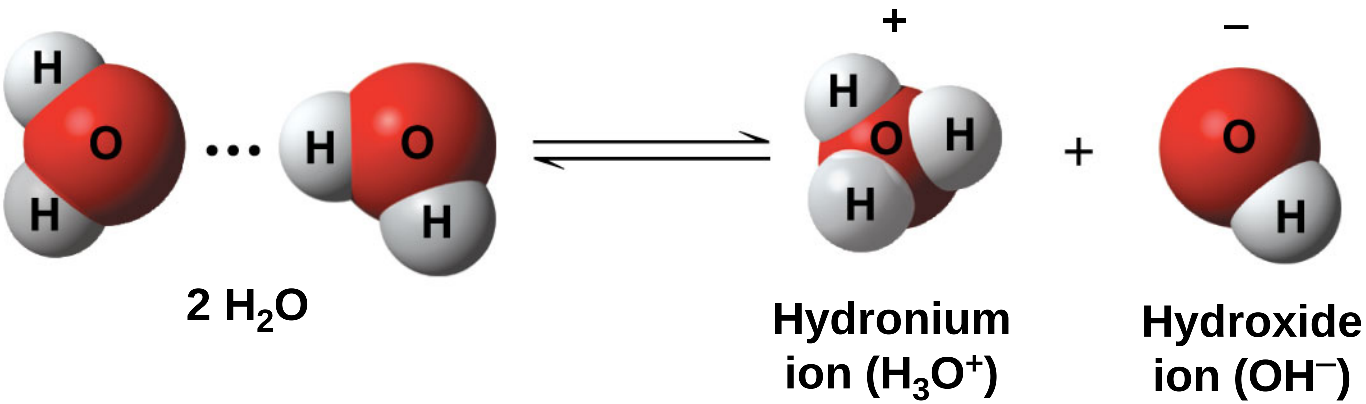


Concept 3.3: Acidic and basic conditions affect living organisms

- A hydrogen atom in a hydrogen bond between two water molecules can shift from one to the other
  - The hydrogen atom leaves its electron behind and is transferred as a proton, or **hydrogen ion** (H^+)
  - The molecule with the extra proton is now a **hydronium ion** (H_3O^+), though it is often represented as H^+
  - The molecule that lost the proton is now a **hydroxide ion** (OH^-)

- Water is in a state of dynamic equilibrium in which water molecules dissociate at the same rate at which they are being reformed

Figure 3.UN02



- Though statistically rare, the dissociation of water molecules has a great effect on organisms
- Changes in concentrations of H^+ and $OH^–$ can drastically affect the chemistry of a cell

- Concentrations of H^+ and OH^- are equal in pure water
- Adding certain solutes, called acids and bases, modifies the concentrations of H^+ and OH^-
- Biologists use something called the pH scale to describe whether a solution is acidic or basic (the opposite of acidic)

Acids and Bases

- An **acid** is any substance that increases the H^+ concentration of a solution
- A **base** is any substance that reduces the H^+ concentration of a solution

The pH Scale

- In any aqueous solution at 25° C the product of H^+ and OH^- is constant and can be written as

$$[H^+][OH^-] = 10^{-14}$$

- The **pH** of a solution is defined by the negative logarithm of H^+ concentration, written as

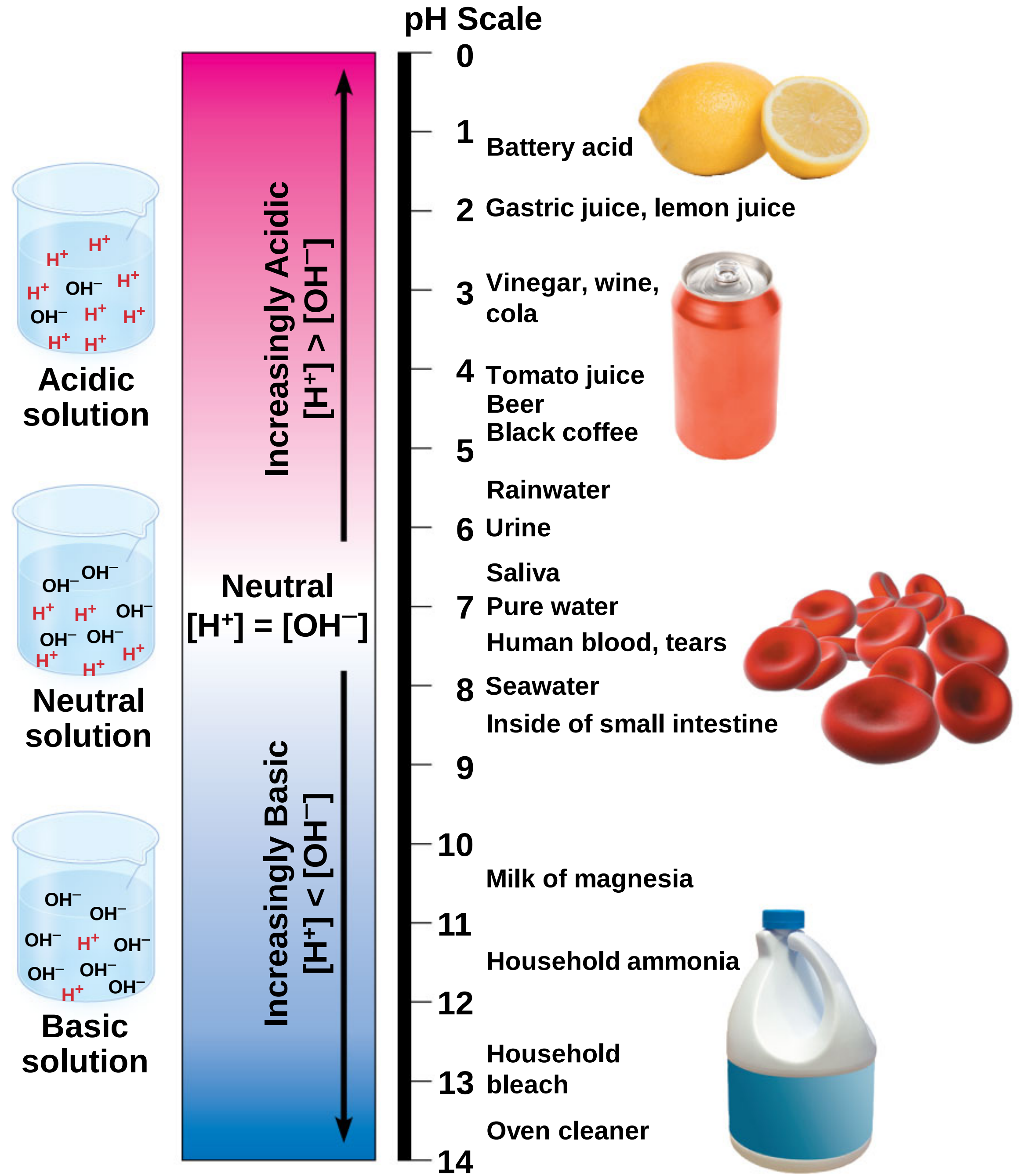
$$pH = -\log [H^+]$$

- For a neutral aqueous solution, $[H^+]$ is 10^{-7}, so

$$pH = -(-7) = 7$$

- Acidic solutions have pH values less than 7
- Basic solutions have pH values greater than 7
- Most biological fluids have pH values in the range of 6 to 8

Figure 3.10



pH Scale
0
1 Battery acid
2 Gastric juice, lemon juice
3 Vinegar, wine, cola
4 Tomato juice
Beer
Black coffee
5
Rainwater
6 Urine
Saliva
7 Pure water
Human blood, tears
8 Seawater
Inside of small intestine
9
10
Milk of magnesia
11
Household ammonia
12
Household bleach
13
Oven cleaner
14
Increasingly Acidic
$[H^+] > [OH^-]$
Neutral
$[H^+] = [OH^-]$
Increasingly Basic
$[H^+] < [OH^-]$
Acidic solution
Neutral solution
Basic solution

Figure 3.10a

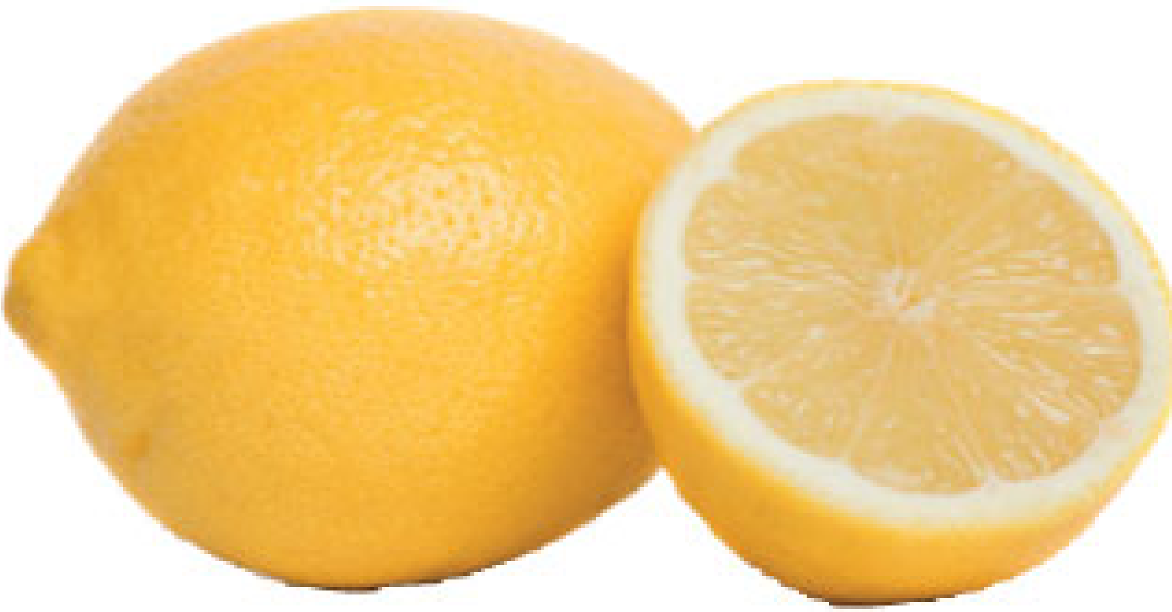


Figure 3.10b

Figure 3.10c

Figure 3.10d

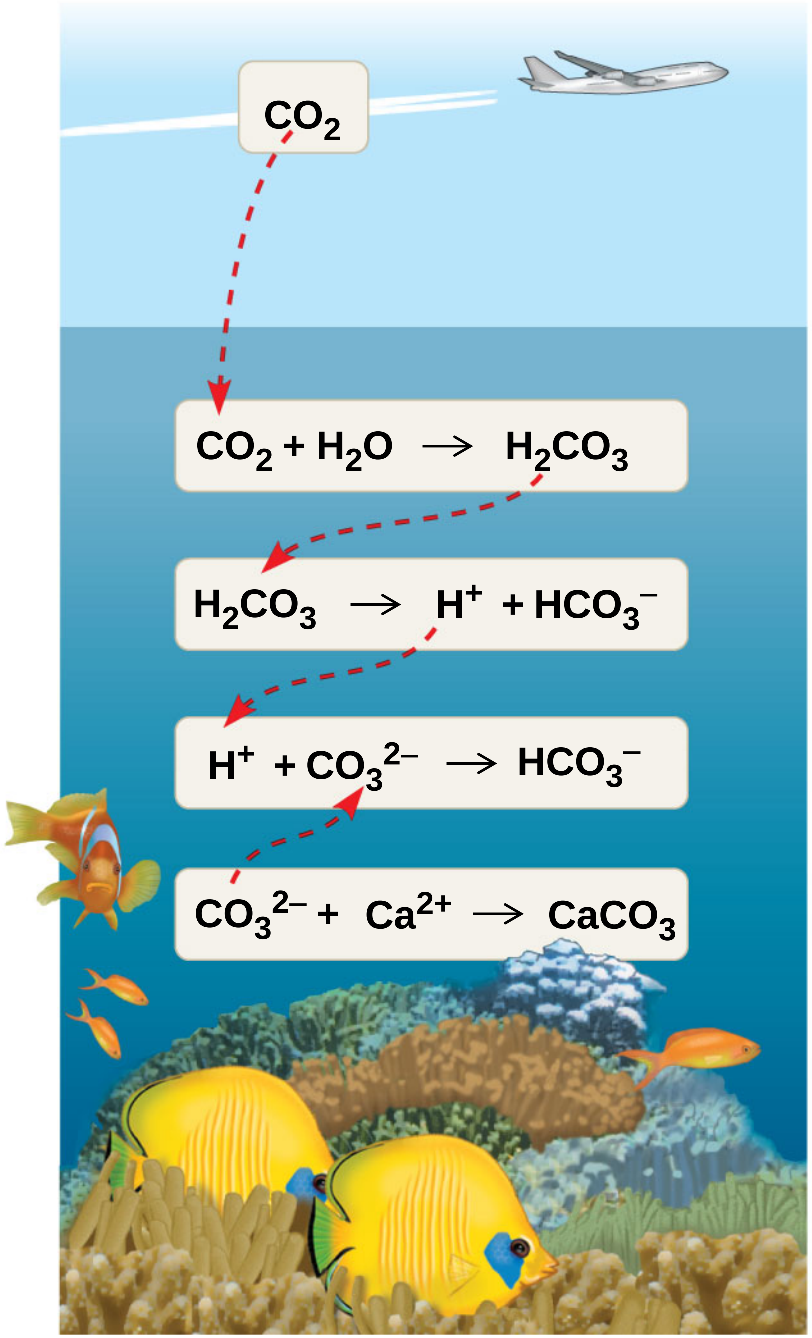
Buffers

- The internal pH of most living cells must remain close to pH 7
- **Buffers** are substances that minimize changes in concentrations of H^+ and OH^- in a solution
- Most buffers consist of an acid-base pair that reversibly combines with H^+

Acidification: A Threat to Water Quality

- Human activities such as burning fossil fuels threaten water quality
- CO_2 is the main product of fossil fuel combustion
- About 25% of human-generated CO_2 is absorbed by the oceans
- CO_2 dissolved in sea water forms carbonic acid; this process is called **ocean acidification**

Figure 3.11



CO_2
$CO_2 + H_2O \rightarrow H_2CO_3$
$H_2CO_3 \rightarrow H^+ + HCO_3^-$
$H^+ + CO_3^{2-} \rightarrow HCO_3^-$
$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3$

- As seawater acidifies, H^+ ions combine with carbonate ions to produce bicarbonate
- Carbonate is required for calcification (production of calcium carbonate) by many marine organisms, including reef-building corals

Figure 3.12

(a) (b) (c)

Figure 3.12a

(a)

Figure 3.12b

(b)

Figure 3.12c

(c)

- The burning of fossil fuels is also a major source of sulfur oxides and nitrogen oxides
- These compounds react with water in the air to form strong acids that fall in rain or snow
- **Acid precipitation** is rain, fog, or snow with a pH lower than 5.2
- Acid precipitation damages life in lakes and streams and changes soil chemistry on land

Figure 3.UN03

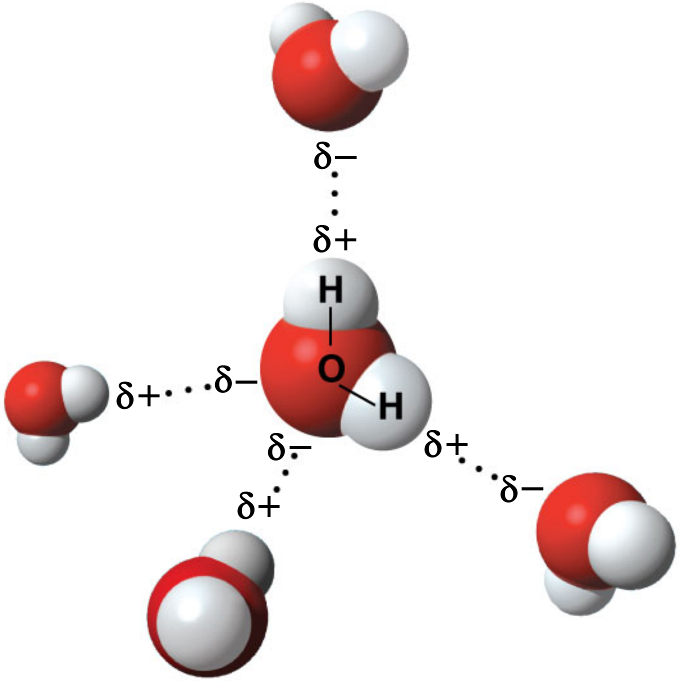
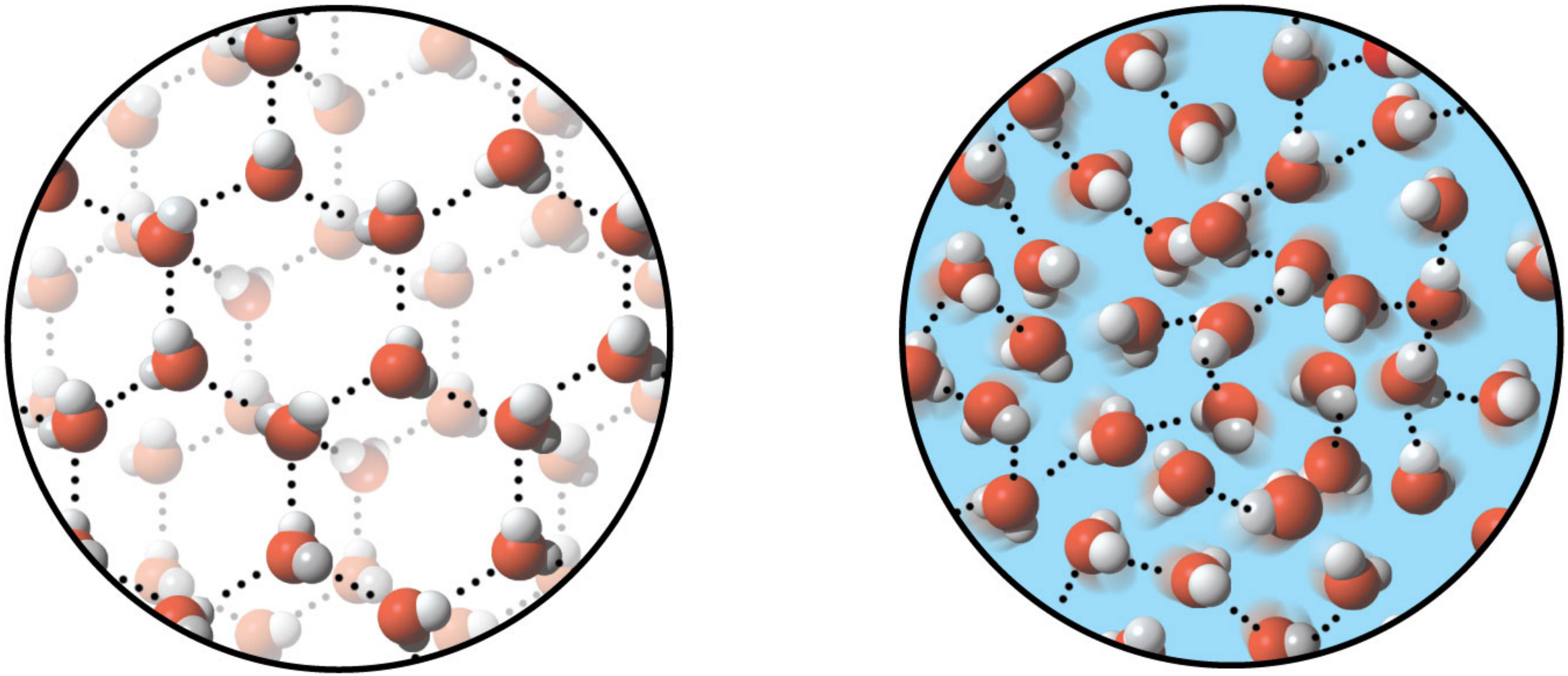


Figure 3.UN04



Ice: stable hydrogen bonds

Liquid water: transient hydrogen bonds

Figure 3.UN05

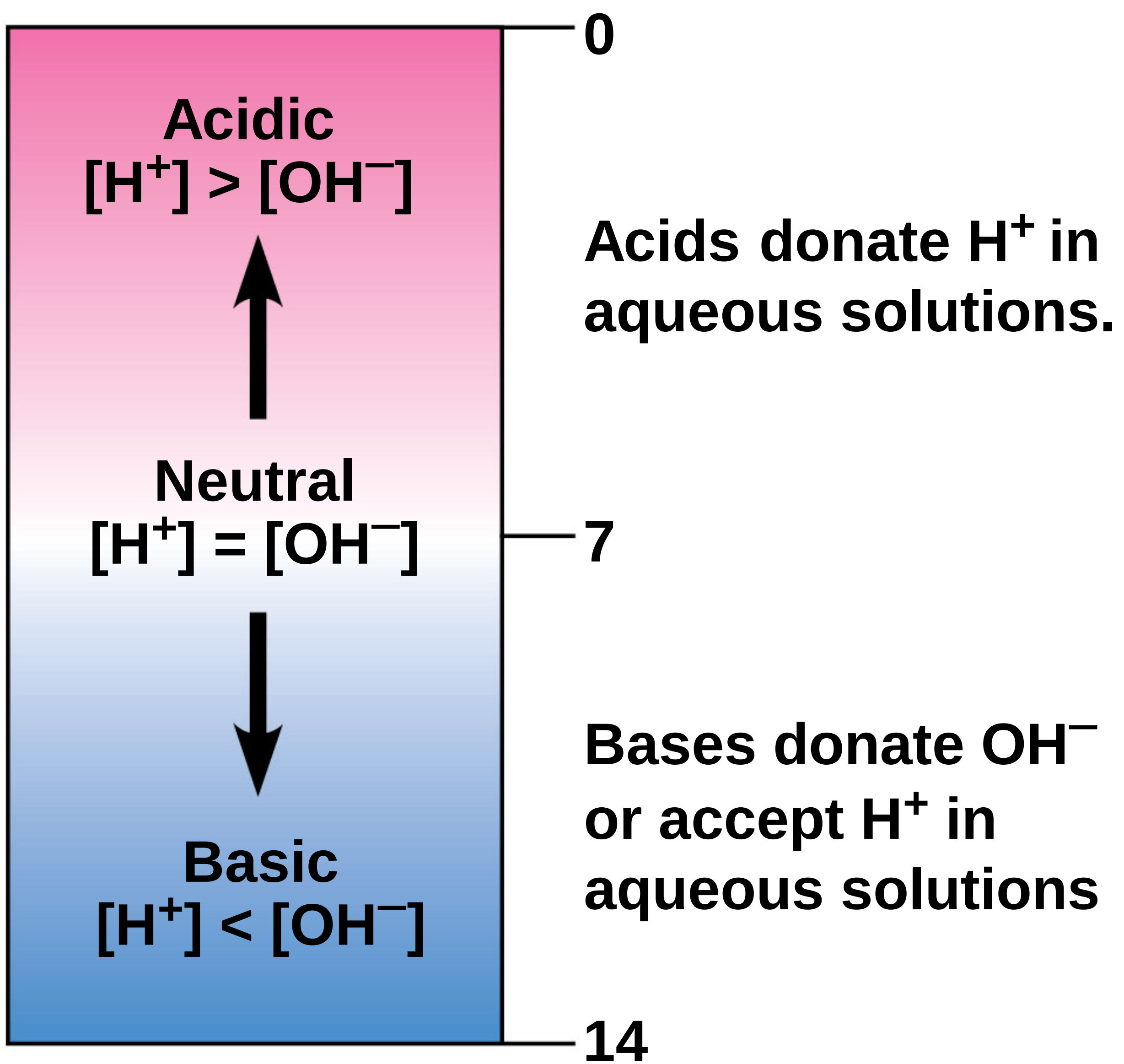


Figure 3.UN06

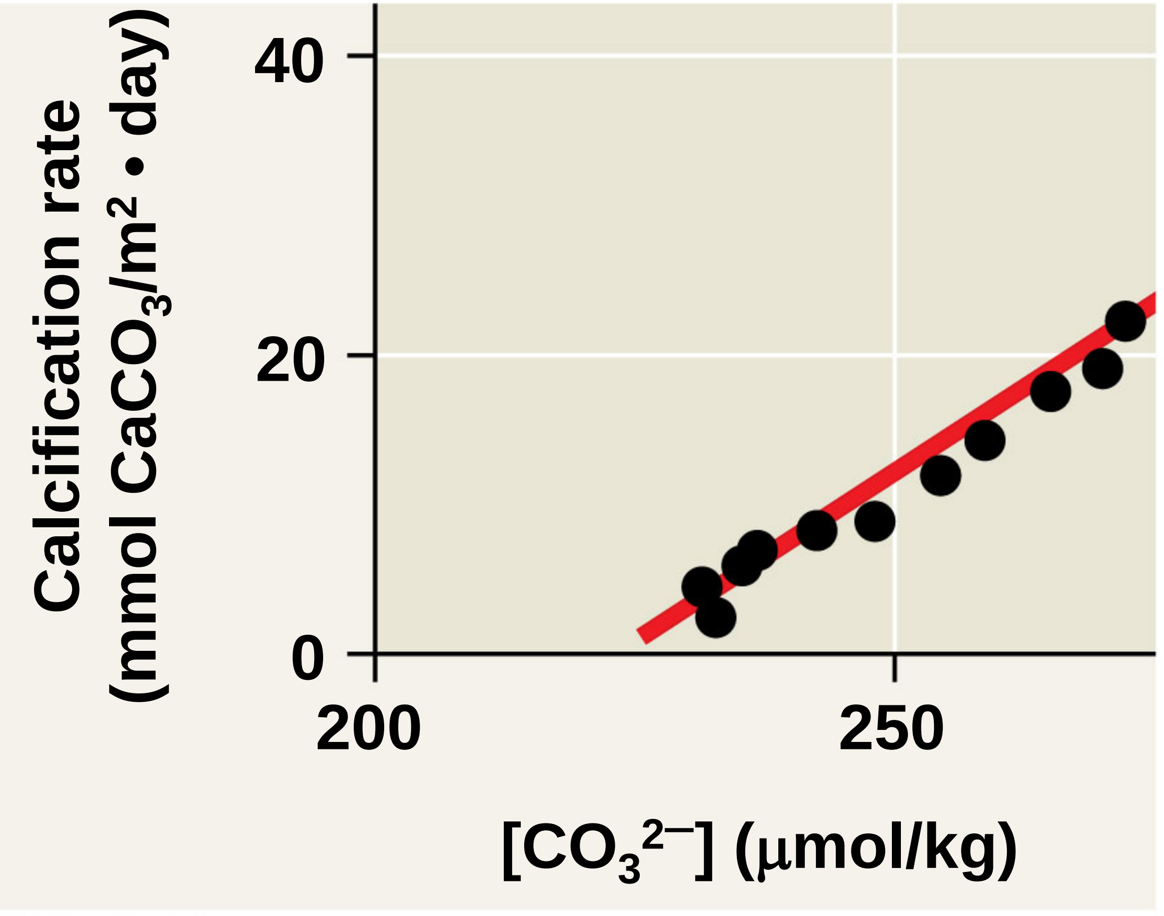


Figure 3.UN07

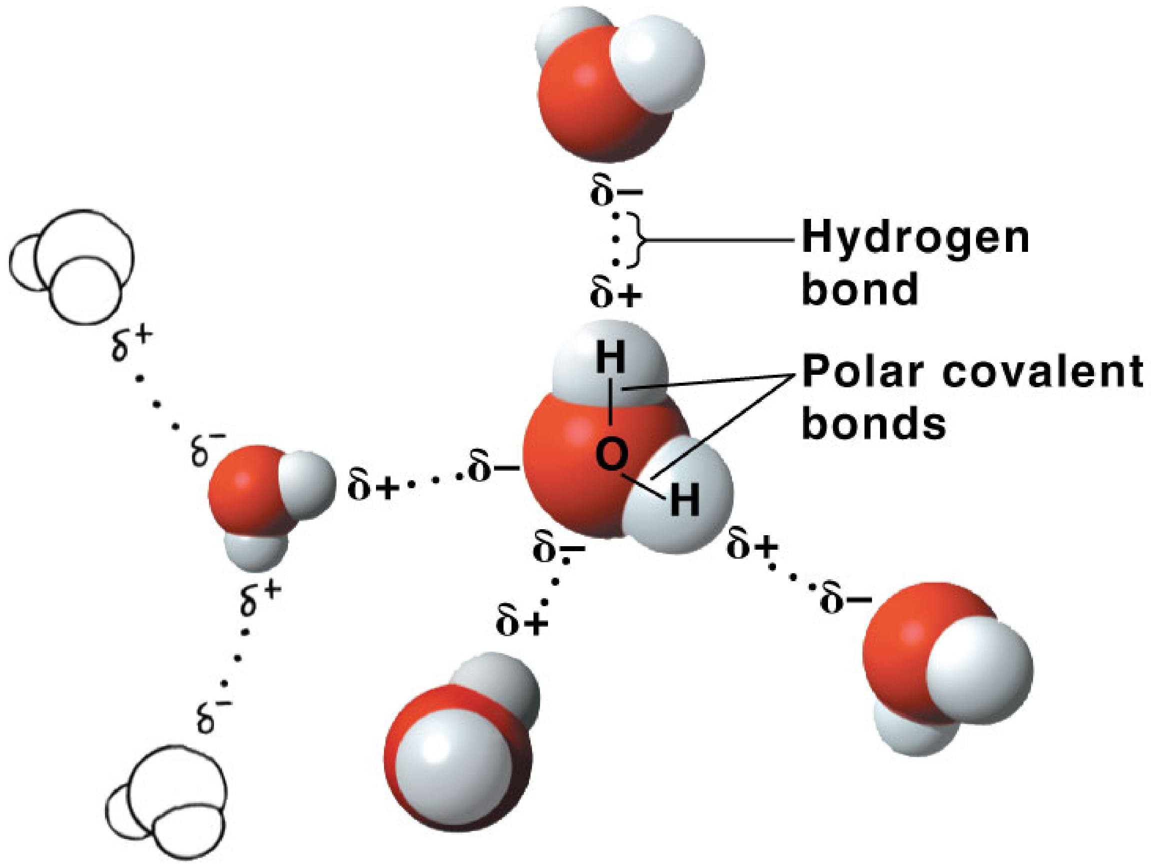


Figure 3.UN08

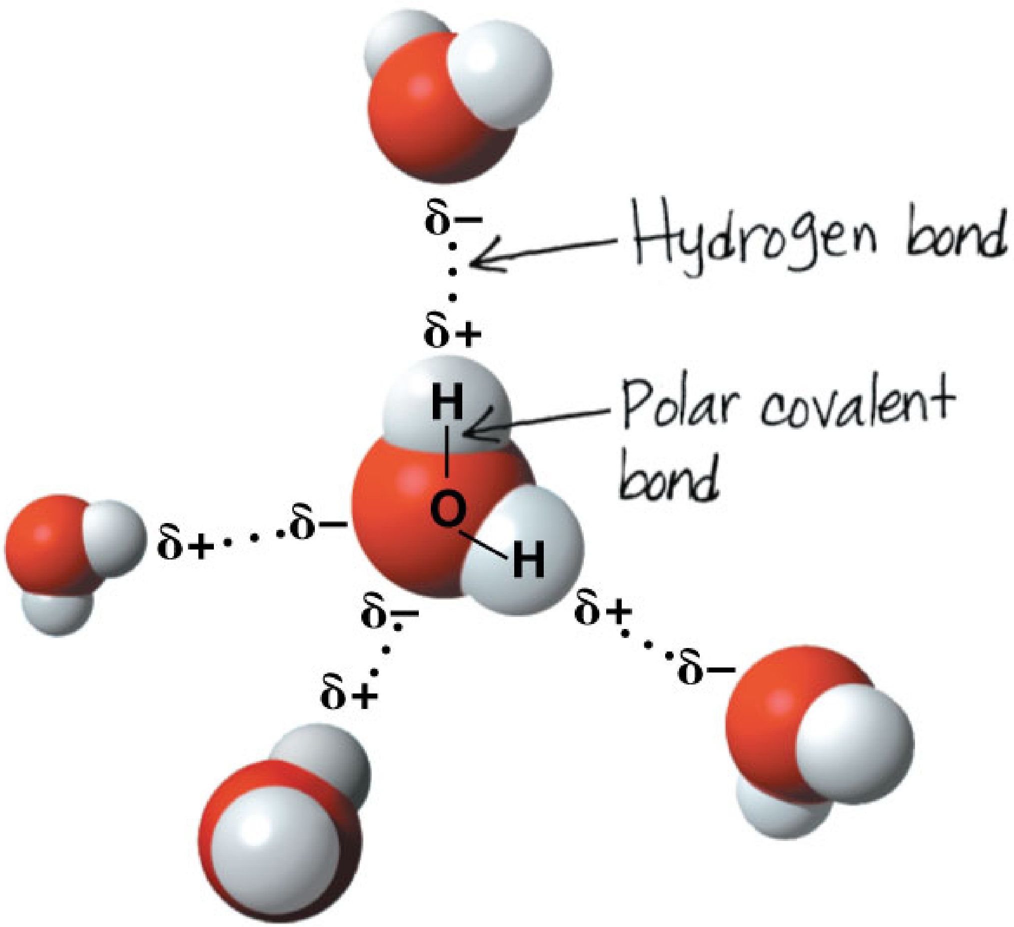
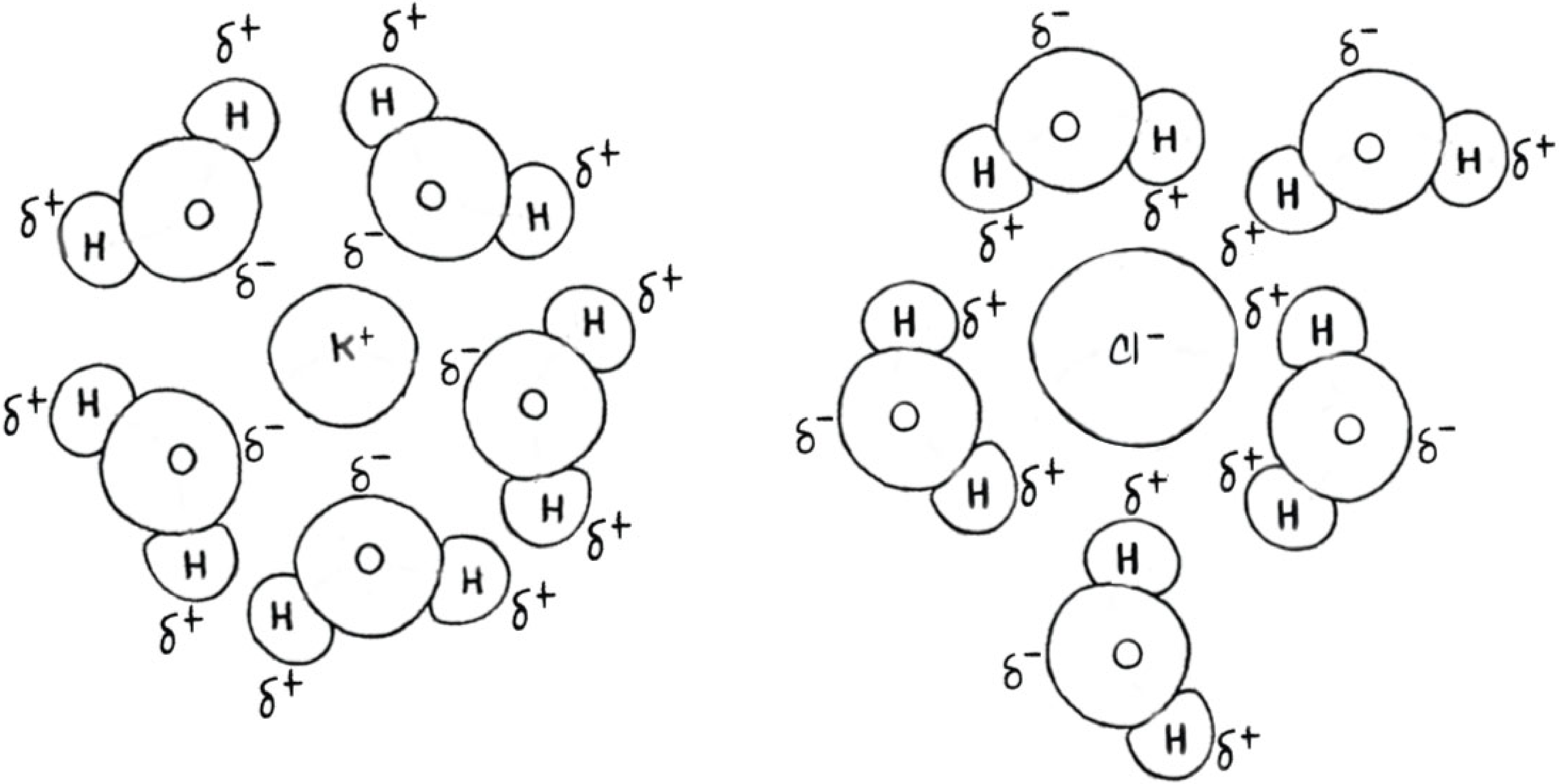


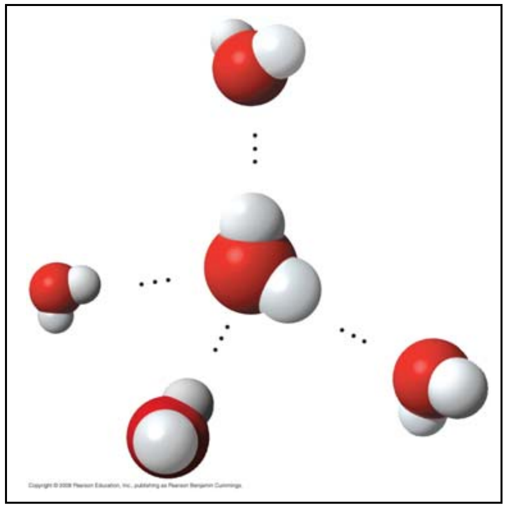
Figure 3.UN09



Name______________________Period___________

Chapter 3: Water and the Fitness of the Environment

Concept 3.1 The polarity of water molecules results in hydrogen bonding



1. Study the water molecules at the right. On the central molecule, label oxygen (O) and hydrogen (H).

2. What is a *polar molecule*? Why is water considered polar?

3. Now, add **+** and **–** signs to indicate the charged regions of *each* molecule. Then, indicate the hydrogen bonds.

4. Explain *hydrogen bonding*. How many hydrogen bonds can a single water molecule form?

Concept 3.2 Four emergent properties of water contribute to Earth's fitness for life

Hydrogen bonding accounts for the unique properties of water. Let's look at several.

Cohesion

5. Distinguish between *cohesion* and *adhesion*.

6. What is demonstrated when you see beads of water on a waxed car hood?

7. Which property explains the ability of a water strider to walk on water?

Moderation of Temperature

8. The calorie is a unit of heat. Define *calorie*.

9. Water has high *specific heat*. What does this mean? How does water's specific heat compare to alcohol's?

10. Explain how hydrogen bonding contributes to water's high specific heat.

11. Summarize how water's high specific heat contributes to the moderation of temperature. How is this property important to life?

12. Define *evaporation*. What is *heat of vaporization*? Explain at least three effects of this property on living organisms.

Expansion upon Freezing

13. Ice floats! So what? Consider what would happen if ponds and other bodies of water accumulated ice at the bottom. Describe why this property of water is important.

14. Now, explain *why* ice floats. Why is $4^{o}C$ the critical temperature in this story?

Solvent of Life

15. Review and define these terms:
    solvent

    solution

    solute

16. Consider coffee to which you have added sugar. Which is the solvent? The solute?

17. Explain why water is such a fine solvent.

18. Define *hydrophobic* and *hydrophilic*.

19. You already know that some materials, such as olive oil, will not dissolve in water. In fact, oil will float on top of water. Explain this property in terms of hydrogen bonding.

20. Now, let's do a little work that will enable you to prepare solutions. Read the section on solute concentrations carefully, and show the calculations here for preparing a 1-molar solution of sucrose. Steps to help you do this follow. The first step is done for you. Fill in the rest.

Steps to prepare a solution:

a. Write the molecular formula. $C_{12}H_{22}O_{11}$

b. Use your periodic table to calculate the mass of each element. Multiply by the number of atoms of the element. (For example, O has a mass of 16. Therefore one mole of O has a mass of 16 x 11 = 176 g/mole.)

c. Add the masses of each element in the molecule.

d. Add this mass of the compound to water to bring it to a volume of 1 liter. This makes 1 liter of a 1-M (1 molar) solution.

21. Can you prepare 1 liter of a 0.5-molar *glucose* solution? Show your work here.

22. Define *molarity.*

Concept 3.3 Acidic and basic conditions affect living organisms

23. What two ions form when water dissociates?

You should have answered "hydronium (H_3O+) and hydroxide ions (OH–)" in the preceding question. However, by convention, we will represent the hydronium ion as H+.

24. What is the concentration of each ion in pure water at 25^{o}C?

25. Water has a pH of 7. *pH* is defined as the negative log of the hydrogen ion concentration [H+]. Can you now see how water is assigned a pH of 7?

26. To go a step further, the product of H+ and OH– concentrations is constant at 10^{-14}.

$$[H+\}[OH-\} = 10^{-14.}$$

Water, which is neutral with a pH of 7, has an equal number of H+ and OH– ions. Now, define

acid

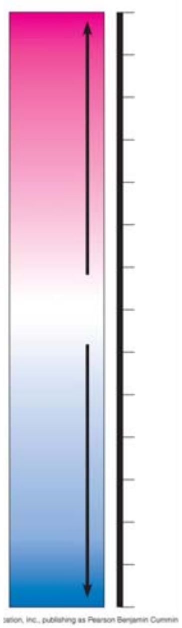
base

27. Because the pH scale is logarithmic, each numerical change represents a 10X change in ion concentration.

a. So, how many times more acidic is a pH of 3 compared to a pH of 5?

b. How many times more basic is a pH of 12 compared to a pH of 8?

c. Explain difference between a pH of 8 and a pH of 12 in terms of H+ concentration.



28. On the pH chart, label pH 1–14. Label *neutral, acid, base*. Indicate the locations of pure water, urine, gastric juice, and bleach.

29. Even a slight change in pH can be harmful! How do *buffers* moderate pH change?

30. Exercise will result in the production of CO_2, which will acidify the blood. Explain the buffering system that minimizes blood pH changes.

31. *Acid precipitation* is increasing. Explain its sources.

32. Discuss how CO_2 emissions affect marine life and ecosystems.

Testing Your Knowledge: Self-Quiz Answers

Now you should be ready to test your knowledge. Place your answers here:

1._______ 2._______ 3._______ 4._______ 5._______ 6._______ 7._______ 8._______

The King's Academy
AP Biology
Mrs. Carruthers
Test – Chapter 3

WATER AND LIFE

Multiple Choice: Identify the choice that best completes the statement or answers the question.

1) In a single molecule of water, two hydrogen atoms are bonded to a single oxygen atom by
A) hydrogen bonds.
B) nonpolar covalent bonds.
C) polar covalent bonds.
D) ionic bonds.
E) van der Waals interactions.

2) The slight negative charge at one end of one water molecule is attracted to the slight positive charge of another water molecule. What is this attraction called?
A) a covalent bond
B) a hydrogen bond
C) an ionic bond
D) a hydrophilic bond
E) a van der Waals interaction

3) The partial negative charge in a molecule of water occurs because
A) the oxygen atom acquires an additional electron.
B) the electrons shared between the oxygen and hydrogen atoms spend more time around the oxygen atom nucleus than around the hydrogen atom nucleus.
C) the oxygen atom has two pairs of electrons in its valence shell that are not neutralized by hydrogen atoms.
D) the oxygen atom forms hybrid orbitals that distribute electrons unequally around the oxygen nucleus.
E) one of the hydrogen atoms donates an electron to the oxygen atom.

4) Water molecules are able to form hydrogen bonds with
A) compounds that have polar covalent bonds.
B) oils.
C) oxygen gas (O2) molecules.
D) chloride ions.
E) any compound that is not soluble in water.

5) Which type of bond must be broken for water to vaporize?
A) ionic bonds
B) both hydrogen bonds and ionic bonds
C) polar covalent bonds
D) hydrogen bonds
E) both polar covalent bonds and hydrogen bonds

6) Temperature usually increases when water condenses. Which behavior of water is most directly responsible for this phenomenon?
A) the change in density when it condenses to form a liquid or solid
B) reactions with other atmospheric compounds
C) the release of heat by the formation of hydrogen bonds
D) the release of heat by the breaking of hydrogen bonds
E) the high surface tension of water

7) Why does evaporation of water from a surface cause cooling of the surface?
A) The breaking of bonds between water molecules absorbs heat.
B) The water molecules with the most heat energy evaporate more readily.
C) The solute molecules left behind absorb heat.
D) Water molecules absorb heat from the surface in order to acquire enough energy to evaporate.
E) The expansion of water vapor extracts heat from the surface.

8) Why does ice float in liquid water?
A) The high surface tension of liquid water keeps the ice on top.
B) The ionic bonds between the molecules in ice prevent the ice from sinking.
C) Ice always has air bubbles that keep it afloat.
D) Hydrogen bonds stabilize and keep the molecules of ice farther apart than the water molecules of liquid water.
E) The crystalline lattice of ice causes it to be denser than liquid water.

9) Hydrophobic substances such as vegetable oil are
A) nonpolar substances that repel water molecules.
B) nonpolar substances that have an attraction for water molecules.
C) polar substances that repel water molecules.
D) polar substances that have an affinity for water.
E) charged molecules that hydrogen-bond with water molecules.

-continue-

10) One mole (mol) of glucose (molecular mass = 180 daltons) is
A) 180×10^{23} molecules of glucose.
B) 1 kg of glucose dissolved in 1 L of solution.
C) the largest amount of glucose that can be dissolved in 1 L of solution.
D) 180 kilograms of glucose.
E) both 180 grams of glucose and 6.02×10^{23} molecules of glucose.

11) The molar mass of glucose is 180 g/mol. Which of the following procedures should you carry out to make a 1 *M* solution of glucose?
A) Dissolve 1 g of glucose in 1 L of water.
B) Dissolve 180 g of glucose in 1 L of water.
C) Dissolve 180 g of glucose in 180 g of water.
D) Dissolve 180 milligrams (mg) of glucose in 1 L of water.
E) Dissolve 180 g of glucose in 0.8 L of water, and then add more water until the total volume of the solution is 1 L.

12) The molecular weight of water is 18 daltons. What is the molarity of 1 liter of pure water? (*Hint:* What is the mass of 1 liter of pure water?)
A) 55.6 *M*
B) 18 *M*
C) 37 *M*
D) 0.66 *M*
E) 1.0 *M*

13) You have a freshly prepared 1 *M* solution of glucose in water. You carefully pour out a 100 mL sample of that solution. How many glucose molecules are included in that 100 mL sample?
A) 6.02×10^{23}
B) 3.01×10^{23}
C) 6.02×10^{24}
D) 12.04×10^{23}
E) 6.02×10^{22}

14) A strong acid like HCl
A) ionizes completely in an aqueous solution.
B) increases the pH when added to an aqueous solution.
C) reacts with strong bases to create a buffered solution.
D) is a strong buffer at low pH.
E) both ionizes completely in aqueous solutions and is a strong buffer at low pH.

-continue-

15) A solution contains 0.0000001(10^{-7}) moles of hydroxyl ions [OH^-] per liter. Which of the following best describes this solution?

A) acidic: H^+ acceptor

B) basic: H^+ acceptor

C) acidic: H^+ donor

D) basic: H^+ donor

E) neutral

16) Which of the following solutions would require the greatest amount of base to be added to bring the solution to neutral pH?

A) gastric juice at pH 2

B) vinegar at pH 3

C) tomato juice at pH 4

D) black coffee at pH 5

E) household bleach at pH 12

17) What is the hydrogen ion [H^+] concentration of a solution of pH 8?

A) 8 *M*

B) 8×10^{-6} *M*

C) 0.01 *M*

D) 10^{-8} *M*

E) 10^{-6} *M*

18) If the pH of a solution is decreased from 9 to 8, it means that the

A) concentration of H^+ has decreased to one-tenth (1/10) what it was at pH 9.

B) concentration of H^+ has increased tenfold (10X) compared to what it was at pH 9.

C) concentration of OH^- has increased tenfold (10X) compared to what it was at pH 9.

D) concentration of OH^- has decreased to one-tenth (1/10) what it was at pH 9.

E) concentration of H^+ has increased tenfold (10X) and the concentration of OH^- has decreased to one-tenth (1/10) what they were at pH 9.

19) If the pH of a solution is increased from pH 5 to pH 7, it means that the

A) concentration of H^+ is twice (2X) what it was at pH 5.

B) concentration of H^+ is one-half (1/2) what it was at pH 5.

C) concentration of OH^- is 100 times greater than what it was at pH 5.

D) concentration of OH^- is one-hundredth (0.01X) what it was at pH 5.

E) concentration of H^+ is 100 times greater and the concentration of OH^- is one-hundredth what they were at pH 5.

-continue-

20) Buffers are substances that help resist shifts in pH by

A) releasing H^+ to a solution when acids are added.

B) donating H^+ to a solution when bases are added.

C) releasing OH^- to a solution when bases are added.

D) accepting H^+ from a solution when acids are added.

E) both donating H+ to a solution when bases are added, and accepting H+ when acids are added.

21) One of the buffers that contribute to pH stability in human blood is carbonic acid (H_2CO_3). Carbonic acid is a weak acid that, when placed in an aqueous solution, dissociates into a bicarbonate ion (HCO_3^- and a hydrogen ion (H^+). Thus,

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+$$

If the pH of the blood increases, one would expect

A) a decrease in the concentration of H_2CO_3 and an increase in the concentration of HCO_3^-.

B) an increase in the concentration of H_2CO_3 and a decrease in the concentration of HCO_3^-.

C) a decrease in the concentration of HCO_3^- and an increase in the concentration of H^+.

D) an increase in the concentration of HCO_3^- and a decrease in the concentration of OH^-.

E) a decrease in the concentration of HCO_3^- and an increase in the concentration of both H_2CO_3 and H^+.

22) Assume that acid rain has lowered the pH of a particular lake to pH 4.0. What is the hydroxyl ion concentration of this lake?

A) 1×10^{-10} mol of hydroxyl ion per liter of lake water

B) 1×10^{-4} mol of hydroxyl ion per liter of lake water

C) 10.0 *M* with regard to hydroxyl ion concentration

D) 4.0 *M* with regard to hydroxyl ion concentration

E) 1×10^{-4} mol of hydroxyl ion per liter of lake water and 4.0 *M* with regard to hydrogen ion concentration

23) Research indicates that acid precipitation can damage living organisms by

A) buffering aquatic systems such as lakes and streams.

B) decreasing the H^+ concentration of lakes and streams.

C) increasing the OH^- concentration of lakes and streams.

D) washing away certain mineral ions that help buffer soil solution and are essential nutrients for plant growth.

E) both decreasing the H^+ concentration of lakes and streams and increasing the OH^- concentration of lakes and streams.

24) Consider two solutions: solution X has a pH of 4; solution Y has a pH of 7. From this information, we can reasonably conclude that

A) solution Y has no free hydrogen ions (H^+).
B) the concentration of hydrogen ions in solution X is 30 times as great as the concentration of hydrogen ions in solution Y.
C) the concentration of hydrogen ions in solution Y is 1,000 times as great as the concentration of hydrogen ions in solution X.
D) the concentration of hydrogen ions in solution X is 3 times as great as the concentration of hydrogen ions in solution Y.
E) the concentration of hydrogen ions in solution X is 1,000 times as great as the concentration of hydrogen ions in solution Y.

25) Carbon dioxide (CO_2) is readily soluble in water, according to the equation $CO_2 + H_2O \leftrightarrow H_2CO_3$. Carbonic acid ($H_2CO_3$) is a weak acid. Respiring cells release CO_2 into the bloodstream. What will be the effect on pH of blood as that blood first comes in contact with respiring cells?
A) Blood pH will decrease slightly.
B) Blood pH will increase slightly.
C) Blood pH will remain unchanged.
D) Blood pH will first increase, then decrease as CO_2 combines with hemoglobin.
E) Blood pH will first decrease, then increase sharply as CO_2 combines with hemoglobin.

26) A beaker contains 100 mL of NaOH solution at pH = 13. A technician carefully pours into the beaker 10 mL of HCl at pH = 1. Which of the following statements correctly describes the results of this mixing?
A) The concentration of Na^+ ion rises.
B) The concentration of Cl^- ion will be 0.1 *M*.
C) The concentration of undissociated H_2O molecules remains unchanged.
D) The pH of the beaker's contents will be neutral.
E) The pH of the beaker's contents falls.

27) How would acidification of seawater affect marine organisms?
A) Acidification would increase dissolved carbonate concentrations and promote faster growth of corals and shell-building animals.
B) Acidification would decrease dissolved carbonate concentrations and promote faster growth of corals and shell-building animals.
C) Acidification would increase dissolved carbonate concentrations and hinder growth of corals and shell-building animals.
D) Acidification would decrease dissolved carbonate concentrations and hinder growth of corals and shell-building animals.
E) Acidification would increase dissolved bicarbonate concentrations, and cause increased calcification of corals and shellfish.

28) One idea to mitigate the effects of burning fossil fuels on atmospheric CO_2 concentrations is to pipe liquid CO_2 into the ocean at depths of 2,500 feet or greater. At the high pressures at such depths, CO_2 is heavier than water. What potential effects might result from implementing such a scheme?
A) increased photosynthetic carbon fixation because of the increased dissolved carbon dioxide in the deep water
B) increased carbonate concentrations in the deep waters
C) reduced growth of corals from a change in the carbonate—bicarbonate equilibrium
D) no effect because carbon dioxide is not soluble in water
E) both increased acidity of the deep waters and changes in the growth of bottom-dwelling organisms with calcium carbonate shells

29) If the cytoplasm of a cell is at pH 7, and the mitochondrial matrix is at pH 8, this means that
A) the concentration of H+ ions is tenfold higher in the cytoplasm than in the mitochondrial matrix.
B) the concentration of H+ ions is tenfold higher in the mitochondrial matrix than in the cytoplasm.
C) the concentration of H+ ions in the cytoplasm is 7/8 the concentration in the mitochondrial matrix.
D) the mitochondrial matrix is more acidic than the cytoplasm.
E) the concentration of H+ ions in the cytoplasm is 8/7 the concentration in the mitochondrial matrix.

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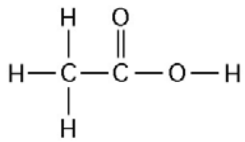


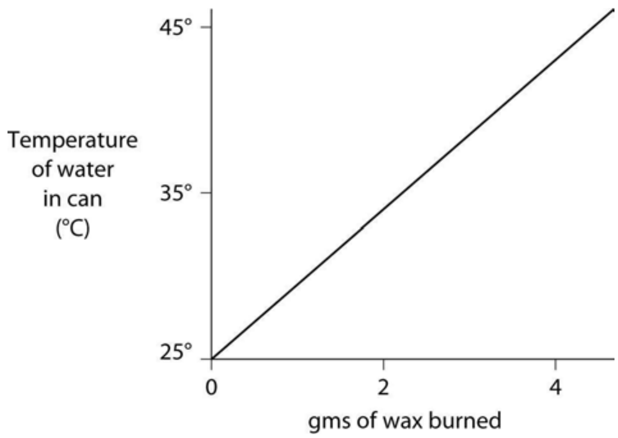
30) How many grams would be equal to 1 mol of the compound shown in the figure above?
(carbon = 12, oxygen = 16, hydrogen = 1)
A) 29
B) 30
C) 60
D) 150
E) 342

31) How many grams of the compound in the figure above would be required to make 1 L of a 0.5 *M* solution?
(carbon = 12, oxygen = 16, hydrogen = 1)
A) 29
B) 30
C) 60
D) 150
E) 342

32) How many grams of the compound in the figure above would be required to make 2.5 L of a 1 *M* solution?
(carbon = 12, oxygen = 16, hydrogen = 1)
A) 29
B) 30
C) 60
D) 150
E) 342

-continue-

33) A small birthday candle is weighed, then lighted and placed beneath a metal can containing 100 mL of water. Careful records are kept as the temperature of the water rises. Data from this experiment are shown on the graph. What amount of heat energy is released in the burning of candle wax?



A) 0.5 kilocalories per gram of wax burned
B) 5 kilocalories per gram of wax burned
C) 10 kilocalories per gram of wax burned
D) 20 kilocalories per gram of wax burned
E) 50 kilocalories per gram of wax burned

34) You have two beakers. One contains pure water, the other contains pure methanol (wood alcohol). The covalent bonds of methanol molecules are nonpolar, so there are no hydrogen bonds among methanol molecules. You pour crystals of table salt (NaCl) into each beaker. Predict what will happen.
A) Equal amounts of NaCl crystals will dissolve in both water and methanol.
B) NaCl crystals will NOT dissolve in either water or methanol.
C) NaCl crystals will dissolve readily in water but will not dissolve in methanol.
D) NaCl crystals will dissolve readily in methanol but will not dissolve in water.
E) When the first crystals of NaCl are added to water or to methanol, they will not dissolve; but as more crystals are added, the crystals will begin to dissolve faster and faster.

35) You have two beakers. One contains a solution of HCl at pH = 1.0. The other contains a solution of NaOH at pH = 13. Into a third beaker, you slowly and cautiously pour 20 mL of the HCl and 20 mL of the NaOH. After complete stirring, the pH of the mixture will be
A) 2.0.
B) 12.0.
C) 7.0.
D) 5.0.
E) 9.0.

-continue-

Short Answer Essay: Thoroughly answer each question using complete sentences. Diagrams may be used to help clarify but should not be used alone without explanation.

1. Several emergent properties of water contribute to the suitability of the environment for life. **Describe** how the ability of water to function as a versatile solvent arises from the structure of water molecules.

CARBON AND THE MOLECULAR DIVERSITY OF LIFE

CHAPTER 4

Big Idea 1: The process of evolution drives the diversity and unity of life.

Enduring understanding 1.D: The origin of living systems is explained by natural processes.

Essential knowledge 1.D.1: There are several hypotheses about the natural origin of life on Earth, each with supporting scientific evidence.

a. Scientific evidence supports the various models.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Primitive Earth provided inorganic precursors from which organic molecules could have been synthesized due to the presence of available free energy and the absence of a significant quantity of oxygen.
2. In turn, these molecules served as monomers or building blocks for the formation of more complex molecules, including amino acids and nucleotides. [See also **4.A.1**]
3. The joining of these monomers produced polymers with the ability to replicate, store and transfer information.
4. These complex reaction sets could have occurred in solution (organic soup model) or as reactions on solid reactive surfaces. [See also **2.B.1**]
5. The RNA World hypothesis proposes that RNA could have been the earliest genetic material.

Learning Objectives:

LO 1.27 The student is able to describe a scientific hypothesis about the origin of life on Earth. [See **SP 1.2**]

LO 1.28 The student is able to evaluate scientific questions based on hypotheses about the origin of life on Earth. [See **SP 3.3**]

LO 1.29 The student is able to describe the reasons for revisions of scientific hypotheses of the origin of life on Earth. [See **SP 6.3**]

LO 1.30 The student is able to evaluate scientific hypotheses about the origin of life on Earth. [See **SP 6.5**]

LO 1.31 The student is able to evaluate the accuracy and legitimacy of data to answer scientific questions about the origin of life on Earth. [See **SP 4.4**]

Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce and to maintain dynamic homeostasis.

Enduring understanding 2.A: Growth, reproduction and maintenance of the organization of living systems require free energy and matter.

Essential knowledge 2.A.3: Organisms must exchange matter with the environment to grow, reproduce and maintain organization.

a. Molecules and atoms from the environment are necessary to build new molecules.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Carbon moves from the environment to organisms where it is used to build carbohydrates, proteins, lipids or nucleic acids. Carbon is used in storage compounds and cell formation in all organisms.

Learning Objectives:

LO 2.8 The student is able to justify the selection of data regarding the types of molecules that an animal, plant or bacterium will take up as necessary building blocks and excrete as waste products. [See **SP 4.1**]

LO 2.9 The student is able to represent graphically or model quantitatively the exchange of molecules between an organism and its environment, and the subsequent use of these molecules to build new molecules that facilitate dynamic homeostasis, growth and reproduction. [See **SP 1.1, 1.4**]

Chapter 4

Carbon and the Molecular Diversity of Life

Lecture Outline

Overview: Carbon—The Backbone of Life

- Although cells are 70–95% water, the rest consists of mostly carbon-based compounds.
- Carbon enters the biosphere when photosynthetic organisms use the sun's energy to transform CO_2 into organic molecules, which are taken in by plant-eating animals.
- Carbon accounts for the diversity of biological molecules, which has made possible the wide variety of living things.
- Proteins, DNA, carbohydrates, and other molecules that distinguish living matter from inorganic material are all composed of carbon atoms bonded to each other and to atoms of other elements.
    - These other elements commonly include hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), and phosphorus (P).

Concept 4.1 Organic chemistry is the study of carbon compounds

- **Organic chemistry** focuses on organic compounds containing carbon.
    - Organic compounds can range from simple molecules, such as CH_4, to complex molecules such as proteins, with thousands of atoms.
    - Most organic compounds contain hydrogen atoms as well as carbon.
- The overall percentages of the major elements of life (C, H, O, N, S, and P) are quite uniform from one organism to another.
- Because of carbon's versatility, these few elements can be combined to build an inexhaustible variety of organic molecules.
- Variations in organic molecules can distinguish even individuals of a single species.
- The science of organic chemistry began with attempts to purify and improve the yield of products obtained from organisms.
    - Initially, chemists learned to synthesize simple compounds in the laboratory but had no success with more complex compounds.
- The Swedish chemist Jons Jacob Berzelius was the first to make a distinction between organic compounds, thought to arise in only living organisms, and inorganic compounds that were found in the nonliving world.
- Early organic chemists proposed *vitalism***,** the belief that physical and chemical laws do not apply to living things.

- Support for vitalism waned as organic chemists learned to synthesize complex organic compounds in the laboratory.
- In the early 1800s, the German chemist Friedrich Wöhler and his students synthesized urea. A few years later, Hermann Kolbe, a student of Wöhler's, made the organic compound acetic acid from inorganic substances prepared directly from pure elements.

- In 1953, Stanley Miller at the University of Chicago set up a laboratory simulation of possible chemical conditions on the primitive Earth and demonstrated the spontaneous synthesis of organic compounds.
  - The mixture of gases Miller created probably did not accurately represent the atmosphere of the primitive Earth.
  - However, similar experiments using more accurate atmospheric conditions also led to the formation of organic compounds.
  - Spontaneous abiotic synthesis of organic compounds, possibly near volcanoes, may have been an early stage in the origin of life on Earth.
- Organic chemists finally rejected vitalism and embraced *mechanism***,** the belief that the same physical and chemical laws govern all natural phenomena, including the processes of life.
- Organic chemistry was redefined as the study of carbon compounds, regardless of their origin.
  - Organisms produce the majority of organic compounds.
  - The laws of chemistry apply to both inorganic and organic compounds.
- The foundation of organic chemistry is not a mysterious life force but rather the unique versatility of carbon-based compounds.

Concept 4.2 Carbon atoms can form diverse molecules by bonding to four other atoms

- A carbon atom has a total of 6 electrons: 2 in the first electron shell and 4 in the second shell.
- Carbon has little tendency to form ionic bonds by losing or gaining 4 electrons to complete its valence shell.
- Carbon usually completes its valence shell by sharing electrons with other atoms in four covalent bonds, which may include single and double bonds.
- The ability of carbon to form four covalent bonds makes large, complex molecules possible.
  - When a carbon atom forms covalent bonds with four other atoms, they are arranged at the corners of an imaginary tetrahedron with bond angles of 109.5°.
  - In molecules with multiple carbon atoms, every carbon atom bonded to four other atoms has a tetrahedral shape.
  - When two carbon atoms are joined by a double bond, all bonds around those carbons are in the same plane as the carbons.

- The electron configuration of carbon enables it to form covalent bonds with many different elements.

- The valences of carbon and its partners can be viewed as the building code that governs the architecture of organic molecules.
- In carbon dioxide (CO_2), one carbon atom forms two double bonds with two oxygen atoms.
  - In the structural formula, O=C=O, each line represents a pair of shared electrons. This arrangement completes the valence shells of all atoms in the molecule.
- Although CO_2 can be classified as either organic or inorganic, its importance to the living world is clear: CO_2 is the source of carbon for all organic molecules found in organisms.
  - CO_2 is usually fixed into organic molecules by the process of photosynthesis.
- Urea, $CO(NH_2)_2$, is another simple organic molecule in which each atom forms covalent bonds to complete its valence shell.
  - In urea, one carbon atom is involved in both single and double bonds.

Molecular diversity arises from variations in the carbon skeleton.

- Carbon chains form the skeletons of most organic molecules.
  - Carbon skeletons vary in length and may be straight, branched, or arranged in closed rings.
  - Carbon skeletons may include double bonds.
  - Atoms of other elements can be bonded to the atoms of the carbon skeleton.
- **Hydrocarbons** are organic molecules that consist of only carbon and hydrogen atoms.
- Hydrocarbons are the major component of petroleum, a fossil fuel that consists of the partially decomposed remains of organisms that lived millions of years ago.
- Fats are biological molecules that have long hydrocarbon tails attached to a nonhydrocarbon component.
- Petroleum and fat are hydrophobic compounds that cannot dissolve in water because of their many nonpolar carbon-hydrogen bonds.
- Hydrocarbons can undergo reactions that release a relatively large amount of energy.
- **Isomers** are compounds that have the same molecular formula but different structures and, therefore, different chemical properties.
- **Structural isomers** have the same molecular formula but differ in the covalent arrangement of atoms.
  - Structural isomers may also differ in the location of the double bonds.
- ***Cis-trans* isomers** have the same covalent partnerships but differ in the spatial arrangement of atoms around a carbon-carbon double bond.

- The double bond does not allow the atoms to rotate freely around the bond axis.
- Consider a simple molecule with two double-bonded carbons, each of which has an H and an X attached to it. The arrangement with both Xs on the same side of the double bond is called a *cis* isomer; the arrangement with the Xs on opposite sides is called a *trans* isomer.
- The biochemistry of vision involves a light-induced change in the structure of rhodopsin in the retina from the *cis* isomer to the *trans* isomer.

- **Enantiomers** are molecules that are mirror images of each other.
- Enantiomers are possible when four different atoms or groups of atoms are bonded to an **asymmetric carbon**.
    - The four groups can be arranged in space in two different ways that are mirror images of each other.
    - They are like left-handed and right-handed versions of the molecule.
    - Usually one is biologically active, while the other is inactive.
- Even subtle structural differences in two enantiomers may have important functional significance because of emergent properties from specific arrangements of atoms.
    - For example, methamphetimine occurs in two enantiomers with very different effects. One is a highly addictive street drug called "crank", while the other is sold for treatment of nasal congestion.

<u>Concept 4.3 A few chemical groups are key to the functioning of biological molecules</u>

- The distinctive properties of an organic molecule depend not only on the arrangement of its carbon skeleton but also on the chemical groups attached to that skeleton.
- If we start with hydrocarbons as the simplest organic molecules, characteristic chemical groups can replace one or more of the hydrogen atoms bonded to the carbon skeleton of a hydrocarbon.
- These chemical groups may be involved in chemical reactions or may contribute to the shape and function of the organic molecule in a characteristic way, giving it unique properties.
    - As an example, the basic structure of testosterone (a male sex hormone) and estradiol (a female sex hormone) is the same.
    - Both are steroids with four fused carbon rings, but the hormones differ in the chemical groups attached to the rings.
    - As a result, testosterone and estradiol have different shapes, causing them to interact differently with many targets throughout the body.
- In other cases, chemical groups known as **functional groups** affect molecular function through their direct involvement in chemical reactions.
- Seven chemical groups are most important to the chemistry of life: hydroxyl, carbonyl, carboxyl, amino, sulfhydryl, phosphate, and methyl groups.

- The first six chemical groups are functional groups. They are hydrophilic and increase the solubility of organic compounds in water.
- Methyl groups are not reactive but may serve as important markers on organic molecules.
- In a **hydroxyl** group (—OH), a hydrogen atom forms a polar covalent bond with an oxygen atom, which forms a polar covalent bond to the carbon skeleton.
    - Because of these polar covalent bonds, hydroxyl groups increase the solubility of organic molecules.
    - Organic compounds with hydroxyl groups are alcohols, and their names typically end in *-ol*.
- A **carbonyl** group (>CO) consists of an oxygen atom joined to the carbon skeleton by a double bond.
    - If the carbonyl group is on the end of the skeleton, the compound is an **aldehyde**.
    - If the carbonyl group is within the carbon skeleton, the compound is a **ketone**.
    - Isomers with aldehydes and those with ketones have different properties.
- A **carboxyl** group (—COOH) consists of a carbon atom with a double bond to an oxygen atom and a single bond to the oxygen atom of a hydroxyl group.
    - Compounds with carboxyl groups are **carboxylic acids**.
    - A carboxyl group acts as an acid because the combined electronegativities of the two adjacent oxygen atoms increase the chance of dissociation of hydrogen as an ion (H^+).
- An **amino** group (—NH_2) consists of a nitrogen atom bonded to two hydrogen atoms and the carbon skeleton.
    - Organic compounds with amino groups are **amines**.
    - The amino group acts as a base because it can pick up a hydrogen ion (H^+) from the solution.
    - Amino acids, the building blocks of proteins, have amino and carboxyl groups.
- A **sulfhydryl** group (—SH) consists of a sulfur atom bonded to a hydrogen atom and to the backbone.
    - This group resembles a hydroxyl group in shape.
    - Organic molecules with sulfhydryl groups are **thiols**.
    - Two sulfhydryl groups can interact to help stabilize the structure of proteins.
- A **phosphate** group (—OPO_3^{2-}) consists of a phosphorus atom bound to four oxygen atoms (three with single bonds and one with a double bond).
    - A phosphate group connects to the carbon backbone via one of its oxygen atoms.
    - Phosphate groups are anions with two negative charges because 2 protons dissociate from the oxygen atoms.

    - One function of phosphate groups is to transfer energy between organic molecules.

ATP is an important source of energy for cellular processes.

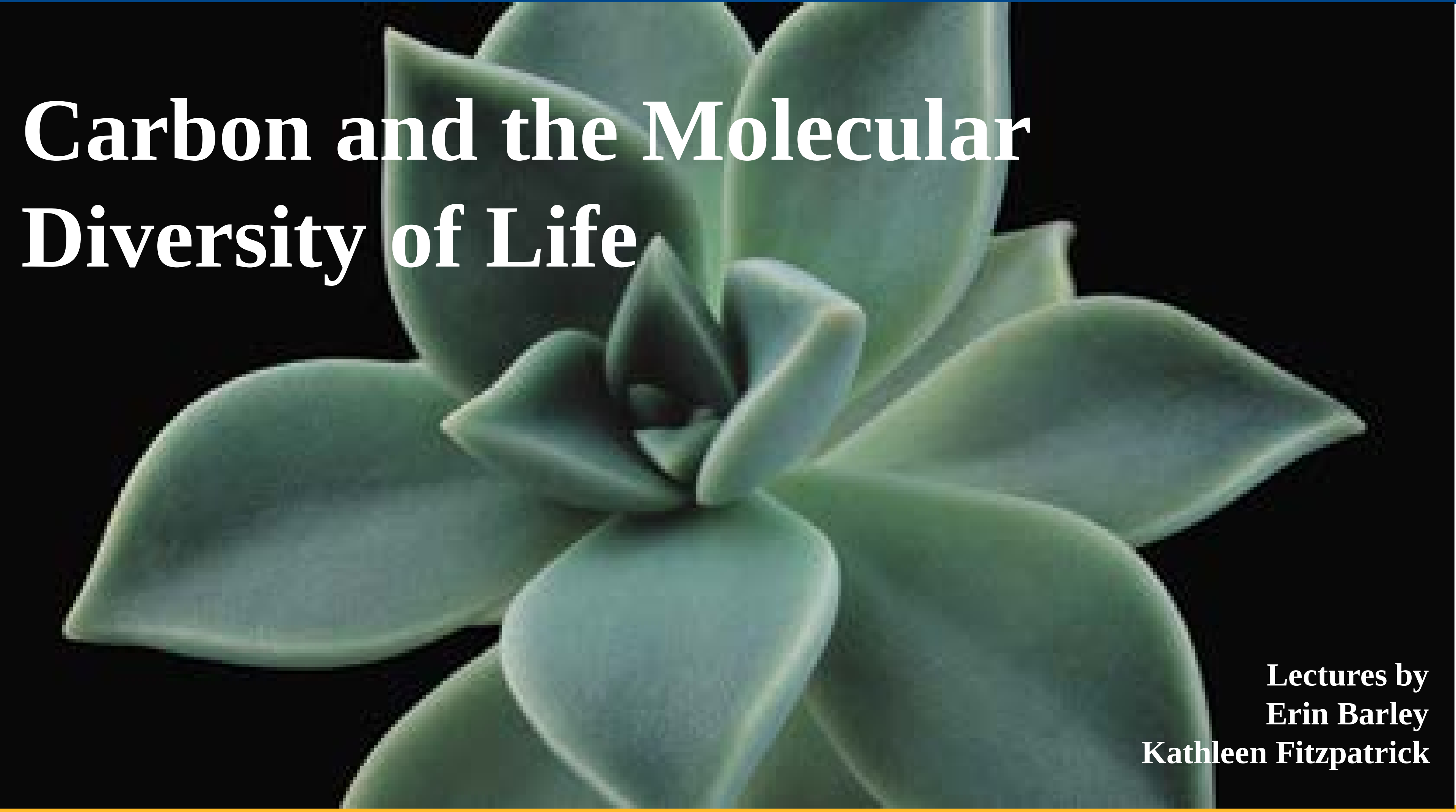
- **Adenosine triphosphate**, or **ATP**, is the primary energy transfer molecule in living cells.
- ATP consists of an organic molecule called adenosine attached to a string of three phosphate groups.
- When one inorganic phosphate ion is split off as a result of a reaction with water, ATP becomes adenosine *di*phosphate, or ADP.

- In a sense, ATP “stores” the potential to react with water, releasing energy that can be used by the cell.

Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson

Chapter 4

Carbon and the Molecular Diversity of Life



Lectures by
Erin Barley
Kathleen Fitzpatrick

Overview: Carbon: The Backbone of Life

- Living organisms consist mostly of carbon-based compounds
- Carbon is unparalleled in its ability to form large, complex, and diverse molecules
- Proteins, DNA, carbohydrates, and other molecules that distinguish living matter are all composed of carbon compounds

Figure 4.1

Concept 4.1: Organic chemistry is the study of carbon compounds

- **Organic chemistry** is the study of compounds that contain carbon
- Organic compounds range from simple molecules to colossal ones
- Most organic compounds contain hydrogen atoms in addition to carbon atoms

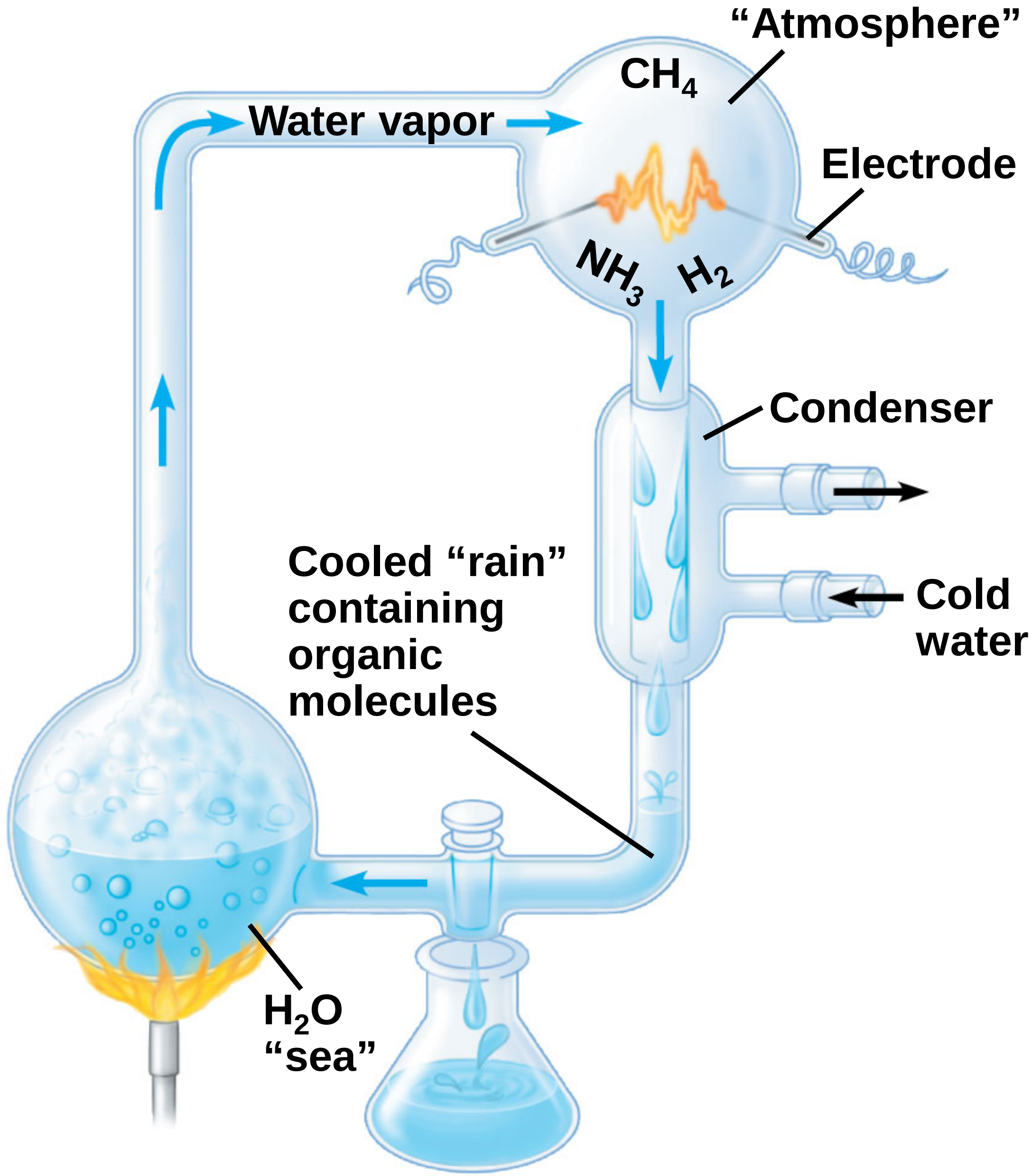
- *Vitalism*, the idea that organic compounds arise only in organisms, was disproved when chemists synthesized these compounds
- *Mechanism* is the view that all natural phenomena are governed by physical and chemical laws

Organic Molecules and the Origin of Life on Earth

- Stanley Miller's classic experiment demonstrated the abiotic synthesis of organic compounds
- Experiments support the idea that abiotic synthesis of organic compounds, perhaps near volcanoes, could have been a stage in the origin of life

Figure 4.2

EXPERIMENT



Sample for chemical analysis

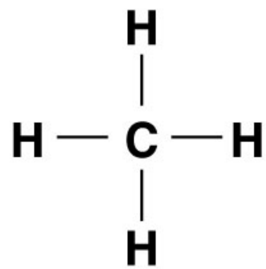
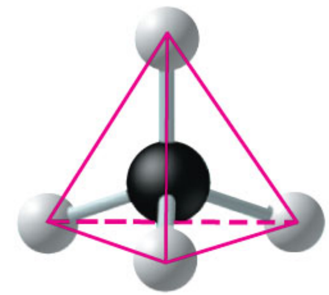
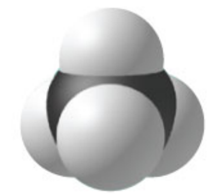
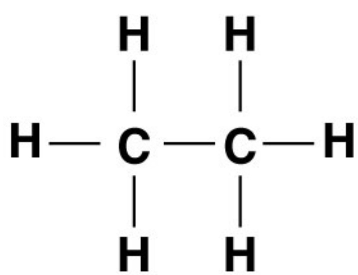
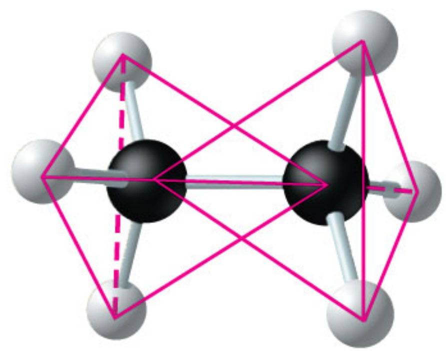
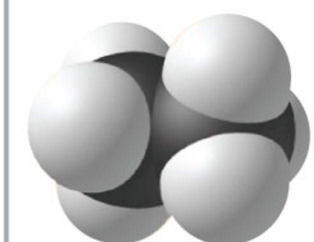
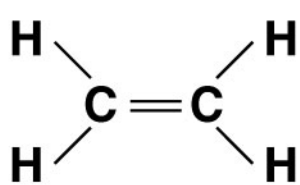
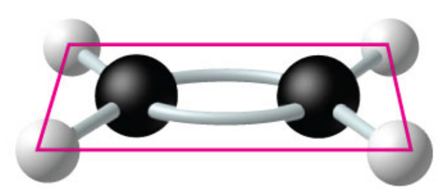
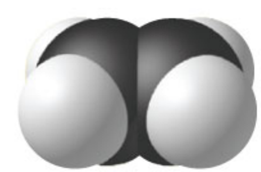
Concept 4.2: Carbon atoms can form diverse molecules by bonding to four other atoms

- Electron configuration is the key to an atom's characteristics
- Electron configuration determines the kinds and number of bonds an atom will form with other atoms

The Formation of Bonds with Carbon

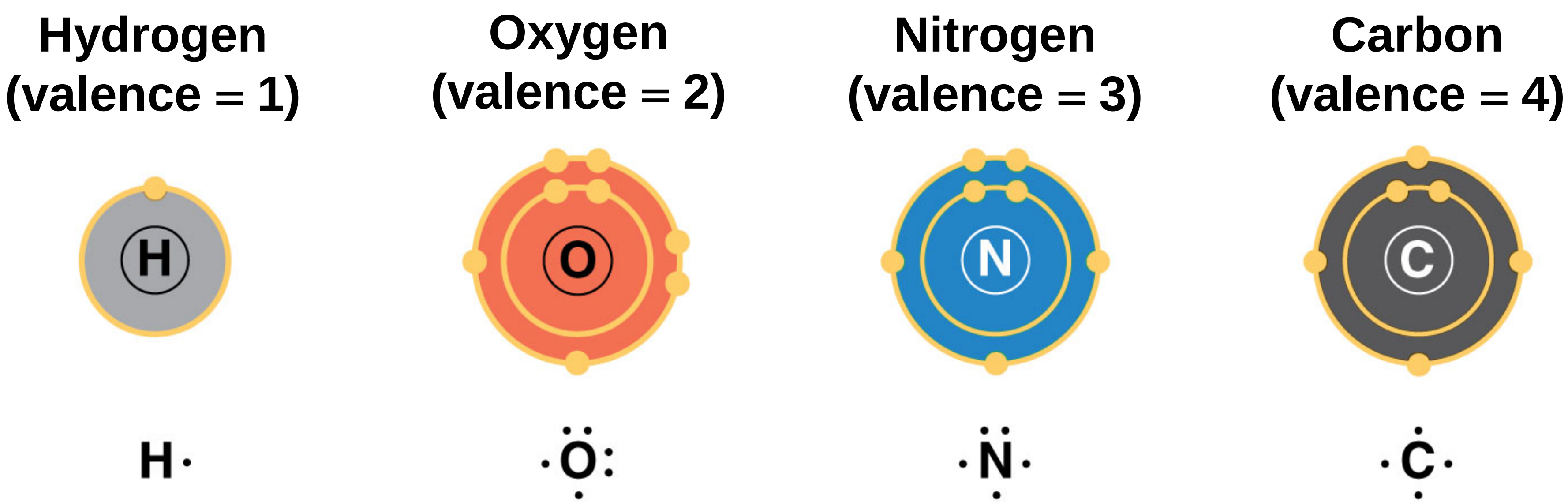
- With four valence electrons, carbon can form four covalent bonds with a variety of atoms
- This ability makes large, complex molecules possible
- In molecules with multiple carbons, each carbon bonded to four other atoms has a tetrahedral shape
- However, when two carbon atoms are joined by a double bond, the atoms joined to the carbons are in the same plane as the carbons

Figure 4.3

Name and Comment	Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
(a) Methane	CH_4			
(b) Ethane	C_2H_6			
(c) Ethene (ethylene)	C_2H_4			

- The electron configuration of carbon gives it covalent compatibility with many different elements
- The valences of carbon and its most frequent partners (hydrogen, oxygen, and nitrogen) are the “building code” that governs the architecture of living molecules

Figure 4.4

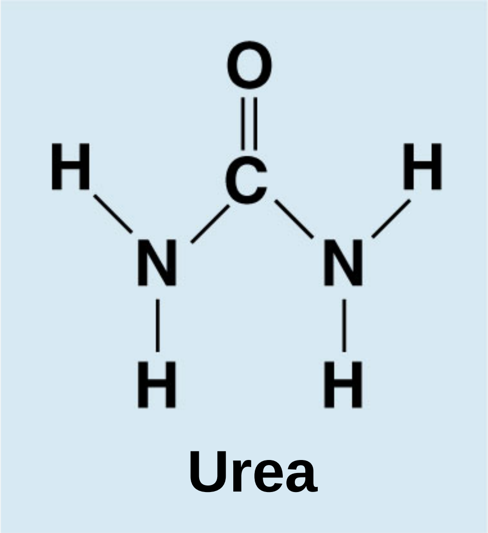


Hydrogen
(valence = 1)
Oxygen
(valence = 2)
Nitrogen
(valence = 3)
Carbon
(valence = 4)
H
O
N
C
H
O
N
C

- Carbon atoms can partner with atoms other than hydrogen; for example:
  - Carbon dioxide: CO_2

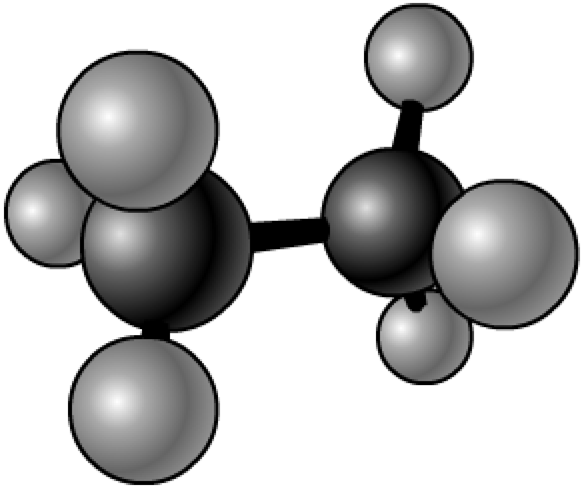
  - Urea: $CO(NH_2)_2$

Figure 4.UN01



Molecular Diversity Arising from Carbon Skeleton Variation

- Carbon chains form the skeletons of most organic molecules
- Carbon chains vary in length and shape



Animation: Carbon Skeletons

Right-click slide/select “Play”

Figure 4.5

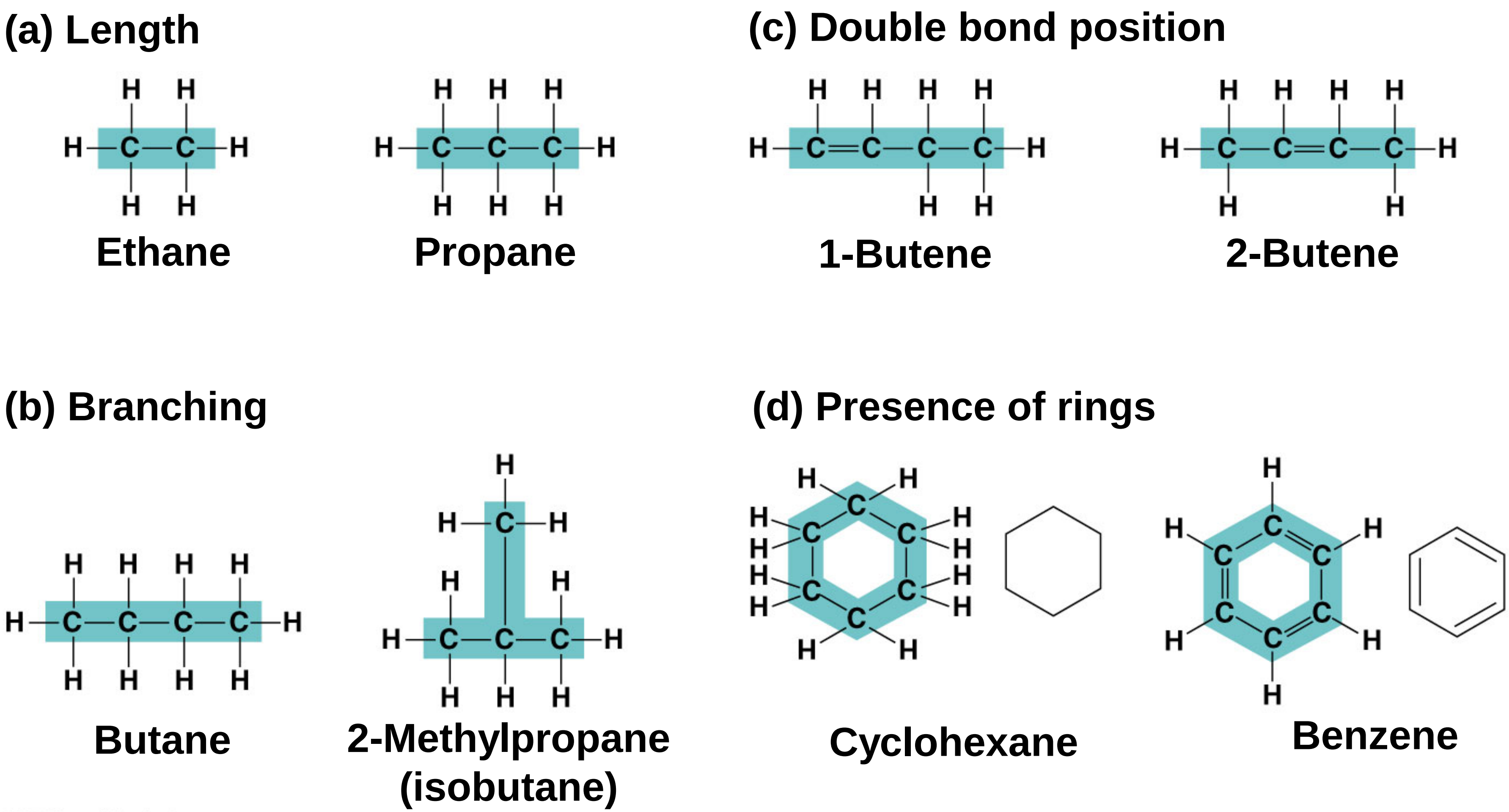
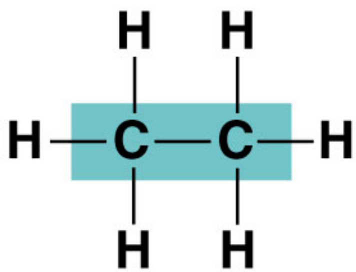
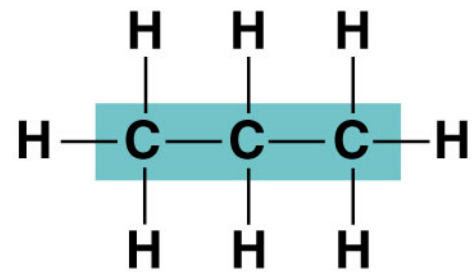

(a) Length
Ethane
Propane
(c) Double bond position
1-Butene
2-Butene
(b) Branching
Butane
2-Methylpropane
(isobutane)
(d) Presence of rings
Cyclohexane
Benzene

Figure 4.5a

(a) Length



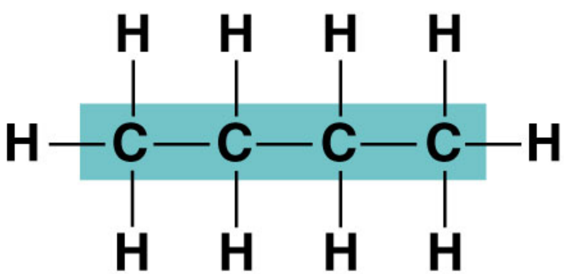
Ethane



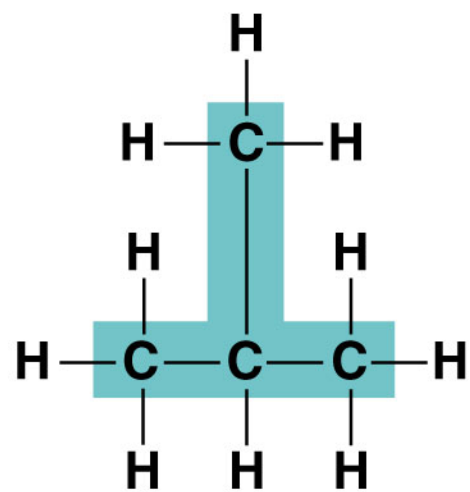
Propane

Figure 4.5b

(b) Branching



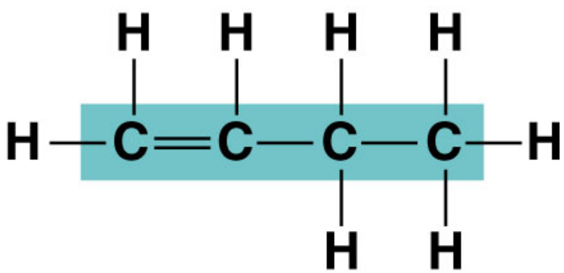
Butane



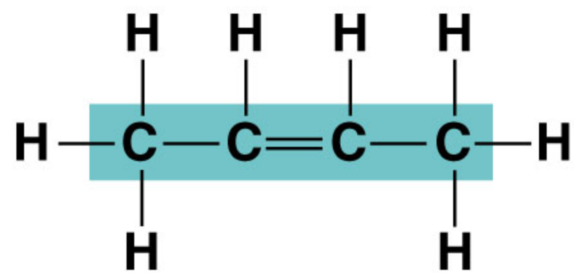
2-Methylpropane
(commonly called isobutane)

Figure 4.5c

(c) Double bond position



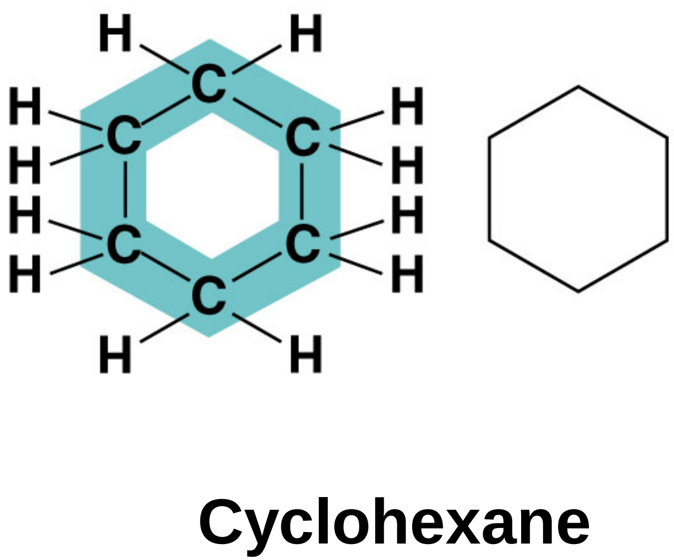
1-Butene

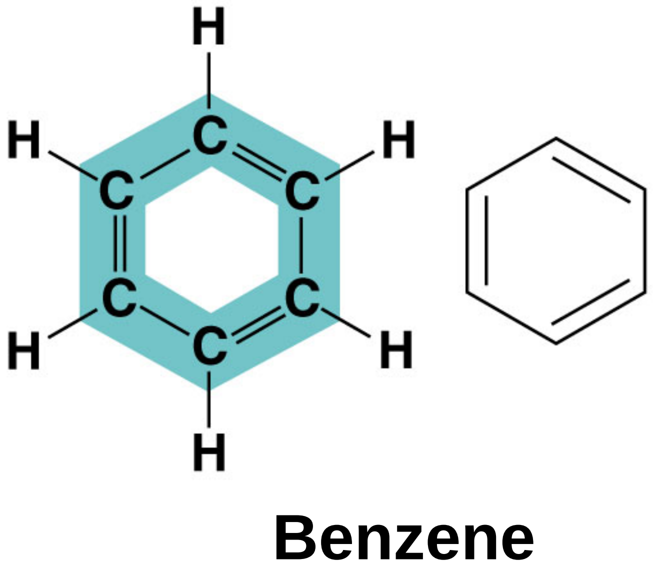


2-Butene

Figure 4.5d

(d) Presence of rings

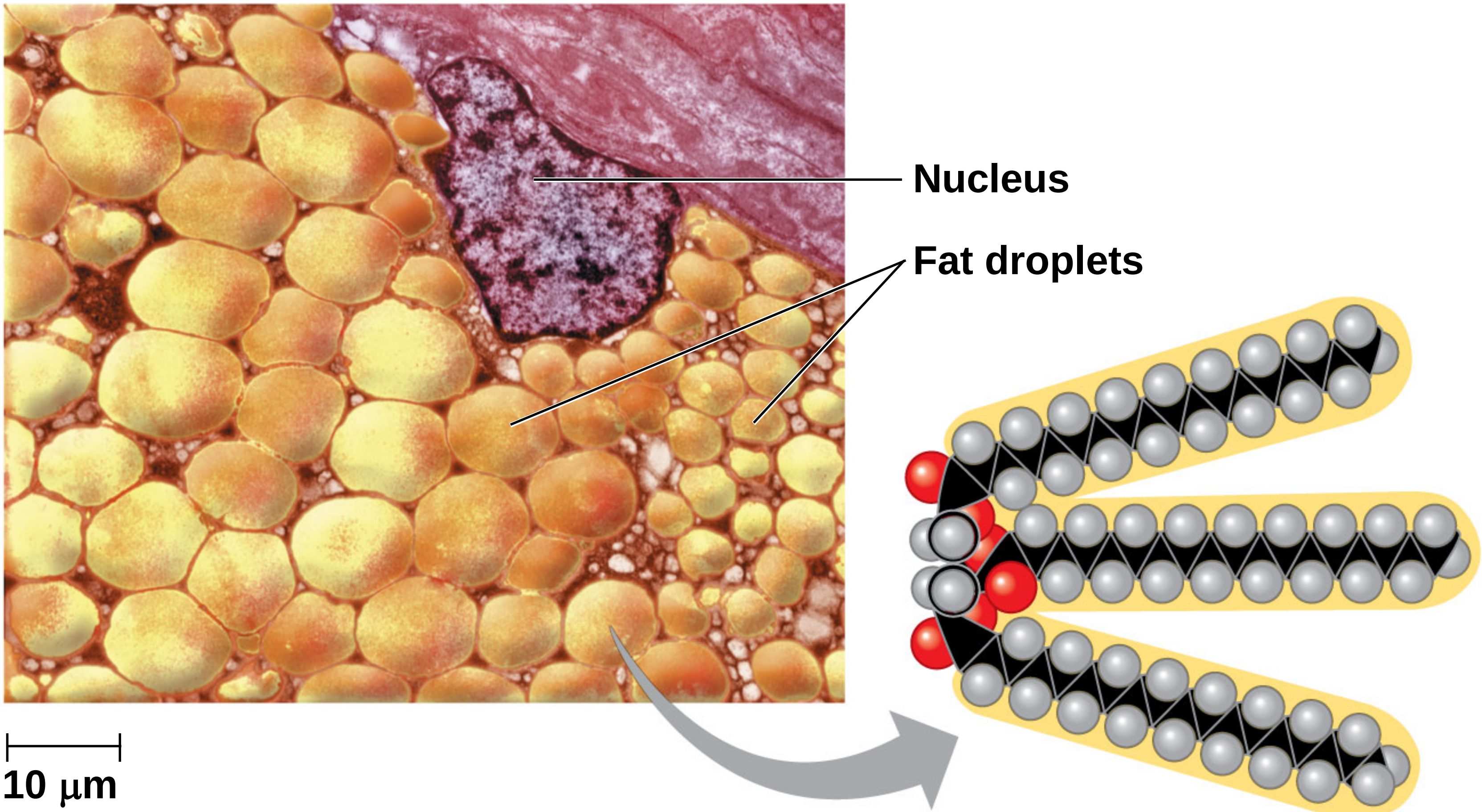




Hydrocarbons

- **Hydrocarbons** are organic molecules consisting of only carbon and hydrogen
- Many organic molecules, such as fats, have hydrocarbon components
- Hydrocarbons can undergo reactions that release a large amount of energy

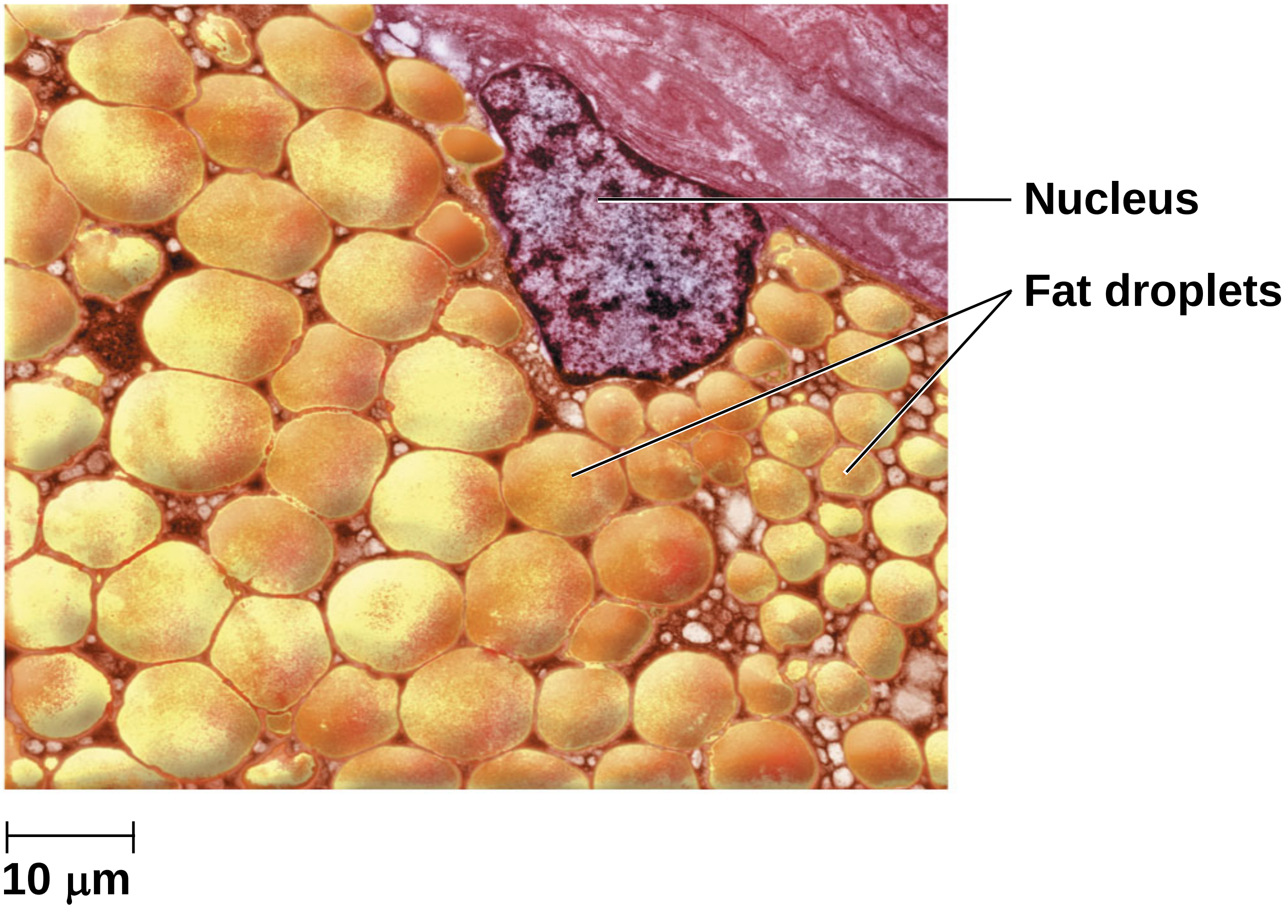
Figure 4.6



(a) Part of a human adipose cell

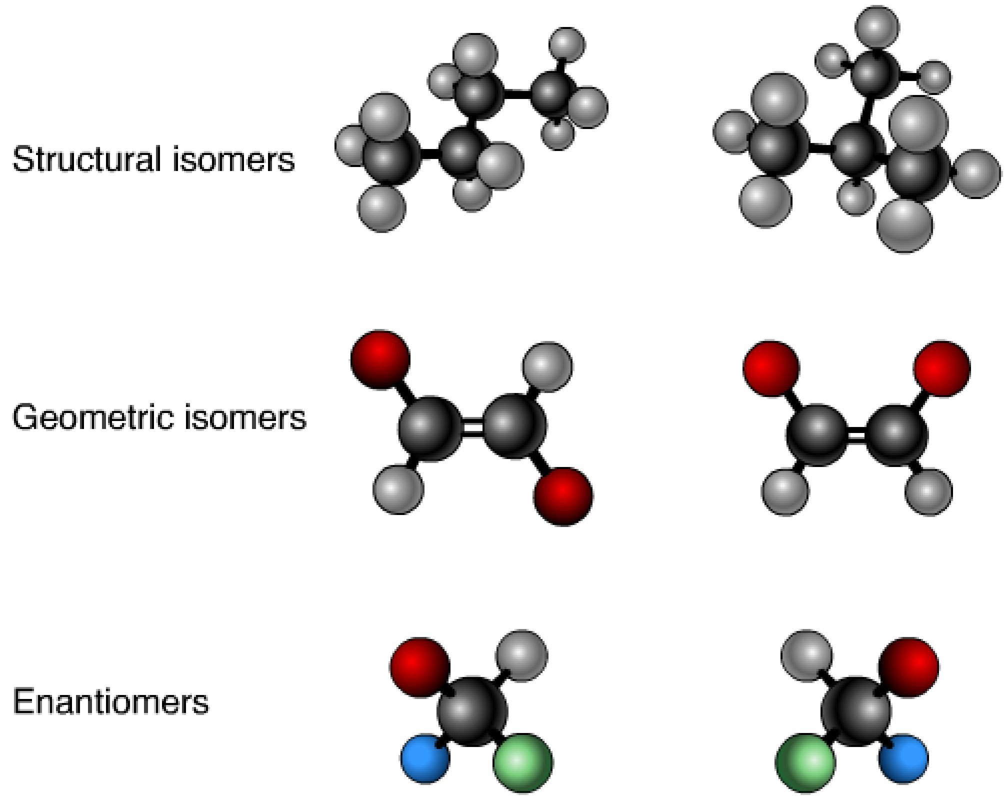
(b) A fat molecule

Figure 4.6a



Isomers

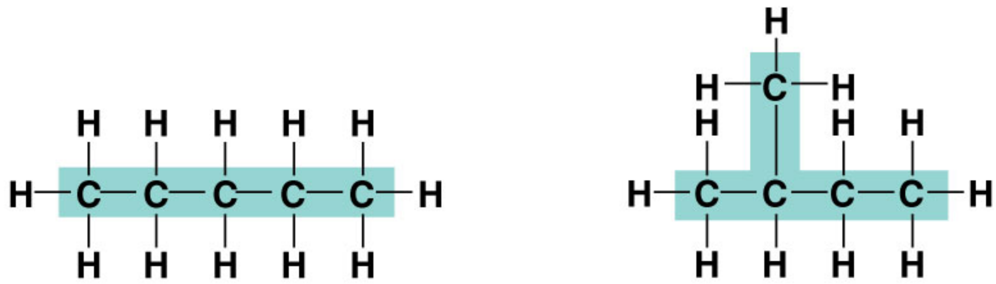
- **Isomers** are compounds with the same molecular formula but different structures and properties
  - **Structural isomers** have different covalent arrangements of their atoms
  - ***Cis-trans*** **isomers** have the same covalent bonds but differ in spatial arrangements
  - **Enantiomers** are isomers that are mirror images of each other



Animation: Isomers
Right-click slide / select “Play”

Figure 4.7

(a) Structural isomers

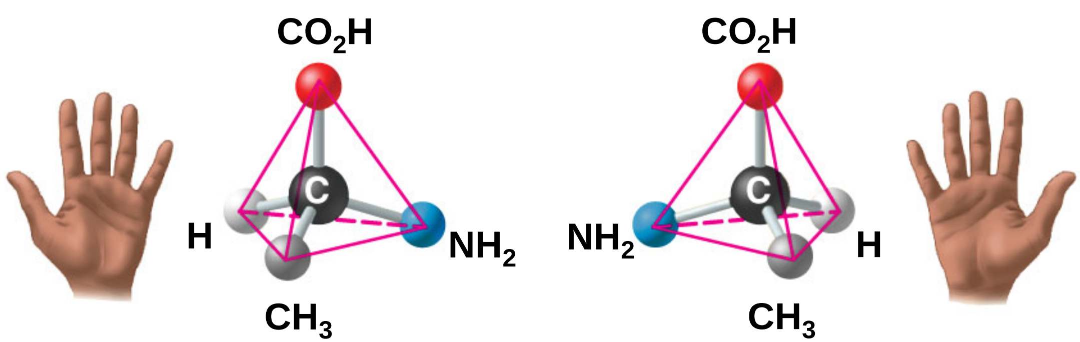


(b) *Cis-trans* isomers

cis **isomer: The two Xs are on the same side.**

trans **isomer: The two Xs are on opposite sides.**

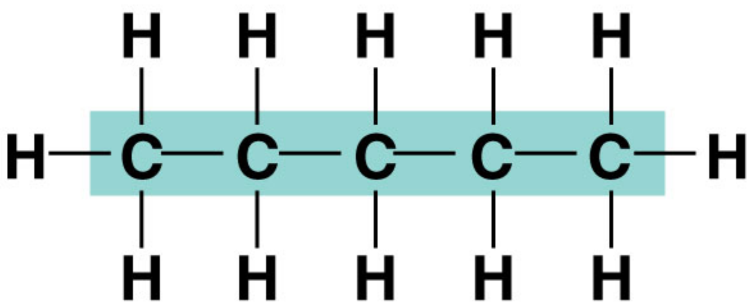
(c) Enantiomers



L isomer **D isomer**

Figure 4.7a

(a) Structural isomers



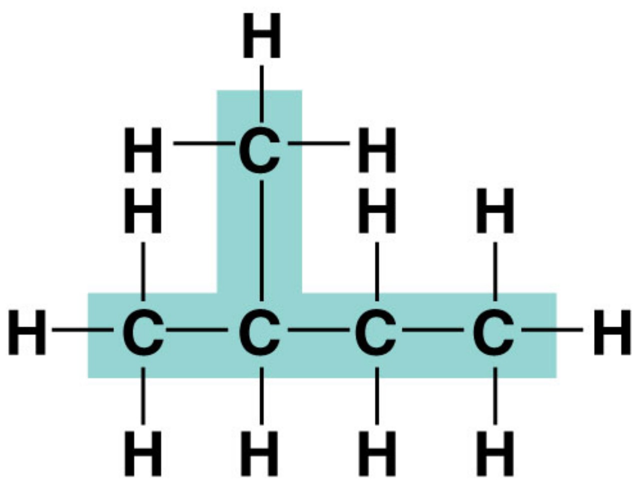
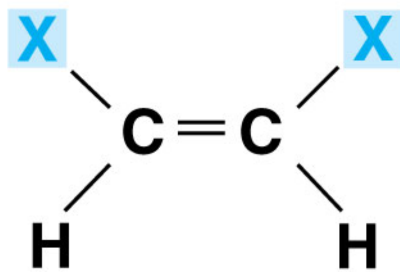
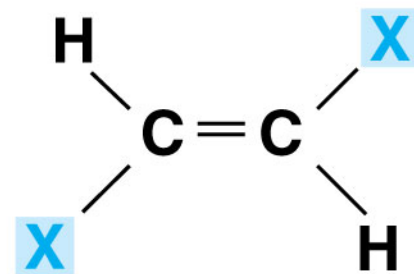


Figure 4.7b

(b) *Cis-trans* isomers

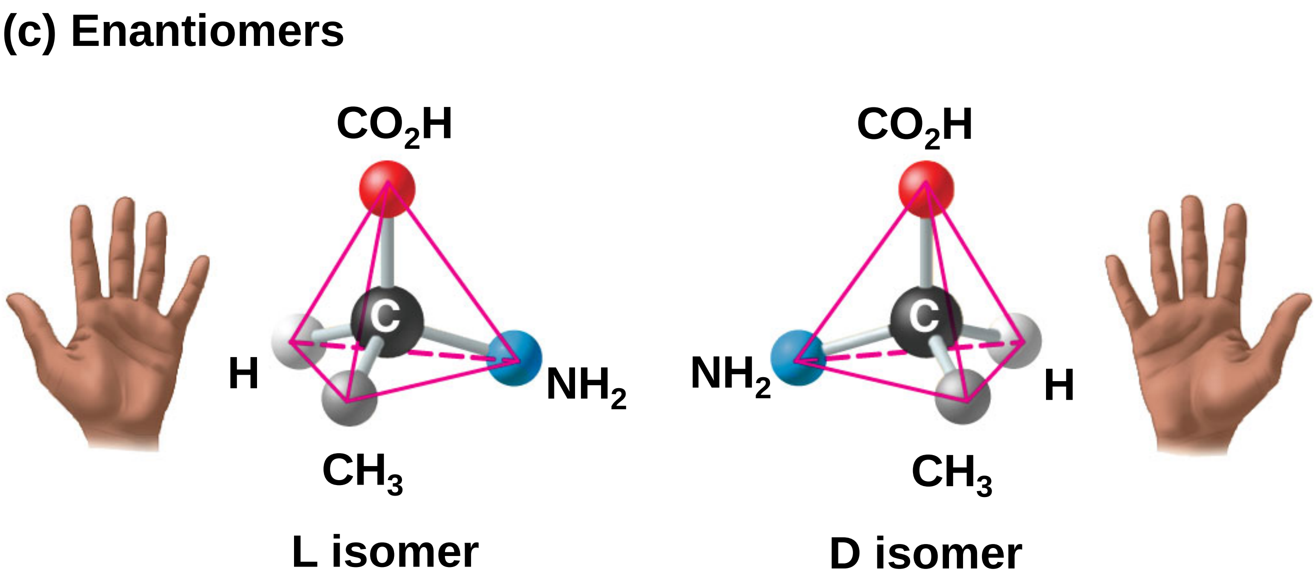


cis **isomer: The two Xs are on the same side.**



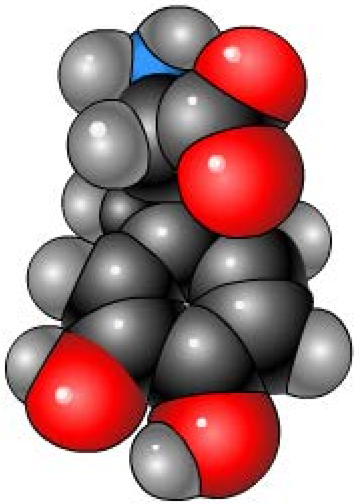
trans **isomer: The two Xs are on opposite sides.**

Figure 4.7c



(c) Enantiomers
CO2H
C
H
NH2
CH3
L isomer
CO2H
C
NH2
H
CH3
D isomer

- Enantiomers are important in the pharmaceutical industry
- Two enantiomers of a drug may have different effects
- Usually only one isomer is biologically active
- Differing effects of enantiomers demonstrate that organisms are sensitive to even subtle variations in molecules

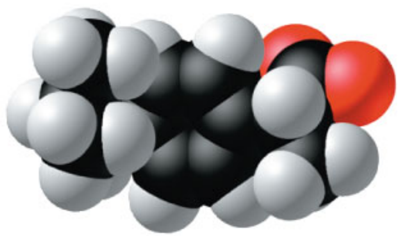
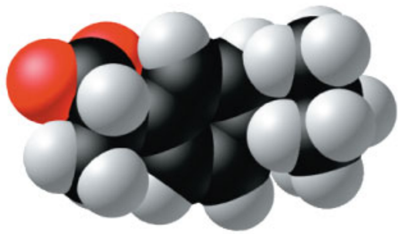
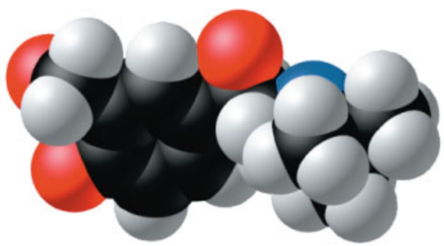
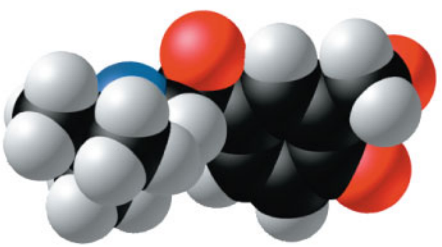


$C_9H_{11}NO_4$

Animation: L-Dopa

Right-click slide / select “Play”

Figure 4.8

Drug	Condition	Effective Enantiomer	Ineffective Enantiomer
Ibuprofen	**Pain; inflammation**	 ***S*-Ibuprofen**	 ***R*-Ibuprofen**
Albuterol	**Asthma**	 ***R*-Albuterol**	 ***S*-Albuterol**

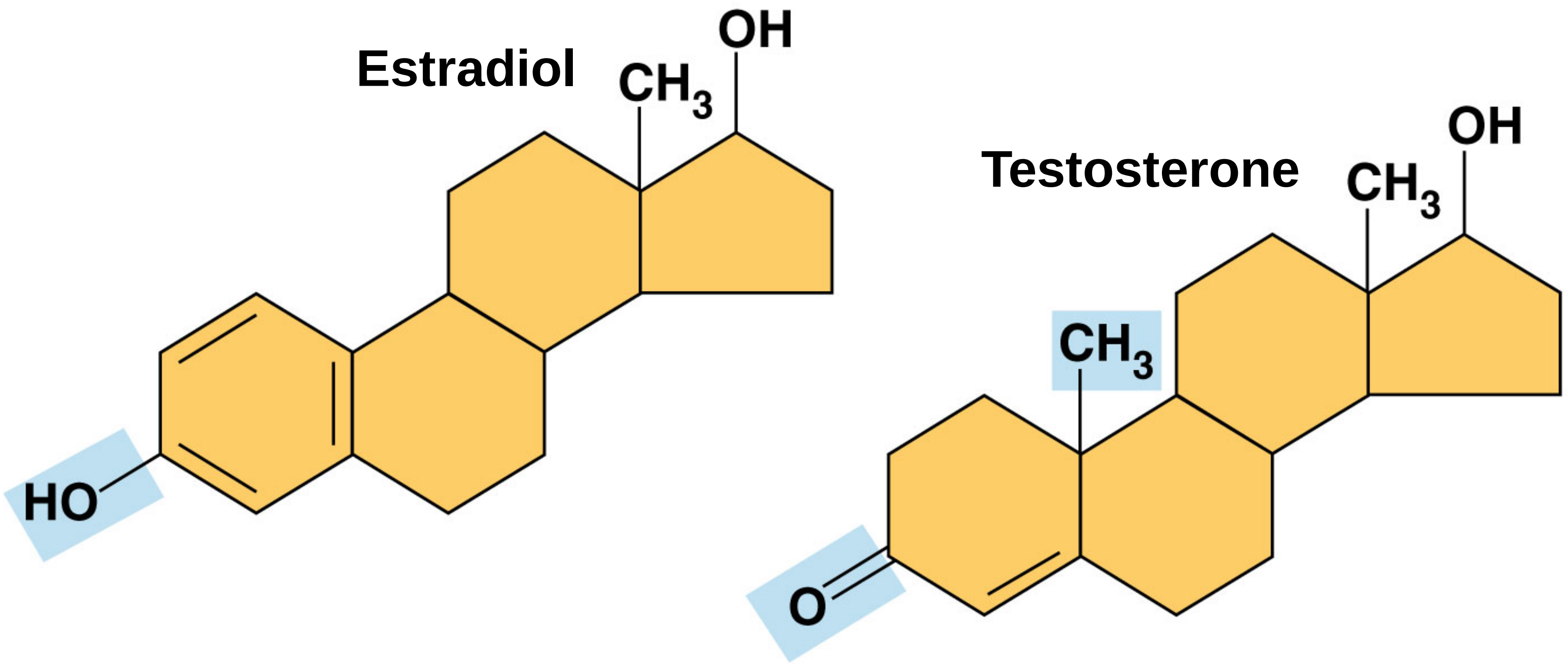
Concept 4.3: A few chemical groups are key to the functioning of biological molecules

- Distinctive properties of organic molecules depend on the carbon skeleton and on the molecular components attached to it
- A number of characteristic groups can replace the hydrogens attached to skeletons of organic molecules

The Chemical Groups Most Important in the Processes of Life

- **Functional groups** are the components of organic molecules that are most commonly involved in chemical reactions
- The number and arrangement of functional groups give each molecule its unique properties

Figure 4.UN02



- The seven functional groups that are most important in the chemistry of life:
  - Hydroxyl group
  - Carbonyl group
  - Carboxyl group
  - Amino group
  - Sulfhydryl group
  - Phosphate group
  - Methyl group

Figure 4.9-a

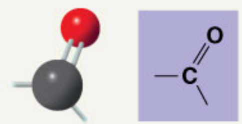
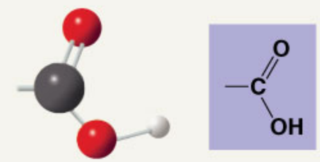
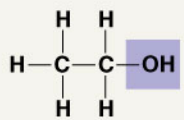
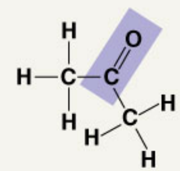
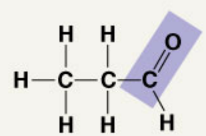
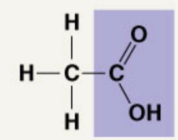
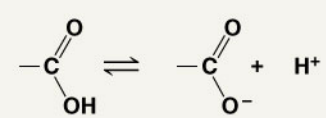
CHEMICAL GROUP	Hydroxyl	Carbonyl	Carboxyl
STRUCTURE	 —OH (may be written HO—)		
NAME OF COMPOUND	Alcohols (Their specific names usually end in *-ol.)*	Ketones if the carbonyl group is within a carbon skeleton Aldehydes if the carbonyl group is at the end of the carbon skeleton	Carboxylic acids, or organic acids
EXAMPLE	 Ethanol	 Acetone  Propanal	 Acetic acid
FUNCTIONAL PROPERTIES	• Is polar as a result of the electrons spending more time near the electronegative oxygen atom. • Can form hydrogen bonds with water molecules, helping dissolve organic compounds such as sugars.	• A ketone and an aldehyde may be structural isomers with different properties, as is the case for acetone and propanal. • Ketone and aldehyde groups are also found in sugars, giving rise to two major groups of sugars: ketoses (containing ketone groups) and aldoses (containing aldehyde groups).	• Acts as an acid; can donate an H^+ because the covalent bond between oxygen and hydrogen is so polar:  Nonionized Ionized • Found in cells in the ionized form with a charge of 1– and called a carboxylate ion.

Figure 4.9-b

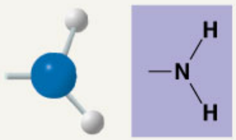
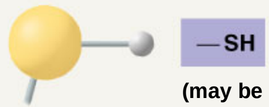
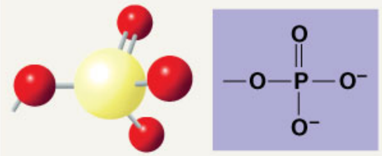
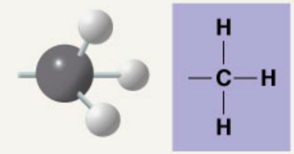
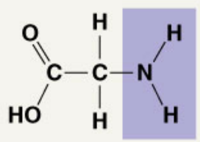
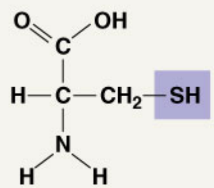
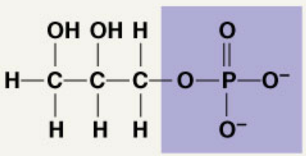
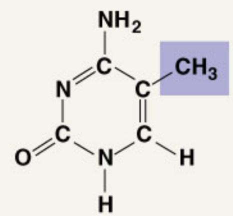
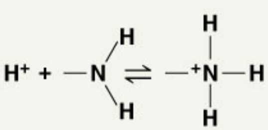
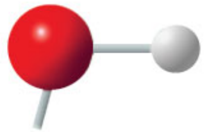
Amino	Sulfhydryl	Phosphate	Methyl
	 (may be written HS—)		
Amines	Thiols	Organic phosphates	Methylated compounds
 Glycine	 Cysteine	 Glycerol phosphate	 5-Methyl cytidine
• Acts as a base; can pick up an H^+ from the surrounding solution (water, in living organisms):  Nonionized Ionized • Found in cells in the ionized form with a charge of 1+.	• Two sulfhydryl groups can react, forming a covalent bond. This “cross-linking” helps stabilize protein structure. • Cross-linking of cysteines in hair proteins maintains the curliness or straightness of hair. Straight hair can be “permanently” curled by shaping it around curlers and then breaking and re-forming the cross-linking bonds.	• Contributes negative charge to the molecule of which it is a part (2– when at the end of a molecule, as above; 1– when located internally in a chain of phosphates). • Molecules containing phosphate groups have the potential to react with water, releasing energy.	• Addition of a methyl group to DNA, or to molecules bound to DNA, affects the expression of genes. • Arrangement of methyl groups in male and female sex hormones affects their shape and function.

Figure 4.9a

Hydroxyl

STRUCTURE



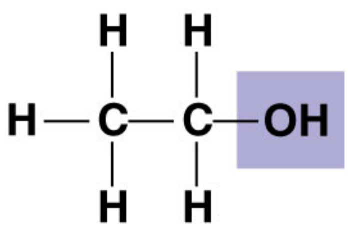
—OH

(may be written HO—)

NAME OF COMPOUND

Alcohols (Their specific names usually end in *-ol*.)

EXAMPLE



Ethanol

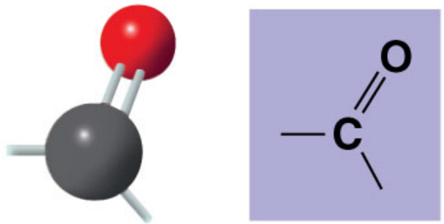
FUNCTIONAL PROPERTIES

- **Is polar as a result of the electrons spending more time near the electronegative oxygen atom.**
- **Can form hydrogen bonds with water molecules, helping dissolve organic compounds such as sugars.**

Figure 4.9b

Carbonyl

STRUCTURE

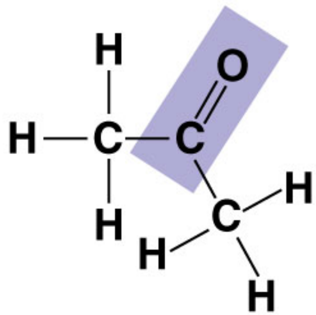


NAME OF COMPOUND

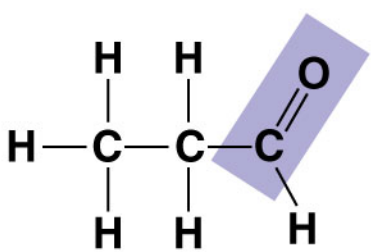
Ketones if the carbonyl group is within a carbon skeleton

Aldehydes if the carbonyl group is at the end of the carbon skeleton

EXAMPLE



Acetone



Propanal

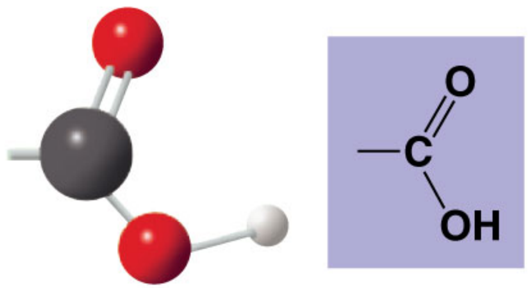
FUNCTIONAL PROPERTIES

- A ketone and an aldehyde may be structural isomers with different properties, as is the case for acetone and propanal.
- Ketone and aldehyde groups are also found in sugars, giving rise to two major groups of sugars: ketoses (containing ketone groups) and aldoses (containing aldehyde groups).

Figure 4.9c

Carboxyl

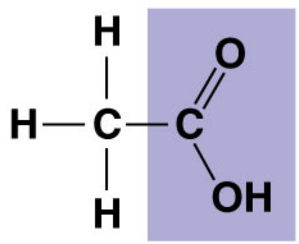
STRUCTURE



NAME OF COMPOUND

Carboxylic acids, or organic acids

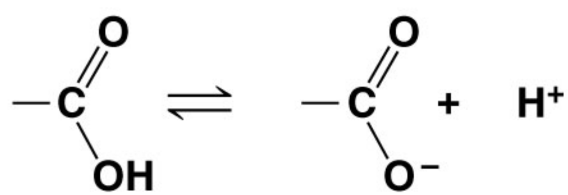
EXAMPLE



Acetic acid

FUNCTIONAL PROPERTIES

- Acts as an acid; can donate an H^+ because the covalent bond between oxygen and hydrogen is so polar:



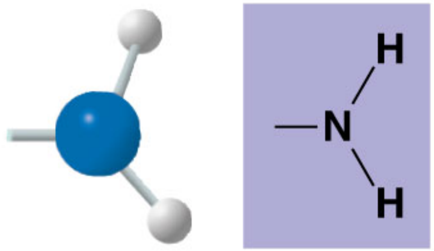
Nonionized Ionized

- Found in cells in the ionized form with a charge of 1– and called a carboxylate ion.

Figure 4.9d

Amino

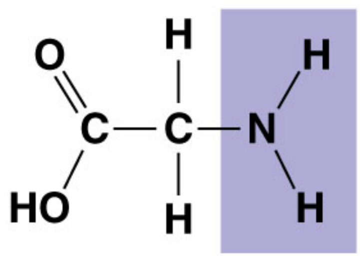
STRUCTURE



NAME OF COMPOUND

Amines

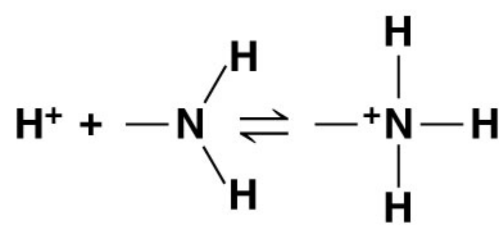
EXAMPLE



Glycine

FUNCTIONAL PROPERTIES

- Acts as a base; can pick up an H^+ from the surrounding solution (water, in living organisms):



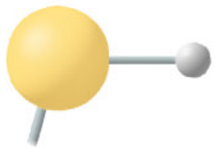
Nonionized Ionized

- Found in cells in the ionized form with a charge of 1+.

Figure 4.9e

Sulfhydryl

STRUCTURE



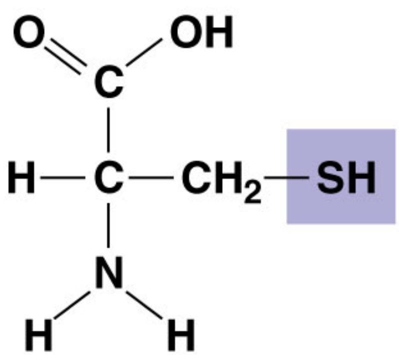
—SH

(may be written HS—)

NAME OF COMPOUND

Thiols

EXAMPLE



Cysteine

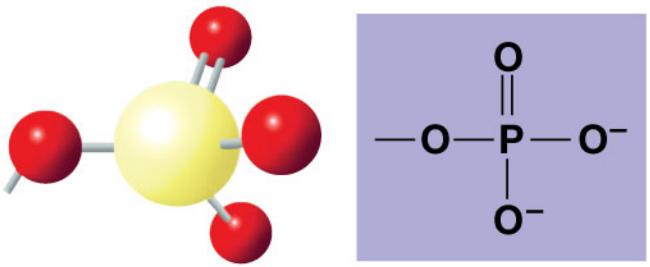
FUNCTIONAL PROPERTIES

- Two sulfhydryl groups can react, forming a covalent bond. This “cross-linking” helps stabilize protein structure.
- Cross-linking of cysteines in hair proteins maintains the curliness or straightness of hair. Straight hair can be “permanently” curled by shaping it around curlers and then breaking and re-forming the cross-linking bonds.

Figure 4.9f

Phosphate

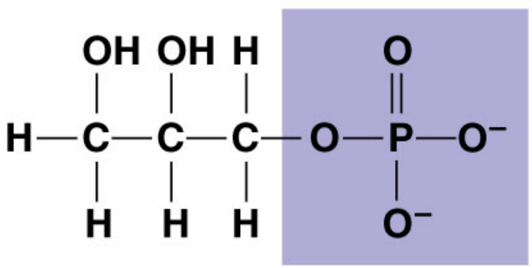
STRUCTURE



Organic phosphates

NAME OF COMPOUND

EXAMPLE



Glycerol phosphate

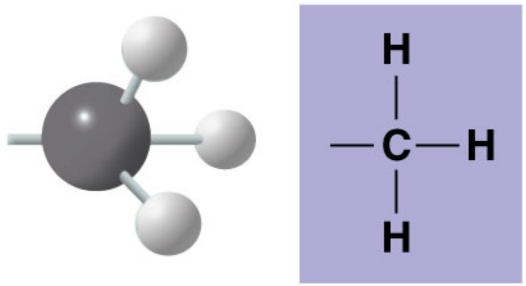
- **Contributes negative charge to the molecule of which it is a part (2– when at the end of a molecule, as at left; 1– when located internally in a chain of phosphates).**
- **Molecules containing phosphate groups have the potential to react with water, releasing energy.**

FUNCTIONAL PROPERTIES

Figure 4.9g

Methyl

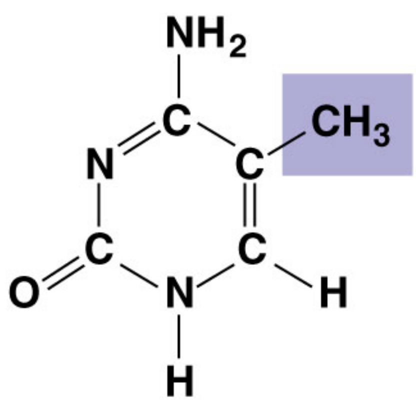
STRUCTURE



Methylated compounds

NAME OF COMPOUND

EXAMPLE



5-Methyl cytidine

FUNCTIONAL PROPERTIES

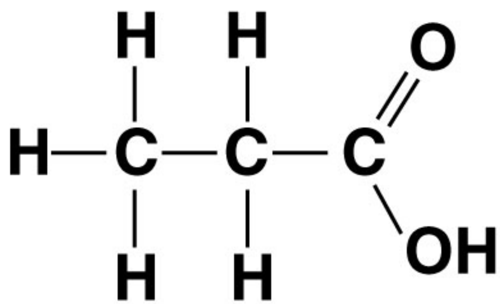
- Addition of a methyl group to DNA, or to molecules bound to DNA, affects the expression of genes.
- Arrangement of methyl groups in male and female sex hormones affects their shape and function.

ATP: An Important Source of Energy for Cellular Processes

- One phosphate molecule, **adenosine triphosphate** (**ATP**), is the primary energy-transferring molecule in the cell
- ATP consists of an organic molecule called adenosine attached to a string of three phosphate groups

Figure 4.UN03

a.



b.

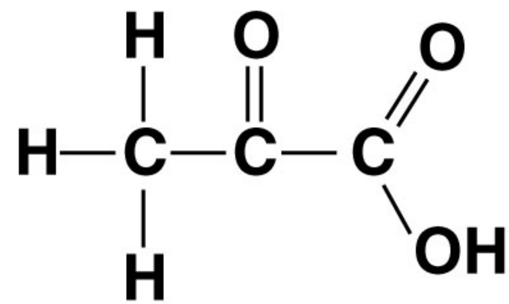
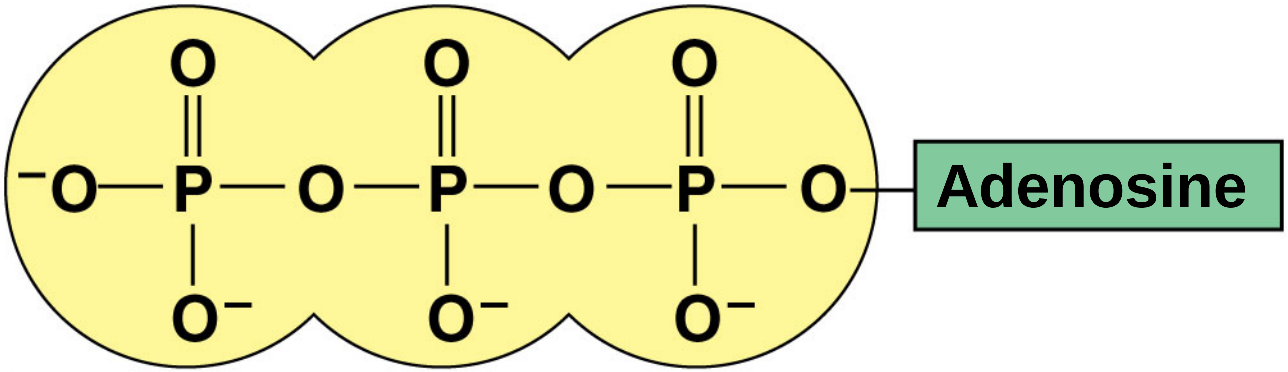


Figure 4. UN04



The Chemical Elements of Life: *A Review*

- The versatility of carbon makes possible the great diversity of organic molecules
- Variation at the molecular level lies at the foundation of all biological diversity

Figure 4. UN05

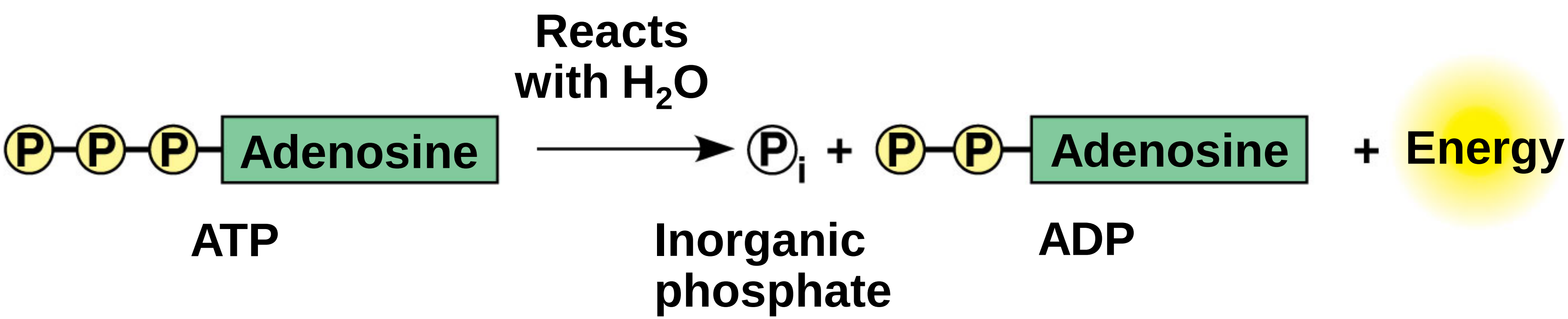


Figure 4. UN07

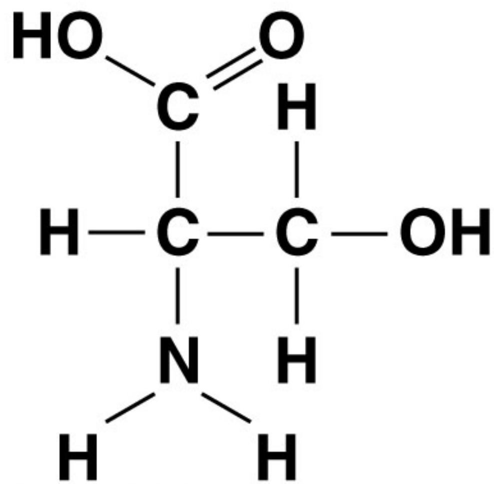


Figure 4. UN08

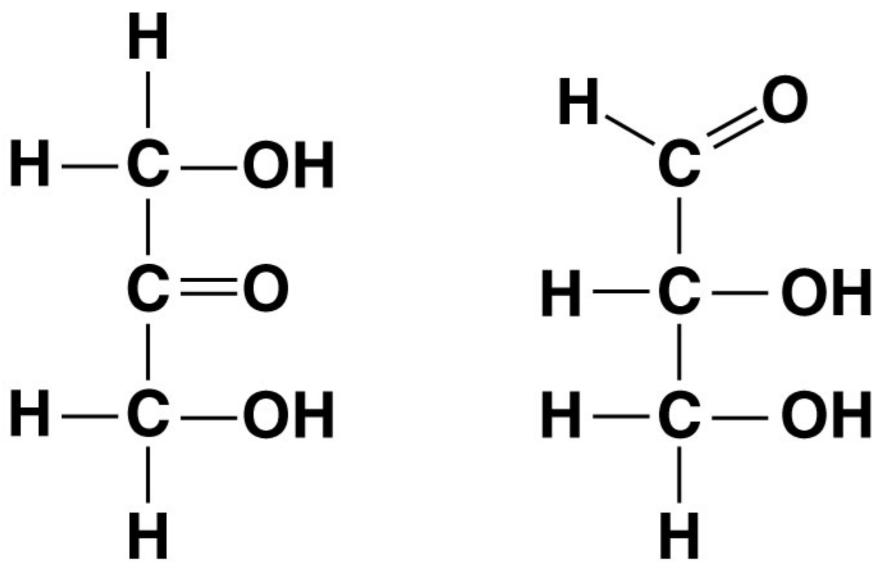


Figure 4. UN09

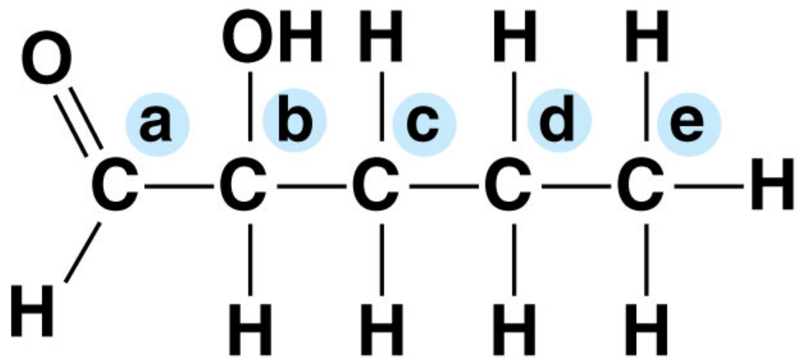
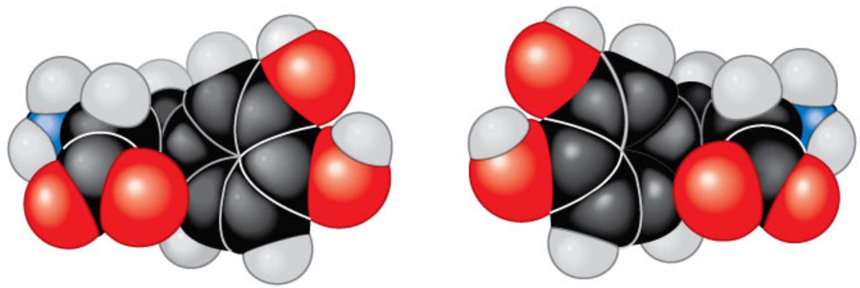


Figure 4. UN10



L-dopa D-dopa

Figure 4. UN11

Figure 4. UN12

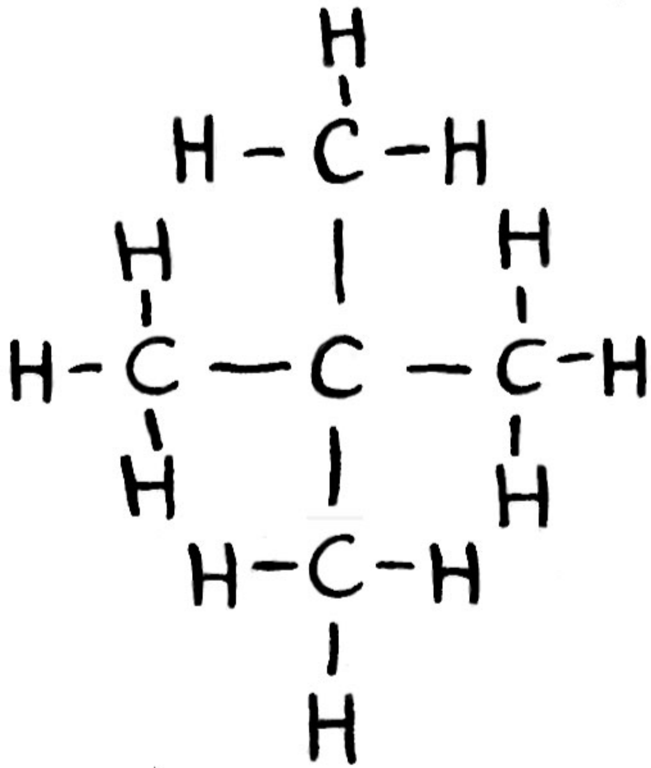


Figure 4. UN13

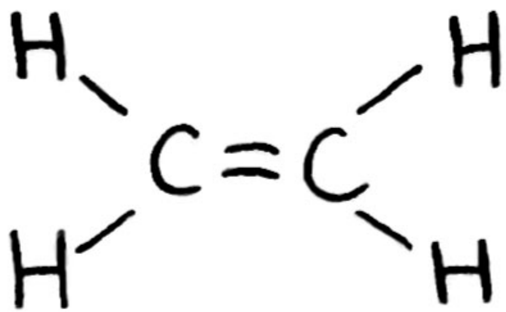


Figure 4. UN14

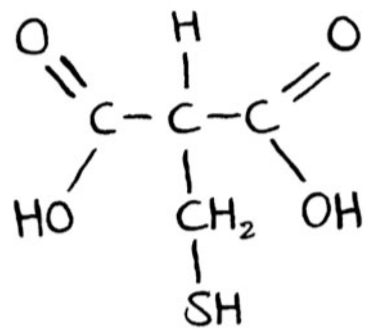
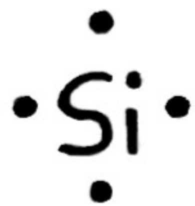


Figure 4. UN15

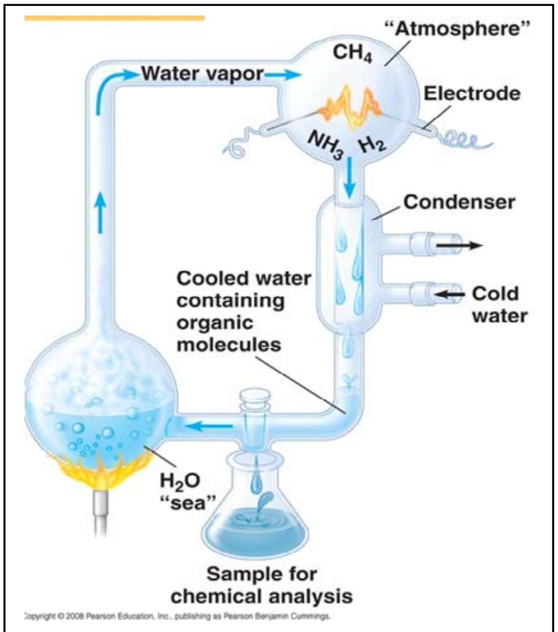


Name______________________Period__________

Chapter 4: Carbon and the Molecular Diversity of Life

Concept 4.1 Organic chemistry is the study of carbon compounds

1. Study this figure of Stanley Miller's experiment to simulate conditions thought to have existed on the early Earth. Explain the elements of this experiment, using arrows to indicate what occurs in various parts of the apparatus.



2. What was collected in the sample for chemical analysis? What was concluded from the results of this experiment?

Concept 4.2 Carbon atoms can form diverse molecules by bonding to four other atoms

3. Make an electron distribution diagram of carbon. It is essential that you know the answers to these questions:

   a. How many valence electrons does carbon have?

   b. How many bonds can carbon form?

   b. What type of bonds does it form with other elements?

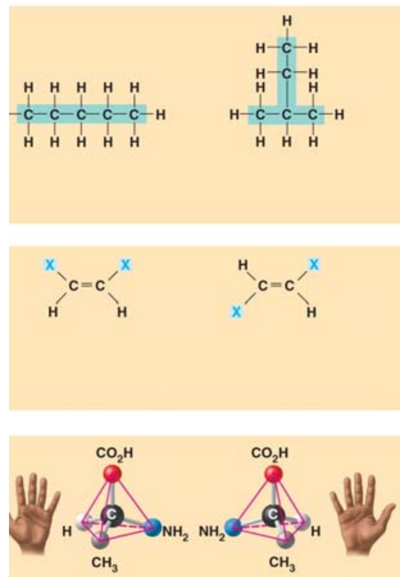
4. Carbon chains form skeletons. List here the types of skeletons that can be formed.

5. What is a *hydrocarbon*? Name two. Are hydrocarbons hydrophobic or hydrophilic?

6. In Chapter 2 you learned what an *isotope* is. Since students often confuse this word with *isomer*, please define each term here and give an example.

	Definition	Example
isotope		
isomer		

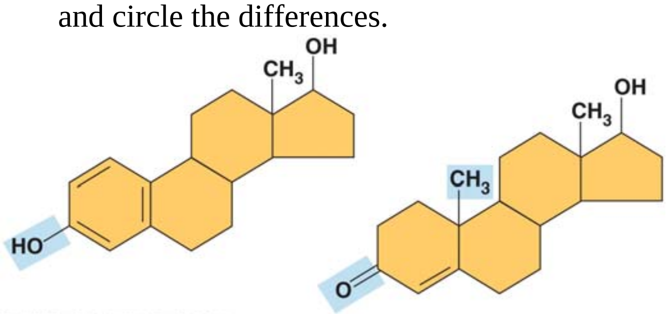
7. Use this figure to identify the three types of isomers. For each type, give a key character and an example.



8. Give one example of enantiomers that vary in their pharmacological effect.

Concept 4.3 A small number of chemical groups are key to the functioning of biological molecules

9. Here is an idea that will recur throughout your study of the function of molecules: Change the structure, change the function. You see this in enantiomers, you will see it in proteins and enzymes, and now we are going to look at testosterone and estradiol. Notice how similar these two molecules are, and yet you know what a vastly different effect each has. Label each molecule in the sketch below, and circle the differences.



10. Define *functional group*.

11. There are seven functional groups. Complete the following chart.

	Hydroxyl	**Carbonyl**	**Carboxyl**	**Amino**	**Sulfhydryl**	**Phosphate**	**Methyl**
Structure							
Example							
Functional Properties							

12. You will need to master the chart and the information in it. Using the functional groups above, see if you can answer the following prompts:

a. $–NH_2$

b. Can form cross-links that stabilize protein structure

c. Key component of ATP

d. Can affect gene expression

e. CH_3

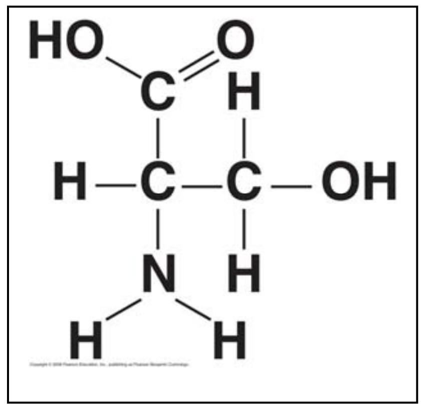
f. Is always polar

g. Determines the two groups of sugars

h. Has acidic properties

i. –COOH

j. Acts as a base



k. Circle and identify three functional groups in the molecule shown above.

Testing Your Knowledge: Self-Quiz Answers
Now you should be ready to test your knowledge. Place your answers here:

1.________ 2.________ 3.________ 4.________ 5.________ 6.________ 7.________

The King's Academy
AP Biology
Mrs. Carruthers
Test – Chapter 4

CARBON AND THE MOLECULAR DIVERSITY OF LIFE

Multiple Choice: Identify the choice that best completes the statement or answers the question.

1) The element present in all organic molecules is
A) hydrogen.
B) oxygen.
C) carbon.
D) nitrogen.
E) phosphorus.

2) The complexity and variety of organic molecules is due to
A) the chemical versatility of carbon atoms.
B) the variety of rare elements in organic molecules.
C) the fact that they can be synthesized only in living organisms.
D) their interaction with water.
E) their tremendously large sizes.

3) The experimental approach taken in current biological investigations presumes that
A) simple organic compounds can be synthesized in the laboratory from inorganic precursors, but complex organic compounds like carbohydrates and proteins can only be synthesized by living organisms.
B) a life force ultimately controls the activities of living organisms and this life force cannot be studied by physical or chemical methods.
C) although a life force, or vitalism, exists in living organisms, this life force cannot be studied by physical or chemical methods.
D) living organisms are composed of the same elements present in nonliving things, plus a few special trace elements found only in living organisms or their products.
E) living organisms can be understood in terms of the same physical and chemical laws that can be used to explain all natural phenomena.

-continue-

4) Stanley Miller's 1953 experiments proved that
A) life arose on Earth from simple inorganic molecules.
B) organic molecules can be synthesized abiotically under conditions that may have existed on early Earth.
C) life arose on Earth from simple organic molecules, with energy from lightning and volcanoes.
D) the conditions on early Earth were conducive to the origin of life.
E) the conditions on early Earth were conducive to the abiotic synthesis of organic molecules.

5) Hermann Kolbe's synthesis of an organic compound, acetic acid, from inorganic substances that had been prepared directly from pure elements was a significant milestone for what reason?
A) It solved an industrial shortage of acetic acid.
B) It proved that organic compounds could be synthesized from inorganic compounds.
C) It disproved the concept of vitalism.
D) It showed that life originated from simple inorganic chemicals.
E) It proved that organic compounds could be synthesized from inorganic compounds and disproved the concept of vitalism.

6) How many electron pairs does carbon share in order to complete its valence shell?
A) 1
B) 2
C) 3
D) 4
E) 8

7) A carbon atom is most likely to form what kind of bond(s) with other atoms?
A) ionic
B) hydrogen
C) covalent
D) covalent bonds and hydrogen bonds
E) ionic bonds, covalent bonds, and hydrogen bonds

8) Why are hydrocarbons insoluble in water?
A) The majority of their bonds are polar covalent carbon-to-hydrogen linkages.
B) The majority of their bonds are nonpolar covalent carbon-to-hydrogen linkages.
C) They are hydrophilic.
D) They exhibit considerable molecular complexity and diversity.
E) They are lighter than water.

-continue-

9) Which of the following statements correctly describes *cis-trans* isomers?
A) They have variations in arrangement around a double bond.
B) They have an asymmetric carbon that makes them mirror images.
C) They have the same chemical properties.
D) They have different molecular formulas.
E) Their atoms and bonds are arranged in different sequences.

10) Research indicates that ibuprofen, a drug used to relieve inflammation and pain, is a mixture of two enantiomers; that is, molecules that
A) have identical chemical formulas but differ in the branching of their carbon skeletons.
B) are mirror images of one another.
C) exist in either linear chain or ring forms.
D) differ in the location of their double bonds.
E) differ in the arrangement of atoms around their double bonds.

11) What determines whether a carbon atom's covalent bonds to other atoms are in a tetrahedral configuration or a planar configuration?
A) the presence or absence of bonds with oxygen atoms
B) the presence or absence of double bonds between the carbon atom and other atoms
C) the polarity of the covalent bonds between carbon and other atoms
D) the presence or absence of bonds with nitrogen atoms
E) the solvent that the organic molecule is dissolved in

12) Organic molecules with only hydrogens and five carbon atoms can have different structures in all of the following ways *except*
A) by branching of the carbon skeleton.
B) by varying the number of double bonds between carbon atoms.
C) by varying the position of double bonds between carbon atoms.
D) by forming a ring.
E) by forming enantiomers.

13) A compound contains hydroxyl groups as its predominant functional group. Which of the following statements is true concerning this compound?
A) It lacks an asymmetric carbon, and it is probably a fat or lipid.
B) It should dissolve in water.
C) It should dissolve in a nonpolar solvent.
D) It won't form hydrogen bonds with water.
E) It is hydrophobic.

-continue-

14) Which of the following is a false statement concerning amino groups?
A) They are basic in pH.
B) They are found in amino acids.
C) They contain nitrogen.
D) They are nonpolar.
E) They are components of urea.

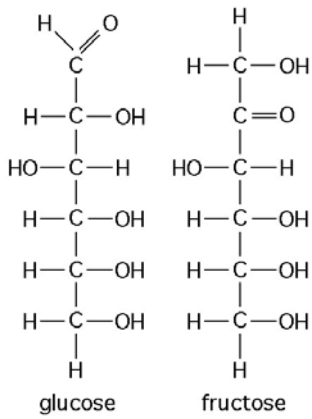
15) Which two functional groups are always found in amino acids?
A) ketone and methyl
B) carbonyl and amino
C) carboxyl and amino
D) amino and sulfhydryl
E) hydroxyl and carboxyl

16) Amino acids are acids because they always possess which functional group?
A) amino
B) carbonyl
C) carboxyl
D) phosphate
E) hydroxyl

17) Which functional groups can act as acids?
A) amino and sulfhydryl
B) carbonyl and carboxyl
C) carboxyl and phosphate
D) hydroxyl and aldehyde
E) ketone and amino

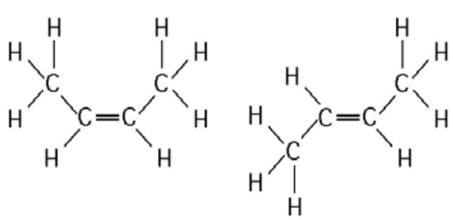
18) Testosterone and estradiol are male and female sex hormones, respectively, in many vertebrates. In what way(s) do these molecules differ from each other?
A) Testosterone and estradiol are structural isomers but have the same molecular formula.
B) Testosterone and estradiol are *cis-trans* isomers but have the same molecular formula.
C) Testosterone and estradiol have different functional groups attached to the same carbon skeleton.
D) Testosterone and estradiol have distinctly different chemical structures, with one including four fused rings of carbon atoms, while the other has three rings.
E) Testosterone and estradiol are enantiomers of the same organic molecule.

-continue-



19) The figure above shows the structures of glucose and fructose. These two molecules differ in the
A) number of carbon, hydrogen, and oxygen atoms.
B) types of carbon, hydrogen, and oxygen atoms.
C) arrangement of carbon, hydrogen, and oxygen atoms.
D) number of oxygen atoms joined to carbon atoms by double covalent bonds.
E) number of carbon, hydrogen, and oxygen atoms; the types of carbon, hydrogen, and oxygen atoms; and the arrangement of carbon, hydrogen, and oxygen atoms.

20) The figure above shows the structures of glucose and fructose. These two molecules are
A) geometric isotopes.
B) enantiomers.
C) *cis-trans* isomers.
D) structural isomers.
E) nonisotopic isomers.

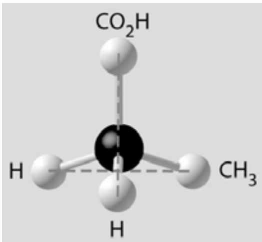


21) The two molecules shown in the figure above are best described as
A) enantiomers.
B) radioactive isotopes.
C) structural isomers.
D) nonisotopic isomers.
E) *cis-trans* isomers.

-continue-

22) Which of the pairs of molecular structures shown below depict enantiomers (enantiomeric forms) of the same molecule?

A)



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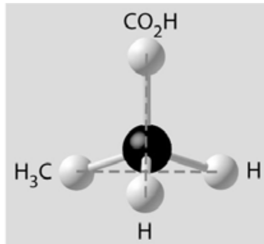
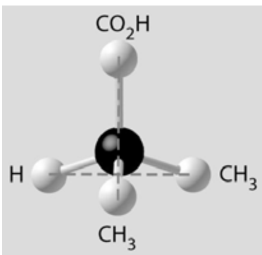


B)



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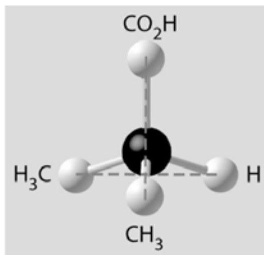
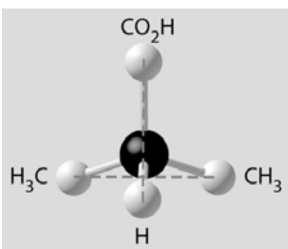


C)



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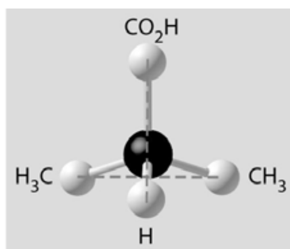
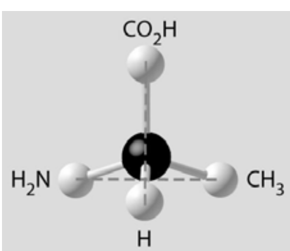


D)



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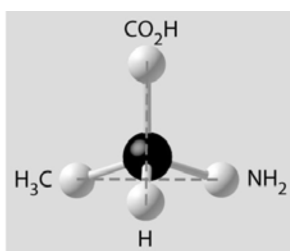
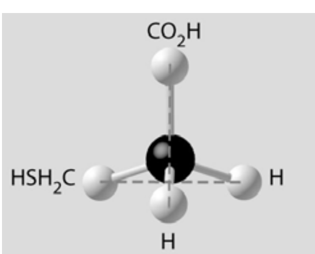


E)



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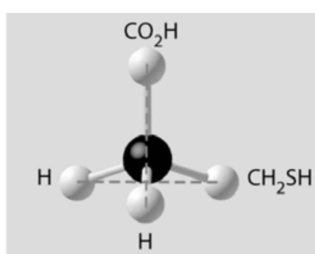

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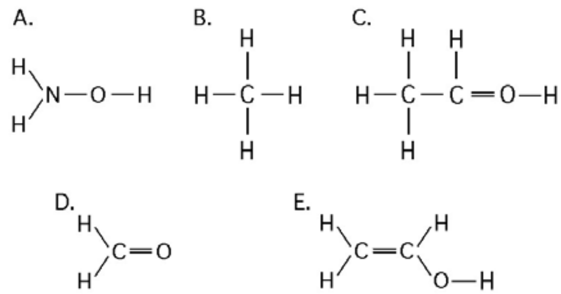
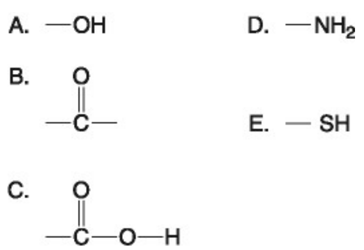


23) Which of the structures illustrated above is an impossible covalently bonded molecule?
A) A
B) B
C) C
D) D
E) E



24) Which functional group shown above is characteristic of alcohols?
A) A
B) B
C) C
D) D
E) E

25) Which functional group(s) shown above is (are) present in all amino acids?
A) A and B
B) B and D
C) C only
D) D only
E) C and D

26) Which of the groups shown above is a carbonyl functional group?
A) A
B) B
C) C
D) D
E) E

-continue-

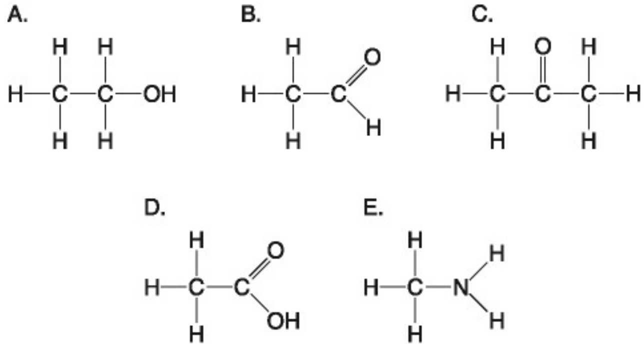
27) Which of the groups shown above is a functional group that helps stabilize proteins by forming covalent cross-links within or between protein molecules?
A) A
B) B
C) C
D) D
E) E

28) Which of the groups above is a carboxyl functional group?
A) A
B) B
C) C
D) D
E) E

29) Which of the groups above is an acidic functional group that can dissociate and release H^+ into a solution?
A) A
B) B
C) C
D) D
E) E

30) Which of the groups above is a basic functional group that can accept H^+ and become positively charged?
A) A
B) B
C) C
D) D
E) E

-continue-



31) Which molecule shown above has a carbonyl functional group in the form of a ketone?
A) A
B) B
C) C
D) D
E) E

32) Which molecule shown above has a carbonyl functional group in the form of an aldehyde?
A) A
B) B
C) C
D) D
E) E

33) Which molecule shown above can increase the concentration of hydrogen ions in a solution and is therefore an organic acid?
A) A
B) B
C) C
D) D
E) E

34) A chemist wishes to make an organic molecule less acidic. Which of the following functional groups should be added to the molecule in order to do so?
A) carboxyl
B) sulfhydryl
C) hydroxyl
D) amino
E) phosphate

-continue-

Short Answer Essay: Thoroughly answer each question using complete sentences. Diagrams may be used to help clarify but should not be used alone without explanation.

1. In 1918, an epidemic of sleeping sickness caused an unusual rigid paralysis in some survivors, similar to symptoms of advanced Parkinson's disease. Years later, L-dopa, a chemical used to treat Parkinson's disease, was given to some of these patients, as dramatized in the movie *Awakenings*, starring Robin Williams. L-dopa was remarkably effective at eliminating the paralysis, at least temporarily. However, its enantiomer, D-dopa, was subsequently shown to have no effect at all, as is the case for Parkinson's disease. **Discuss** how the effectiveness of one enantiomer and not the other illustrates the theme of structure and function.

Introduction

GOALS OF THE LABORATORY INVESTIGATIONS

Knowing a collection of facts about biology is beneficial only if you can use that information to understand and investigate a particular aspect of the natural world. AP® Biology lab investigations allow you to explore the natural world, and provide opportunities for you to choose to study what interests you most about each concept. Science is about the process of investigating, and should be a central part of your experience in AP Biology. Performing labs also gives you insight into the nature of science, and helps you appreciate the investigations and processes that result in the collection of facts that your textbook and your teacher often present to you.

This suite of AP Biology laboratory investigations helps you gain enduring understandings of biological concepts and the scientific evidence that supports them. The investigations allow you to develop and apply practices and skills used by scientists. You make observations, ask questions, and then design plans for experiments, data collection, application of mathematical routines, and refinement of testable explanations and predictions. As you work through your experiments, your teacher will ask follow-up questions to assess how well you understand key concepts. Finally, you will communicate your findings and your interpretation of them to your classmates and instructor(s).

For each investigation in this manual, you will find the following:

- Background information and clear learning objectives for each investigation
- Prelab questions, activities, software simulations, and other supplemental resources
- "Checklists" of prior skills and skills that will be developed
- Tips for designing and conducting investigations
- Safety concerns
- Lists of materials and supplies
- Methods of analyzing and evaluating results
- Means of communicating results and conclusions
- Postlab questions and activities
- Suggestions for extending the investigation(s)

CHAPTER 1:
What Is Inquiry?

How do we know what we know? Inquiry begins with observations you make about the natural world — a bare spot under a tree, a bird chirping repeatedly, or an unusual spot on your skin. If you follow such observations by a question, such as *What is causing that?*, you have begun an inquiry. Inquiry-based laboratory investigations allow you to discover information for yourself, and model the behavior of scientists as you observe and explore. Through inquiry, you use a variety of methods to answer questions you raise. These methods include laboratory and field investigations; manipulation of software simulations, models, and data sets; and meaningful online research. By designing experiments to test hypotheses, analyze data, and communicate results and conclusions, you appreciate that a scientific method of investigation is cyclic, not linear; each observation or experimental result raises new questions about how the world works, thus leading to open-ended investigations.

There are four levels of inquiry that lead to the student question. It is not reasonable to think that every part of a particular lab in AP Biology will be completely student directed. However, as written, the labs lead to a student-directed, inquiry-based investigation(s). The four levels of inquiry are as follows:

- **Confirmation**. At this level, you confirm a principle through an activity in which the results are known in advance.
- **Structured Inquiry**. At this level, you investigate a teacher-presented question through a prescribed procedure.
- **Guided Inquiry**. At this level, you investigate a teacher-presented question using procedures that you design/select.
- **Open Inquiry**. At this level, you investigate topic-related questions that are formulated through procedures that you design/select.

As you work on your investigations, your teacher may walk around the room and ask probing questions to provoke your thinking (e.g., *How are you changing the temperature? How are you recording the temperature?*). Your teacher may also ask about data and evidence (e.g., *Is there an alternative way to organize the data? Is there some reason the data may not be accurate? What data are important to collect? What are you hoping to find out? How will you communicate your results?*). This strategy will allow your teacher to diagnose and address any misconceptions immediately.

CHAPTER 2:
Written, Verbal, and Graphic Communication

Experimental results must be communicated to peers to have value. To understand the relationship among your hypothesis, procedures, and results, you should first take part in an informal small-group or class discussion of the experiment, including possible errors, changes in procedures, and alternative explanations for your data. Since many of the laboratory experiences described in this manual contain suggestions for further investigation, discussion of a given experiment can be a launching pad for independent work, culminating in a formal written report, poster, or oral presentation. Some possibilities for more permanent presentations are described below.

Mini-Posters and Presentations

At scientific conferences, many experiments are presented orally or via posters. Posters provide the advantage of clarity and brevity that articulate the essential elements of the research. In a class, an alternative to the standard oral presentation or a full-sized poster is a mini-poster session, which requires fewer materials and less time than a formal presentation. You can include the most important elements of a full-sized poster, present your work, and get feedback from your classmates in an informal setting. The essential elements of a mini-poster are as follows:

- Title
- Abstract
- Introduction with primary question, background context, and hypothesis
- Methodology
- Results, including graphs, tables, charts, and statistical analyses
- Conclusions, or your interpretation of your results based on your hypothesis
- Literature cited

An example of a mini-poster session can be found at ***http://www.nabt.org/blog/2010/05/04/mini-posters-authentic-peer-review-in-the-classroom***. Such a session allows you to evaluate information on your own, and then discuss it with other students, mimicking authentic presentations and peer review.

Lab Notebooks/Portfolios

A lab notebook allows you to organize your work so that you have the information for a more formal report. Your lab notebook should contain the information necessary for making a formal report, which may include a prelab experimental outline with the following information:

- Members of work group
- Primary question for investigation
- Background observations and contextual information
- Hypothesis and rationale for the investigation
- Experimental design — strategies for testing hypothesis, using appropriate controls and variables
- Materials required
- Safety issues
- Procedure in sufficient detail so that someone could replicate your results

In addition, your lab notebook should contain the following:

- Results, including graphs, tables, drawings or diagrams, and statistical analysis
- Conclusion and discussion — Was the hypothesis supported? What additional questions remain for further investigation?
- References

A lab portfolio might contain finished lab reports, notes on individual projects, library research, reflections on particular lab experiences, and connections with other parts of the course, or a combination of these elements as requested by your teacher.

Lab Reports/Papers

A formal report or paper provides an effective method for you to organize your work, and mimics papers in scientific journals. Your teacher might provide a rubric for what information should be included. This type of report gives you writing experience and opportunities to reflect on your work. (Refer to page 10 for tips on constructing informative graphs to include in your report.) The writing center at the University of North Carolina has published an excellent guide for writing lab reports. Find it at ***http://www.unc.edu/depts/wcweb/handouts/lab_report_complete.html***.

You also can see a good example of a descriptive lab report, "Examination of Protozoan Cultures to Determine Cellular Structure and Motion Pattern," at ***http://www.ncsu.edu/labwrite/res/labreport/sampledescriptlab.html***.

Technology

There are numerous websites for posting class data, which can then provide a larger sample for analysis, comparison of different conditions in the experiment, or collaboration between students in different class sections and different schools. Your school's technology or media center personnel may recommend appropriate Web-based options.

Graphs

A graph is a visual representation of your data, and you want your graph to be as clear as possible to the reader for interpretation. First, you have to decide whether to use a scatter plot in order to draw a "best fit" line through data points, a bar graph, or some other representation with appropriate units. Use a line graph if your data are continuous (e.g., the appearance of product over time in an enzyme reaction). If your data are discontinuous (e.g., the amount of water consumption in different high schools), use a bar graph. Your teacher might have other suggestions.

A graph must have a title that informs the reader about the experiment. Labeling a graph as simply "Graph Number Four" doesn't tell the reader anything about the experiment, or the results. In comparison, the title "The Effect of Different Concentrations of Auxin on Root Growth" tells the reader exactly what was being measured. Make sure each line or bar on your graph is easily identifiable by the reader.

Axes must be clearly labeled with units.

- The x-axis shows the independent variable. Time is an example of an independent variable. Other possibilities for an independent variable might be light intensity, or the concentration of a hormone or nutrient.
- The y-axis denotes the dependent variable, or what is being affected by the condition (independent variable) shown on the x-axis.
- Intervals must be uniform. For example, if one square on the x-axis equals five minutes, each interval must be the same and not change to ten minutes or one minute. If there is a break in the graph, such as a time course over which little happens for an extended period, note this with a break in the axis and a corresponding break in the data line.
- For clarity, you do not have to label each interval. You can label every five or ten intervals, or whatever is appropriate.
- Label the x-axis and y-axis so that a reader can easily see the information.

More than one condition of an experiment may be shown on a graph using different lines. For example, you can compare the appearance of a product in an enzyme reaction at different temperatures on the same graph. In this case, each line must be clearly differentiated from the others — by a label, a different style, or color indicated by a key. These techniques provide an easy way to compare the results of your experiments.

Be clear as to whether your data start at the origin (0,0) or not. Do not extend your line to the origin if your data do not start there. In addition, do not extend your line beyond your last data point (extrapolation) unless you clearly indicate by a dashed line (or some other demarcation) that this is your prediction about what may happen.

For more detailed information about graphs, see Appendix B: Constructing Line Graphs.

CHAPTER 3:
Quantitative Reasoning in AP® Biology

Which would you choose? A brain biopsy or a CAT/MRI scan? A vaccine for 90%+ of the population with a risk of 0.001% suffering from side effects, or no vaccine at all? Fresh vegetables sprayed with competing bacteria, or vegetables sprayed with sterilants that are hazardous to ecosystems? To risk conviction of a crime based on a detective's hunch, or to be acquitted based on evidence provided by DNA markers? These are routine questions affected by the use of mathematics in science, including biology, medicine, public health, and agriculture.

To have a rich foundation in biology, you need to include and apply quantitative methods to the study of biology. This is particularly true for a laboratory experience. Quantitative reasoning is an essential part of inquiry in biology. Many mathematical tools (e.g., statistical tests) were developed originally to work out biological problems.

Mathematics can help biologists (and biology students) grasp and work out problems that are otherwise:

- Too big (such as the biosphere)
- Too slow (macroevolution)
- Too remote in time (early extinctions)
- Too complex (human brain)
- Too small (molecular structures and interactions)
- Too fast (photosynthesis)
- Too remote in space (life in extreme environments)
- Too dangerous or unethical (how infectious agents interact with human populations)

The laboratory investigations in this manual were chosen to provide you with an opportunity to do biology — to explore your own questions and try to find answers to those questions. Many of the investigations provide a preliminary, guided exploration to introduce you to a way of looking at a biology problem, or method for studying it, providing just enough familiarity with the topics so that you can begin asking your own questions and investigating them. An essential part of that exploration includes an introduction to various quantitative skills — mathematical routines, concepts, methods, or operations used to interpret information, solve problems, and make decisions — that you will need in order to explore the investigative topic adequately.

The quantitative skills you'll apply as you carry out the investigations in this lab manual are for the most part the same skills you have been acquiring in your mathematics courses. For many of the skills required in these labs, you already understand how to do the math, and these investigations simply extend the application of those math skills. Your teacher can help to guide you as you supplement and review the quantitative skills required for the various laboratory investigations in this manual.

To conceptually organize the scope and nature of the skills involved, refer to Figure 1:

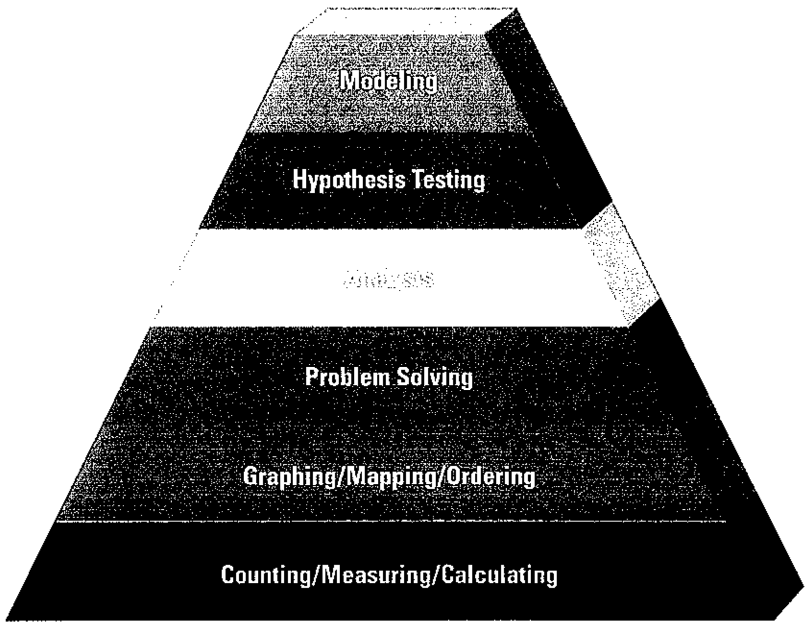


Figure 1. Pyramid of Quantitative Reasoning

The figure graphically organizes the quantitative skills featured in this lab manual. The skills labeled on the bottom of the pyramid are generally less complex, and require the application of standard procedures. As you move up the pyramid, the applications become more complex as you try to make sense out of data and biological phenomena. One of the important lessons about quantitative reasoning is that real data are "messy." The increasing complexity as you move up this pyramid does not necessarily indicate that the mathematical operations themselves are more complex. Good, first approximations of mathematical models often require only simple arithmetic. This chapter describes how the quantitative skills listed in the pyramid are applied when answering questions generated by various lab topics in this manual.

Counting, Measuring, and Calculating

At this point in your education, you may not feel that counting, measuring, and calculating represent much in the way of a "skill." And you'd be right in a theoretical world. The problem is that your investigation will explore the real world of biology, and that is messy.

For example, Investigation 1: Artificial Selection presents the problem of selection of quantitative variation in a population of plants. You identify a trait that can be quantified (counted), and then measure the variation in the population of plants by counting. This is not always as easy as it sounds. You will notice that some of the plants in your population are more hairy than others, so this is the trait you select. What do you count? All the hairs? Some of the hairs on specific parts of the plant? On how many plants? After observing one of your plants more closely, you see that it has very few (if any) hairs, but another plant has hundreds. These hairs are small. You have a limited amount of time to make your counts. How do you sample the population? After discussion with your lab partner(s), you and your class decide to count just the hairs on the first true leaf's petiole (stalk attaching the blade to the stem) — a much smaller and more reasonable amount to count, but you'll still need to work out whether or not it is a representative sample.

Measuring phenomena in the real world presents similar challenges. Investigation 10: Energy Dynamics introduces you to energy dynamics by measuring the biomass of growing organisms. How do you measure the mass of a small caterpillar? What about the water in the organism? Is water included in "biomass"? It is your challenge to come up with solutions to these problems, and to define all measurements carefully so that someone could measure in the same way you did and replicate the experiment. Perhaps you could measure a quantity of caterpillars and sacrifice a few caterpillars to estimate how much the "wet mass" of a caterpillar is biomass, and how much is water. You will have to perform relatively simple calculations, including percentages, ratios, averages, and means.

Nearly every lab investigation requires these kinds of operations and decisions. What is different about this manual is that the decisions are up to you. The manual doesn't make the decisions for you. There are almost always a number of reasonable, productive solutions to such problems. Make sure that your decisions are reasonable and provide a good solution to the problem you are studying.

Precision needed in the experiment is also a consideration and a decision you have to make. Increasing precision requires more time and resources. How precise do your data need to be for you to support or reject your hypothesis?

Graphing, Mapping, and Ordering: Histograms of Variation and/or Energy Flow Diagrams

To build on the previous two examples, consider how the data counted and measured should be represented — not numerically, but with graphs or diagrams. For example, consider the examination of the variation of a quantitative trait in a population of plants. How do you best represent these data? If you count the hairs (trichomes) in a population of 150 plants, do you present each data point on a graph, or do you compile the data into an overall picture? If all data points are the same, then there would be no need to present data graphically, but the messy reality is that the counts likely could vary from 0 to more than 50 hairs per plant. For this reason, a histogram (see Figure 2) is often used to represent the variability and distribution of population data.

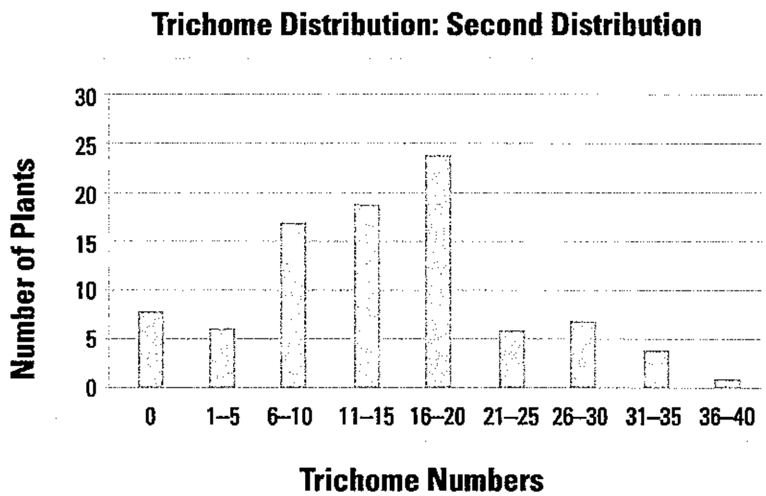


Figure 2. Trichome Distribution: Second Distribution

In a histogram, the data are organized into bins with a defined range of values. For example, for the hairy plants the bin size might be 10 hairs, and bins defined in this manner might include 1–10 hairs, 11–20 hairs, 21–30 hairs, and so on. You simply count the number of plants that fall into each bin, and then graph the distribution as a bar graph — or in this case, a histogram. There are several challenges and decisions you'll have to make where your quantitative skills will be tested. For instance, what should you do about plants with 0 plant hairs? Do you include a separate bin for this one plant? How do you know what the "correct" bin size is? It is usually best to try several bin sizes, but you'll have to make the decision which bin size best captures the nature of the variation you are working with — messy.

Creating Diagrams, Charts, and Maps

Biology is the study of systems at several levels of organization, from molecules and cells to populations and ecosystems. When exploring a topic, such as energy dynamics in Investigation 10, creating a chart or map can help you to logically define the system components and the flows between those components, while simplifying a very complicated process. Creating such a chart is an exercise in logic and graphic design. Such a graphic representation of your work helps to communicate your thinking, and organizes your analysis and modeling structure. Figure 3 is one model of how a disease might infect a population.

Figure 3. A Disease's Infection of a Population

Your teacher may have suggestions on investigations of graphic representation methods you may want to employ to summarize your data and thoughts.

Problem Solving

All sorts of questions and problems are raised and solved during biological investigations. Such questions include the following:

- What is the inheritance pattern for a particular trait?
- What is the critical population size that will ensure genetic diversity in an isolated population?
- How are genes linked to each other on the same chromosome?
- How often do spontaneous mutations occur in a species of yeast?
- What is the Q_{10} temperature coefficient[1] for invertebrates in the Arctic?
- How does a change in ambient temperature affect the rate of transpiration in plants?
- How can the efficiency of transformation be calculated in bacteria exposed to plasmids containing a gene for antibiotic resistance?

Problem solving involves a complex interplay among observation, theory, and inference. For example, say that for one of your investigations you explore a typical dihybrid genetic cross like one you may have studied earlier in an introductory biology course. This time, however, you collect data from the F2 generation, and note four different phenotype combinations (observation). You count the number of each combination. Using your understanding of the role of chromosomes in inheritance, you work to make a theoretical prediction of what your results might be assuming independent assortment of genes (hypothesis). However, you find that the observed results don't quite match your expected results. Now what? You've been using quantitative thinking, and now it is time to extend the thinking into possible solutions to this problem.

1 Q_{10} temperature coefficient: a measure of the rate of change of a biological or chemical system as a consequence of increasing the temperature by 10 °C.

In this case, the deviation from expected may be due to random chance, or it may be due to a phenomenon known as linkage, where two genes are located close together on the same chromosome instead of on separate chromosomes. There is not enough space here to fully explore the strategies for solving such a problem, but realize that the challenge requires a different level of commitment on your part to work through the problem and solve it. Instead of the instructions for each lab investigation walking you through such problems step by step, this manual provides you with opportunities to explore problems you can solve on your own, which will give you a deeper learning experience.

Analysis

When you start to design your own investigations to answer your own questions, you may find that appropriate and adequate data analysis is a challenge. This is the result of having done too many investigations that have the analysis scripted for you. From the very first inkling of the question that you plan to investigate, you also should consider how you plan to analyze your data. Data analysis describes your data quantitatively. Descriptive statistics help to paint the picture of the variation in your data; the central tendencies, standard error, best-fit functions, and the confidence that you have collected enough data. Analysis helps you to make your case when arguing for your conclusion that your data meet accepted standards for reliability and validity. Data analysis is complex. Obviously, there is not enough space in this overview to do the topic justice, but do not let this deter you. Data analysis is an essential component of each investigation in this manual, and is integral to the communication process. Your teacher will be a valuable guide in this process.

Hypothesis Testing

In the investigations in this manual, you are asked to modify your question into an appropriate hypothesis. Your experimental design should provide evidence that will help you to conclude whether or not your hypothesis should be accepted. Part of the evidence needed to produce such a conclusion is based on a number of statistical tests that are designed for specific situations. You may be familiar with a statistical hypothesis test, such as a chi-square test or a T-test. These tests can help you to determine probability that the data you have sampled are significantly different from a theoretical population. You've undoubtedly read about such tests, as they are applied when testing new drug treatments or medical procedures. Your teacher can help guide you as you select the methods appropriate to your study. Deciding on the appropriate methods for hypothesis testing (statistical tests) before you carry out your experiment will greatly facilitate your experimental design.

■ Modeling

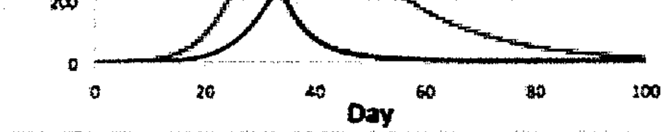
Not all biological research involves wet lab investigations[2]. Investigations also can involve a quantitative model. Quantitative models are often computer based. Thinking about and developing computer models may seem to be a new way of thinking and doing biology, but actually you've been constructing mental models of biological phenomena since you first began your study of biology. Models are simplifications of complex phenomena, and are important tools to help drive prediction and identify the important factors that are largely responsible for particular phenomena.

To develop a mathematical model, you must first define the relevant parameters or variables. For example, if you were creating a model of disease in a population, you might divide the population into three components: the part of the population that is susceptible but not infected, the part of the population that is infected, and the part of the population that has recovered from the disease. The probability of transmitting the infection and the probability for recovery are important parameters to define as well. The next step would be to graphically define these parameters and their relation to one another, as you did previously (see Figure 3).

With this graphic, you can imagine word equations that step through the process of a disease cycle in a population. These word equations can then be interpreted into the language of a spreadsheet to get something like Figure 4.

◇	A	B	C	D	E
1	Day	# Susc	# Inf	# Rec	# Total
2	0	999.00	1.00	0.00	1000
3	1	998.68	1.26	0.06	1000
4	2	998.28	1.59	0.14	1000
5	3	997.77	2.00	0.23	1000
6	4	997.13	2.52	0.35	1000
7	5	996.33	3.17	0.50	1000
8	6	995.32	3.99	0.69	1000
9	7	994.05	5.02	0.93	1000
10	8	992.45	6.32	1.23	1000
11	9	990.45	7.94	1.61	1000
12	10	987.93	9.98	2.09	1000
13	11	984.77	12.54	2.69	1000
14	12	980.82	15.74	3.44	1000
15	13	975.88	19.73	4.38	1000
16	14	969.72	24.71	5.57	1000
17	15	962.05	30.90	7.05	1000
18	16	952.54	38.56	8.90	1000
19	17	940.79	47.99	11.22	1000
20	18	926.34	59.56	14.10	1000
21	19	908.68	73.65	17.67	1000
22	20	887.27	90.64	22.09	1000
23	21	861.53	110.94	27.53	1000
24	22	830.95	134.87	34.18	1000

F	G	H	I	J
	Parameters			
	Transmission rate α:	0.32		
	Recovery rate β:	0.06		



Source: Shodor/Project SUCCEED workshops

Figure 4. A Disease Cycle in a Population

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2 Wet lab investigation: laboratories in which chemicals, drugs, or other material or biological matter are tested and analyzed requiring water, direct ventilation, and specialized piped utilities, as opposed to a computer-based lab.

Models help to provide insight and guidance for an investigation. They help to focus the investigation on parameters that are most influential. Models have to be checked against real data. The assumptions and the limitations of any model should be explicitly articulated. Building models is a challenge, but it is a challenge that, when met, pays very large dividends in learning.

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The King's Academy
AP Biology
Mrs. Carruthers

Constructing Line Graphs – Appendix B
AP Biology Investigative Lab Essentials

Directions: Reading, constructing and interpreting graphs are essential skills for any Biology/Science student. We will spend a significant time this year working with graphs. Please work through the following assignment, while carefully reading the lab handout entitled, *Constructing Line Graphs*.

1. What TWO pieces of information does each dot represent in Figure A3?

2. If the dots represents measurements that we made, what are the lines between the dots representative of?

3. In this line graph, is it possible to obtain a measurement/time, for which there is no 'dot'? How is this measurement denoted on the graph in A.3?

4. In addition to making the graph easy to read, what else may be the purpose of the line?

-continue-

5. In a line graph, one may only represent measurements actually observed with dots and solid lines. What is the purpose of the dotted line which is located between 0-40mg/3-5hrs in Figure A.3? What is this part of the line called?

6. How is an 'extrapolation' different from an 'interpolation?'

7. Why must the reader of the graph be cautious about extrapolations?

8. Read over the suggested titles for the graphs on page A6, a-e. Why is 'e' the superior title?

9. What is 'wrong' with the graph at A.5 on page 6?

10. When marking an axis, units are marked at 'intervals' that correspond to intervals between the experimental points. What do we call these?

11. What is the vertical scale (y-axis) called?

12. What is the horizontal (x-axis) called?

-continue-

13. When time is shown on the abscissa and amount of quantity shown on the ordinate, we call this a 'progress' graph or 'progressive curve.' Why is it possible to represent TWO of these graphs/curves on Fig a.10 on page 9?

14. Which line on the graph at Fig A.10 shows a 'faster' process? How can you tell by looking at the graph?

15. What is the rate for Process I?

16. What is the rate for Process II?

17. What is meant by the term "slope?"

18. What visual aspect of a graph suggests the slope?

19. Study the two graphs at Fig. A11 on page 10. The graph on the left is called a

_______________________ graph/curve while the graph/curve on the right is called

a _______________________ graph. Which part of the graph is different?

20. On a rate graph, rate is shown on the y-axis and is known as the dependent variable. Time, on the x-axis, is known as the 'independent' variable. Why is the measure on the x-axis called INDEPENDENT?

21. What must a rate graph always show on one of its axes?

22. What other types of independent variable may be on the abscissa of a rate graph?

23. Refer back to question #22, what other types of independent variables may be placed on the abscissa when attempting to grow a plant, or to get seeds to germinate?

24. For emphasis here, state what a progress curve and a corresponding rate curve must show:

25. Examine the graph at Fig. A.12. Why is the Process I line higher on the graph? Why are the curves flat?

26. Examine the graphs at Fig A.13 on page 11. What is different about the line, or slope, on the progress curve when comparing this graph to the previous ones studied? Why?

27. How will this be reflected in the rate curve?

28. Study the figure at A.14, line C. Notice that the line is not straight. The average slope is 2.5 units/hr. Why is this information misleading?

29. How can we find the 'true slope' at TWO hours?

30. So, a perfectly flat curve (Process I or II) means that the rate curve will be

depicted as a ______________________ line. However, a progress curve with changes in slope (Process III) will give a rate curve that looks like

______________________. If the progress curve has mild changes indicating a more gradual change in slope, how will this be reflected in what the 'steps' look like in the corresponding rate graph?

31. Carefully read the material on pages 13-15 regarding the progress and rate curves showing the growth of pea plants. Study what happens to the rate curve and how it correlates with the progress curve. Fill in the chart:

What does the shape of the curve mean?	Progress curve/graph	Rate Curve/graph
Flat		
Curving upward	*(refer back to Fig A.8,9)*	
Curving downward	*(refer back to Fig A.8,9)*	
Reaction has stopped		

Other kinds of rate graphs are discussed on pages 15-18. Be certain to read over this, as you may need to refer to this for labs.

Appendix B

CONSTRUCTING LINE GRAPHS*

Suppose we are studying some chemical reaction in which a substance, *A*, is being used up. We begin with a large quantity (100 mg) of *A*, and we measure in some way how much *A* is left after different times. The results of such an experiment might be presented pictorially like this:

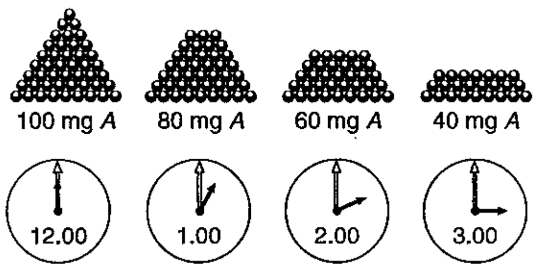


Figure A.1

This is the kind of picture graph that you often see in newspapers. This information can be presented much more simply on a graph — a line graph is permissible — because our experience tells us that when *A* is disappearing in a chemical reaction, it is disappearing more or less smoothly and will not suddenly reappear. In other words, the progress of a chemical reaction is a continuous process, and because time is a continuous process it is permissible to relate the two kinds of information to one another on a line graph. The procedure for constructing the line graph is shown in Figure A.2.

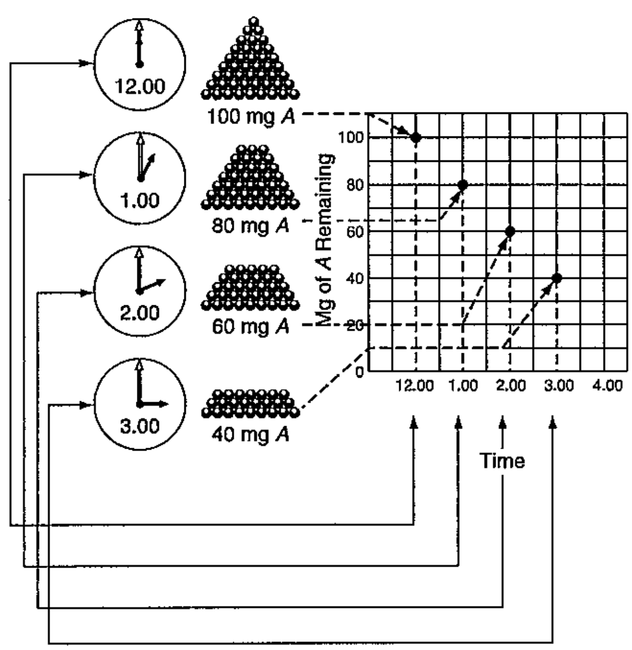


Figure A.2

* Based on a handout by Dr. Mary Stiller, Purdue University.

It should be clear from the diagram that each point corresponds both to a particular measurement of the amount of A remaining and to the particular time at which that amount remained. (A heavy dot is made opposite both of these two related quantities.) When all the measurements have been recorded in this way, we connect the dots with a line, shown in Figure A.3. (Figures A.21–A.23 explain when to connect the data points.)

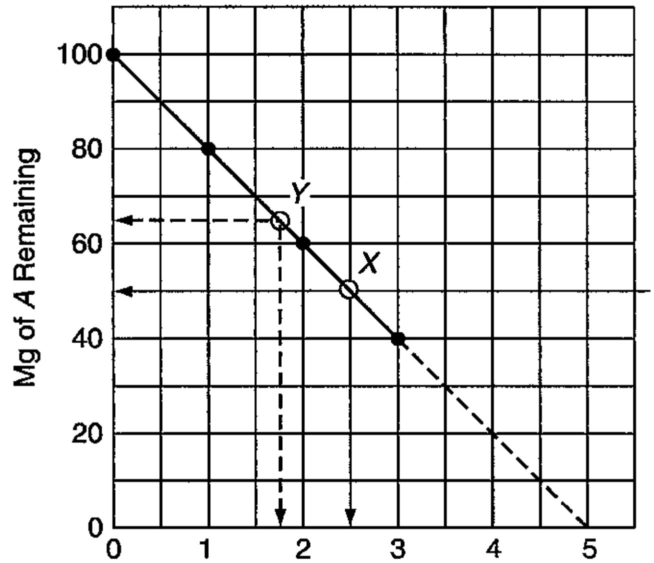


Figure A.3

It should be clear by looking at our graph that the only measurements we actually made are those indicated by the dots. However, because the information on both scales of the graph is assumed to be continuous, we can use the graph to find out how much A would have been found if we had made our measurements at some other time, say 2.5 hours. We merely locate the line that corresponds to 2.5 hours on our time scale and follow it up until it crosses our line graph at the point X; then we look opposite X to the "Mg of A Remaining" scale, and read off 50 mg. We conclude, then, that if we had made a measurement at 2.5 hours, we would have found 50 mg of A left. In a similar way, we can find out from our graph at what time a given amount of A, say 65 mg, would be left. We have merely to find the line that represents 65 mg on the vertical scale and follow it across until it cuts the line graph at point Y. Then we see 1.75 hours on the "Time" scale opposite Y. This tells us that had we wished to stop the reaction with 65 mg of A remaining, we would have had to do so after 1.75 hours.

You will notice that part of the graph has been drawn with a broken line. In making a line graph we are properly allowed to connect only the points representing our actual measurements. It is possible that measurements made after 3 hours will give points that will fall on the broken-line extension of the graph, but this is not necessarily so. In fact, the reaction may begin to slow up perceptibly, so that much less A is used up in the fourth hour than in the third hour. Not having made any measurements during the fourth hour, we cannot tell, and we confess our ignorance quite openly by means of the broken line. The broken line portion of the graph is called an **extrapolation**, because it goes beyond our actual experience with this particular reaction. Between any two of our measured points it seems fairly safe to assume that the reaction is proceeding steadily, and this is called an **interpolation**. Interpolations can only be made between measured points on a graph; beyond the measured points we must extrapolate. We know that the amount of *A* remaining after 4 hours is somewhere between 0 and 40 mg. The amount indicated by the broken line on the graph, 20 mg, is only a logical guess.

Unfortunately, it sometimes happens that even professionals take this sort of limitation of line graphs for granted and do not confess, by means of a broken line, the places where they are just guessing. Therefore, it is up to readers of the graph to notice where the last actual measurement was made and use their own judgment about the extrapolated part. Perhaps the extrapolated part fits quite well with the reader's own experience of this or a similar reaction, and he or she is quite willing to go along with the author's extrapolation. On the other hand, the reader may be interested only in the early part of the graph and be indifferent to what the author does with the rest of it. It may also be that the reader knows that the graph begins to flatten out after 3 hours and so disagrees with the author. The point is that we, the readers, must be aware of what part of the graph is extrapolated, that is, predicted, from the shape of the graph up to the time when the measurements were stopped. Hence, you must clearly indicate on a line graph the points that you actually measured. Regardless of what predictions or conclusions you want to make about the graph, you *must* give the reader the liberty of disagreeing with you. Therefore, it is very improper to construct a line graph consisting of an unbroken line without indicating the experimentally determined points.

BASIC REQUIREMENTS FOR A GOOD GRAPH

The following procedure applies primarily to graphs of experimental data that are going to be presented for critical evaluation. It does not apply to the kind of rough sketch that we often use for purposes of illustration.

Every graph presented for serious consideration should have a good **title** that tells what the graph is about. Notice that we need more than just a title; we need a *good* title. Before we try to make a good title, let us look at an example and try to decide what kind of title is a useful one. Look at Figure A.4.

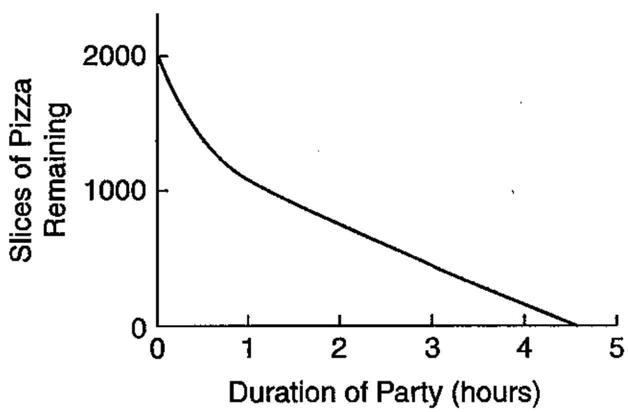


Figure A.4

If you like pizza, it might be very useful to know when this party is being held. Without a title, you cannot tell even whether the graph refers to any particular party at all. It might represent average figures for all the parties held last year, or it might represent the expected figures for a party that is going to be held tonight. Let us suppose that these data refer to a study party given by AP Biology students on March 9. Here, then, are some possible titles:

(a) The APs Have a Party

(b) Pizza Rules! Enjoy it with AP

(c) An AP Biofeast!

None of those titles is especially useful or informative because none of them tells what the graph is all about. Now look at these two titles:

(d) Anticipated Consumption of Slices of Pizza at the AP Biology Party, March 9

(e) Anticipated Consumption of Slices of Pizza at the AP Biology Party, March 9, 2011, 7:00 p.m.–11:00 p.m.

You should be able to see that only title (e) is helpful and useful. It enables you to tell, by glancing at the calendar, whether or not you can attend the party, and it helps make that graph fall a little more steeply. The point we are driving at is that a *good* title is one that tells exactly what information the author is trying to present with the graph. Although brevity is desirable, it should not substitute for completeness and clarity.

Now that you are clear on titles, look at the graph in Figure A.5. Its title tells you that here is some potentially useful information. The graph suggests that, at least for 2011, there was an upper limit to the amount of time people could usefully spend in studying for an exam, and you might wonder, for example, how long you would have had to study to make a perfect score.

Figure A.5: Relation Between Study Time and Score on a Biology Exam in 2011

Unfortunately, however, you cannot tell, because the graph has no labels of numbers or units the scales. Even though this graph has a descriptive and intriguing title, it is of no use to us at all without these very important parts. Obviously, before we can take full advantage of the information that the graph is trying to present, we need to have some additional details.

In Figure A.6 the additional information has been supplied, information that seems to make the graph more useful to us in preparing for the exam.

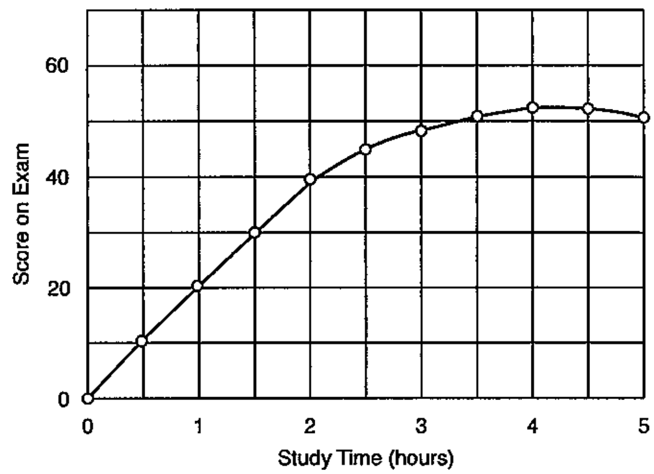


Figure A.6: Relation Between Study Time and Score on a Biology Exam in 2011

This additional information includes scales, or **axes**, that are carefully marked with numbers, and labels and units that are neatly presented. Obviously, one cannot label all the points along the axes; that would make the numbers crowd together and look sloppy. The units should be marked at intervals that correspond more or less to the intervals between the experimental points. The small marks, called **index marks**, can be drawn in if the experimental points are very widely spaced. Most elegantly, a **frame** is put around the whole graph, and index marks are placed all around. This makes it easy to lay a ruler across the graph when interpolating between the experimental points. The diagram in Figure A.7 summarizes some features of a good graph.

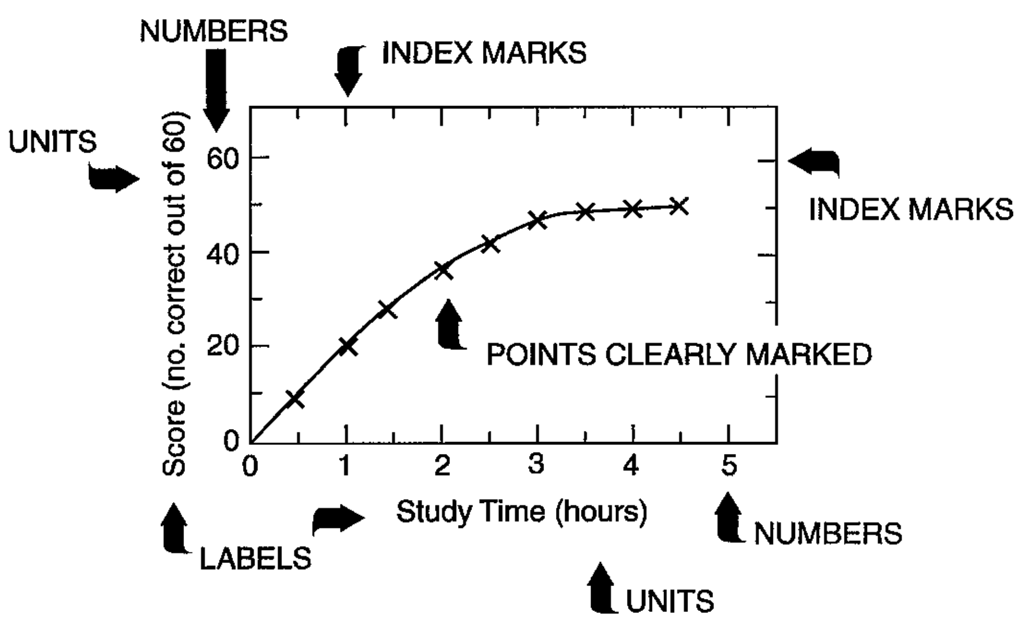
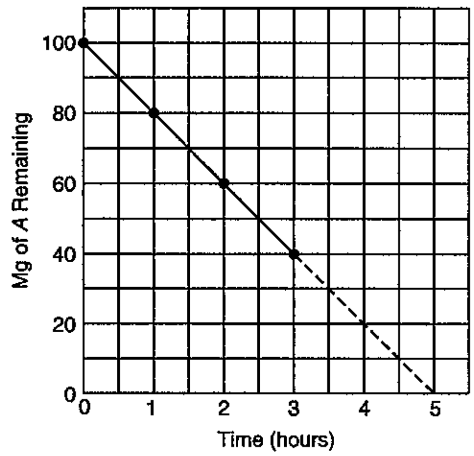


Figure A.7: Relation Between Study Time and Score on a Biology Exam in 2011

STEEPNESS OR SLOPE OF A LINE GRAPH

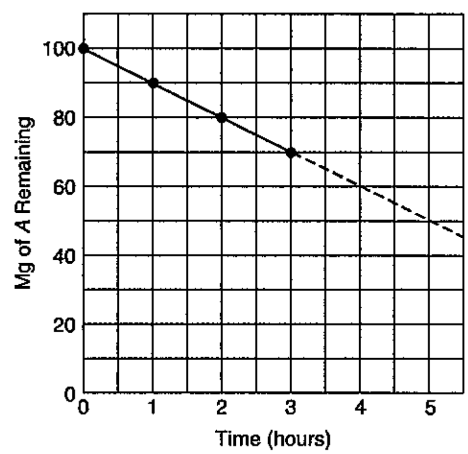
Look at the graph in Figure A.8 for the disappearance of *A* in a chemical reaction. Such a graph, in which the amount of some quantity is shown on the vertical scale, or **ordinate,** with time shown on the horizontal scale, or **abscissa,** is frequently called a "progress graph" or "progressive curve," because it shows how some process progresses in time. This graph may also be called a "time course" for the process because it shows the extent to which the process has occurred at different times.



Time Course of Disappearance of *A* in Process I

Figure A.8

Let us call the process represented by the graph "Process I" and consider another reaction, "Process II," in which *A* is also consumed. Suppose that we start Process II also with 100 mg of *A*, and that after 1, 2, and 3 hours there are 90, 80, and 70 mg, respectively, left. The progress curve for Process II is displayed in Figure A.9.

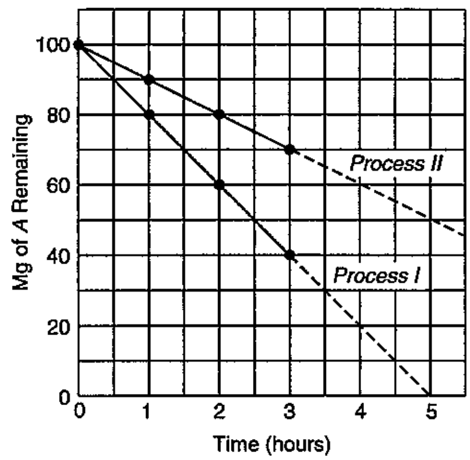


Time Course of Disappearance of *A* in Process II

Figure A.9

Now, suppose we want to compare the graphs for the two processes. Because they have exactly the same scales, we can put both lines on the same graph, as shown in Figure A.10. Notice, however, that now in addition to the labels on the scales, we need labels on the two lines to distinguish between the two processes.

Look at the 1-hour mark on the time scale of the graph. Opposite this put an X on the line for Process I and a Y on the line for Process II. Then, opposite X on the ordinate you should be able to see that 80 mg of *A* are left in Process I; opposite Y you can see that 90 mg of *A* are left in Process II. Apparently, Process I has used up 20 mg of *A* and Process II has used up only 10 mg in the same amount of time. Obviously, Process I is faster, and the line graph for Process I is steeper than the graph for Process II.



Time Course of Disappearance of *A* in Process I and II

Figure A.10

The rate for Process I is 20 mg A used/hr, while the rate for Process II is 10 mg *A* used/hr.

We have seen that a steeper line graph means a faster reaction when the progress curves for two reactions are plotted on the same scale. (Obviously, if the progress curves are plotted on different scales, we cannot compare the steepness of the line directly, but have to calculate what the slope would be if the two curves were plotted on the same scale.)

Suppose, now, that we make a new kind of graph, one that will show the steepness, or slope, of the progress curve. Because the **slope** of the progress curve is a measure of the speed of velocity, or **rate** of the reaction or process, such a graph is frequently called a "rate graph" or "rate curve." The diagram in Figure A.11 shows how a rate curve can be made for Process I.

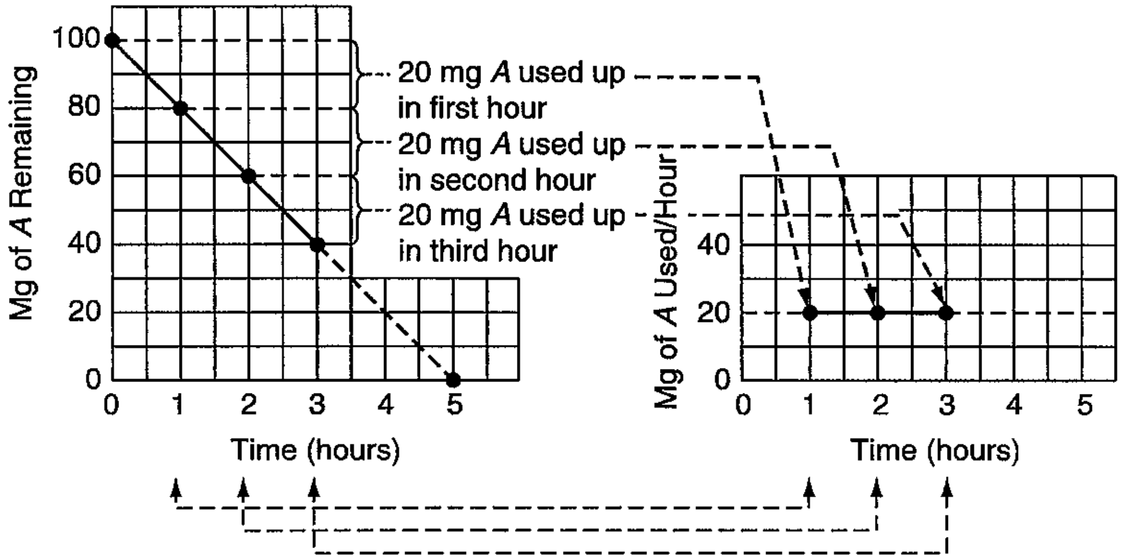


Figure A.11

Notice that the time scale of this rate graph is exactly like the time scale of the progress curve from which it was derived, but that the ordinate is different. The ordinate of the progress curve shows milligrams of *A* remaining; the ordinate of the rate curve shows milligrams of *A* used per hour. Obviously, a rate graph must always show rate on one of its scales, and it is ordinarily the vertical one that is used. This is because the rate of a reaction or process is what mathematicians call a **dependent variable.** Time is the **independent variable** in this experiment; it is independent of changes in the dependent variable (the rate of reaction), and it is the variable that is shown on the horizontal axis. Regardless of whether the process is the increase in height or weight of a plant, or the using up or producing of something in a reaction, the rate graph for the process must always show *amount of something per unit time* on one of its axes. One very common type of rate graph is the one shown in Figure A.11, with a rate on the ordinate and the time on the abscissa. Other kinds of rate graphs may have temperature or molarity on the abscissa. The rate of growth of a plant, for example, depends on how many factors that we might wish to vary, and so we can have as many different kinds of rate graphs for that process as there are independent variables.

Let us emphasize: a progress curve always shows amount of reaction on the vertical scale and time on the horizontal scale. The corresponding rate curve *may* show time or some other variable on the horizontal scale, but it *always* shows rate, or amount of reaction per unit time, on the vertical scale. This point is very important. When we look at a rate curve that has time on the horizontal scale, we must visualize the progress curve from which the rate curve was derived. When we look at a rate curve that has any other variable except time on the horizontal scale, we shall see that each point on the rate curve represents a separate progress curve.

In the same way as for Process I, a rate curve can be made for Process II. Plotted on the same graph, the two should look something like the diagram in Figure A.12.

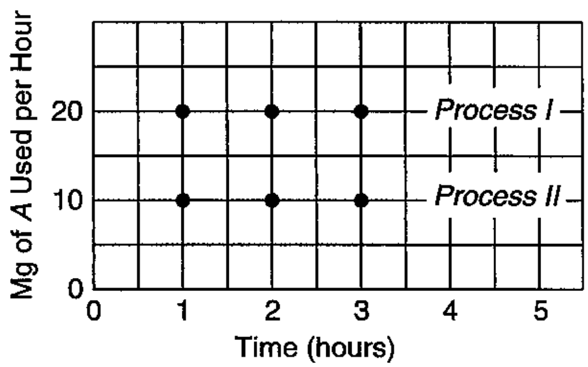


Figure A.12

There are two things to notice in this example. First, the curve for Process I lies higher than that for Process II. This is in accord with the facts as we have seen them, namely, that Process I is faster and so has a greater slope or higher value for the steepness. Second, notice that both curves are perfectly flat. Naturally, because the progress curves for the two processes were both perfectly straight lines, having everywhere the *same* slope, the rate of steepness graph must show exactly the same thing, that is, that the rate or steepness is everywhere the same.

On the other hand, consider the graph in Figure A.13, which represents the disappearance of *A* in yet another reaction, Process III.

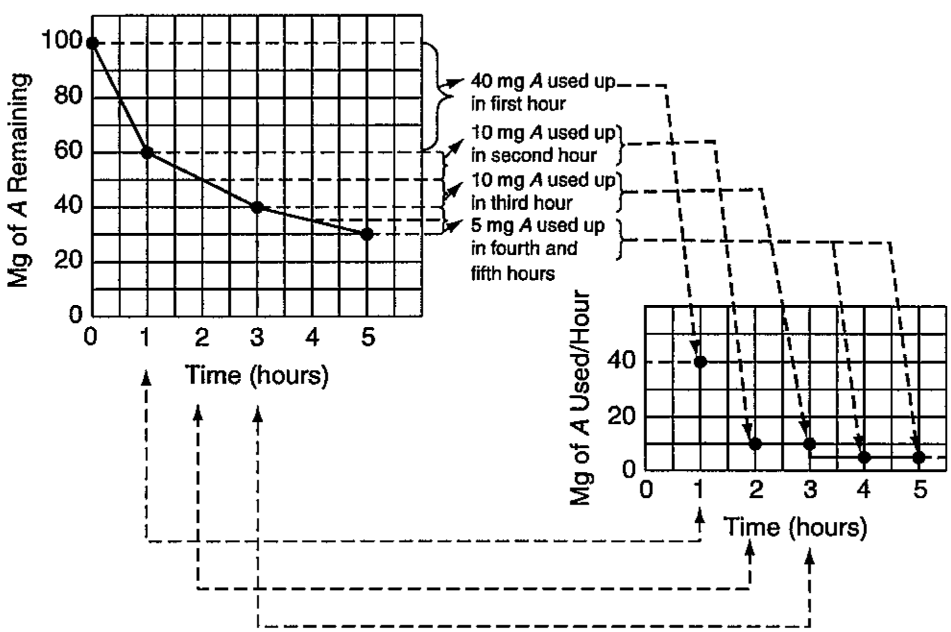


Figure A.13: Time Course of Disappearance of *A* in Process III

You can see that Process III differs from Processes I and II in that the progress curve for III is not a perfectly straight line. It is steepest at the beginning, becomes less steep after 1 hour, and again after 3 hours. Obviously, because the rate of the process is changing with time, the corresponding rate curve will not be perfectly flat. The rate has to start out high, then drop at 1 hour and at 3 hours, and you can see in the graph on the right that this is exactly what it does. In fact, the rate curve looks like steps because whenever the slope of the progress curve decreases, the rate curve must show a drop to a lower value. Conversely, if the progress curve for a process should get steeper, as sometimes happens (the reaction goes faster after it gets "warmed up"), the rate curve must show a corresponding increase to a higher value.

Until now we have been able to read the steepness, or slope, of the progress curve directly from the scales of the graph because the progress curves we have been studying were either perfectly straight lines or else made up of straight-line segments. In most real situations, however, we cannot do this because the slope of the progress curve does not change sharply at a given time, but, gradually, over a period of time. You probably remember how to measure the slope of a curved line, but let us review the process anyway. (See Figure A.14.)

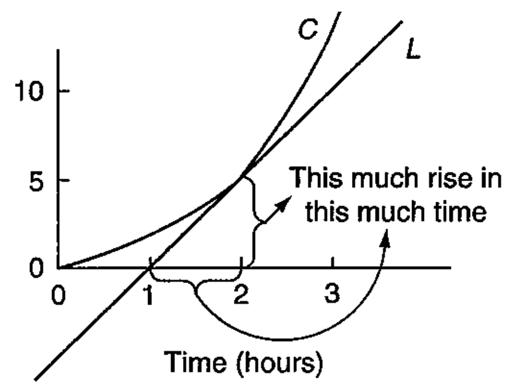
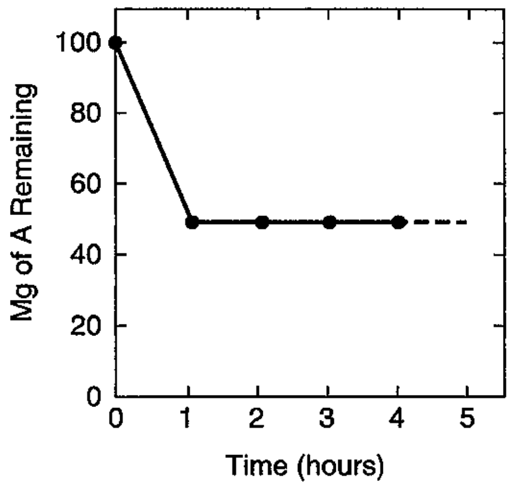


Figure A.14

Suppose we want to measure the slope, or steepness, of the curved line *C* at time 2 hours. We can see that the curve rises 5 units total in the 2 hours, so that the average slope is 2.5 units per hour. However, it is easy to see from the graph that this average is very misleading; the progress curve is almost flat at the beginning (i.e., has 0 slope) and then accelerates rapidly, so that the line curves upward. If we want to find the true slope at 2 hours, we must draw line *L* in such a way that *L* has the same slope as *C* at the 2-hour point. Then we can see that L rises about 5 units between 1 and 2 hours, just twice the average slope for the first 2 hours.

We have seen that a perfectly flat curve, like that for Process I or II, means that the corresponding progress curve is a perfectly straight line having the same slope at all points. Conversely, a progress curve that changes in slope, like that of Process III, will give a rate curve that looks like steps. You should be able to figure out that the "steps" on the rate curve will be sharp and square if the progress curve has an abrupt change in slope, and more rounded off if the progress curve changes slope gradually. In any case, in regions where the rate curve is perfectly flat it is clear that the progress curve must have constant steepness, or slope. However, if the progress curve itself gets perfectly flat, then that portion of the progress curve has 0 slope; in other words, the reaction has stopped. This kind of situation is pictured in Figure A.15 where the rate and progress curves for another reaction, call it Process IV, are shown.



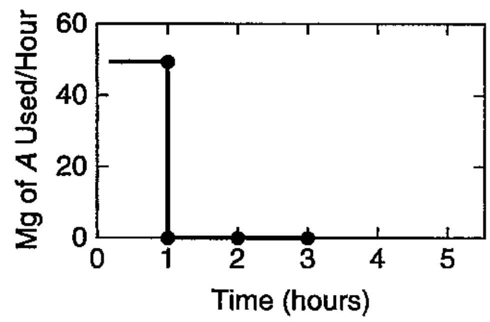
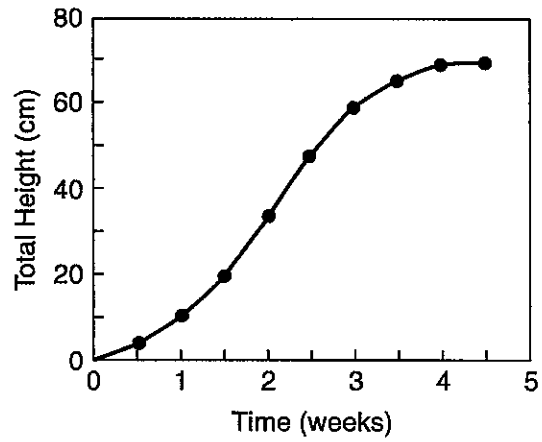


Figure A.15

In the progress curve on the left, we can see that after the first hour the reaction stopped. From the graph we can see that after 1 hour there were 50 mg of *A* remaining; after 2 hours there were still 50 mg remaining; and there are still 50 mg remaining even at 4 hours. Obviously, Process IV stopped when one-half of *A* had been used up. Now look at the rate curve on the right. It is perfectly flat for the first hour because the slope of the progress curve was constant during that time. After the first hour the rate curve is also perfectly flat but it has dropped down to 0, indicating that although the progress curve has constant slope, the slope is actually 0. Obviously, flatness in a rate curve and flatness in a progress curve mean different things. Flatness in the progress curve for a reaction means that the reaction has stopped; flatness in the rate curve means that the reaction is going on at a constant rate. You can see, then, that we have to be able to glance at a graph and tell whether it is a rate curve or a progress curve in order to be able to interpret what the shape of the curve is trying to tell us.

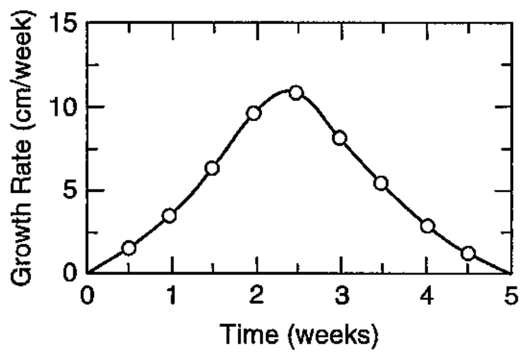
Now let us take one more example of this kind of rate curve. The graph in Figure A.16 shows the progress in the growth of a pea plant. First, we can see that the slope is not the same everywhere. In fact, there is an interval where the slope increases very gradually from 0. By 1 week or so the slope has reached its maximum value and is steady until about 3 weeks. Thereafter, the slope begins to decrease again, as the curve bends over, and eventually, at about 4.5 weeks, as the curve gets perfectly flat, the slope, or steepness, tends to be 0 again.



Progress Curve for the
Growth of a Pea Plant

Figure A.16

Suppose, now, that we try to imagine what the rate curve for the growth of this pea plant will look like. If you read through the preceding paragraph, you will have a rough description of it. In fact, it will look like the graph in Figure A.17.



Growth Rate of a Pea Plant

Figure A.17

Notice from the two graphs that where the steepness of the progress curve gets larger, the corresponding rate curve turns upward. Similarly, when the slope of the progress curve decreases again, the rate curve turns downward. A rate curve that is turning up means, therefore, that the process is speeding up; a flat rate curve means that the process is going at a constant rate; and a rate curve that is turning down means that the process is slowing down. When the rate curve hits the x-axis, it means that the reaction has stopped.

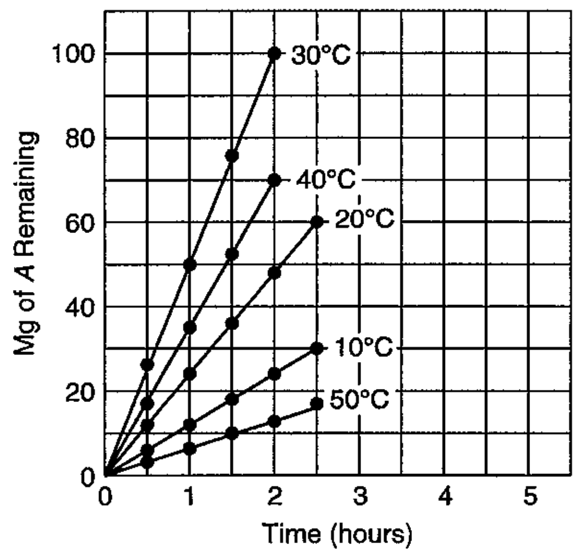
Probably 80 percent of the graphs you will encounter in biology are either rate curves or progress curves. You will have noticed from the preceding discussion that biologists tend to use the words "graph" and "curve" interchangeably. Technically, of course, the entire picture, including the abscissa, ordinate, labels, numbers, units, index marks, and title, together with the line graph portrayed, is the "graph," while the line graph itself is called the "curve." You will notice, too, that biologists call a line graph a "curve," even though the line itself may be perfectly straight.

To summarize, remember that a progress curve is made from measurements at different times during the progress of a reaction that is continuous with time. A graph that shows how much or to what extent a reaction has occurred at different times is a progress or time-course curve. In contrast, a rate curve is a picture of the steepness of one or more progress curves, and any graph that has rate on one of its scales is a rate curve.

So far we have been considering only rate graphs that have time on the abscissa; we could call these **time-rate** curves. As we have seen, a time-rate curve can be made from any progress curve. Next, we are going to consider rate curves that do not have time as the abscissa. As you shall see, such curves are made by combining data from several progress curves, each representing the time course of the reaction under a different set of conditions.

OTHER KINDS OF RATE GRAPHS

Let us look at and try to analyze the graph in Figure A.18. Obviously, it is a progress curve because it shows an amount of something on the ordinate and time on the abscissa. There are several different curves all plotted on the same graph, and each is labeled with a different temperature. The title indicates that this graph is trying to tell us how Process I behaves at different temperatures.



Temperature Dependence of Process I

Figure A.18

Before we try to construct the rate curve for this graph, we should try to imagine how this experiment was carried out. It seems clear that the experiment must have started with several different batches of *A* and that each reaction mixture was kept at a different temperature. Then, every half-hour, the amount of *A* remaining was measured and the amount consumed was calculated. The results might have been plotted in five separate progress curves, as shown in Figure A.19.

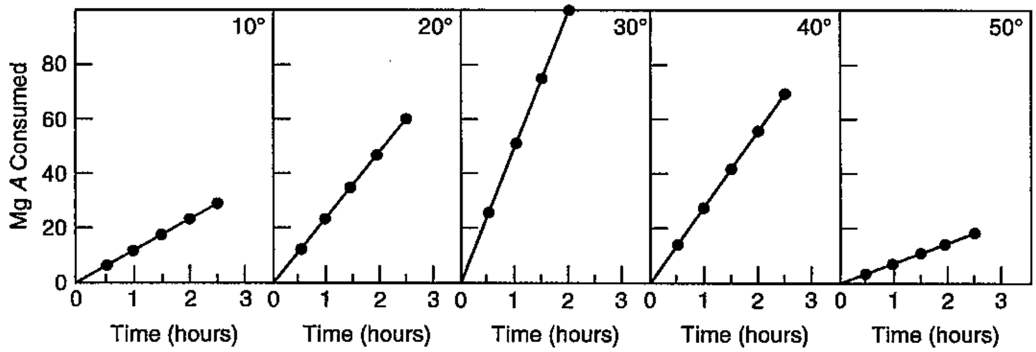


Figure A.19

When all these progress curves are plotted on the same graph, as was done in Figure A.18, we have what is called a "family" of curves. If we look at the slopes of the various members of the family of curves for Process I, we see that the steepest slope does not correspond to the highest temperature. In fact, the curve for 30° is the steepest, whereas the curve for 50° is the least steep; the curve for 10°, the lowest temperature, has an intermediate slope. By analyzing and comparing the slopes of the family of curves in this way we can get a reasonably good notion of the effect of temperature on Process I, but this effect could be shown much more clearly in a rate graph that has temperature as the abscissa. Such a graph would show us at a glance how the rate varies with temperature and, of course, would be preferable, as the whole point in making a graph is to present information simply and clearly. The diagram in Figure A.20 shows how a **rate-temperature** graph would be constructed from this family of curves for Process I.

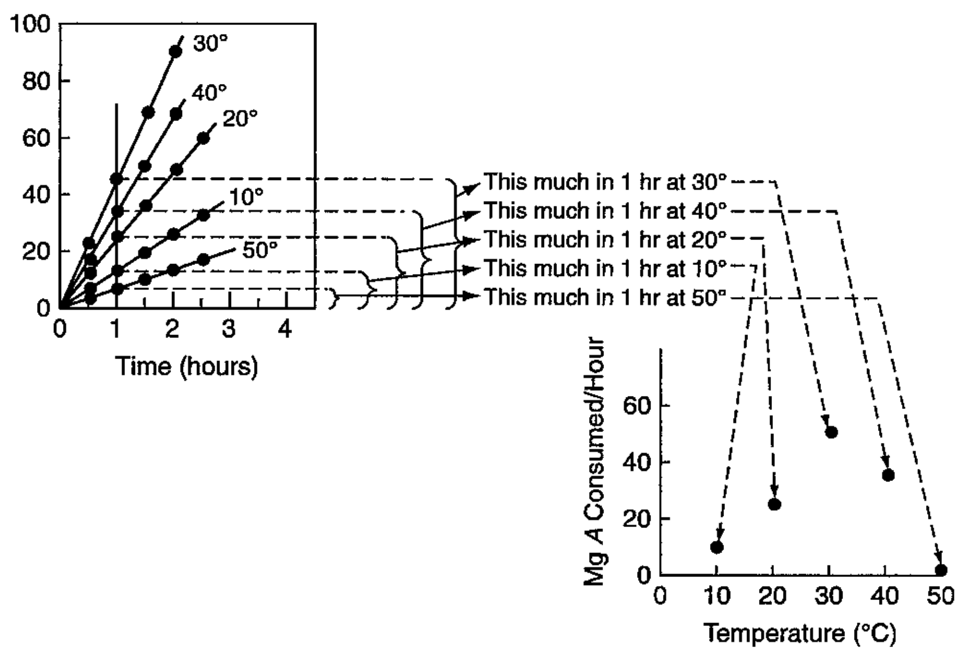


Figure A.20

Having found, as shown in Figure A.20, the five points for our rate graph, we are faced with the question of whether or not it is legitimate to connect these points with a smooth line. We recognize, of course, that both temperature and rate are continuous processes. Between any two given temperatures or rates there are an infinite number of temperatures or rates. The question here, however, is the following: If we do draw a smooth line through our five points, will that line pass through the infinite number of other rates that we could have measured if we had chosen some other temperature? Let us go ahead and draw the line, as shown in Figure A.21

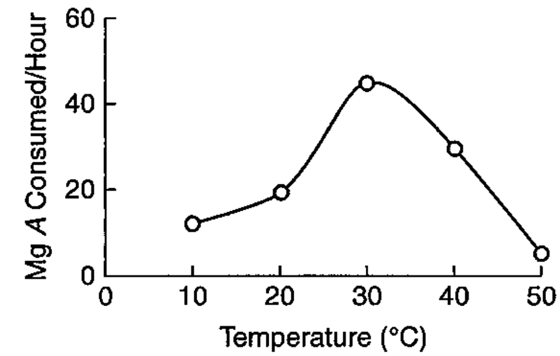


Figure A.21

As we have drawn it, the curve indicates that the rate at 29° and at 31° would be slightly lower than at 30°, and this may not be true. In order to determine the true shape of the curve in the region of the maximum rate we would have to make progress curves at smaller temperature intervals, say, every two degrees. However, it is extremely unlikely that the true shape of the curve is anything like the two possibilities shown on the diagrams in Figure A.22. All our experience tells us that if a reaction depends on temperature, then that dependence will be a smooth curve, without sharp bends. In fact, if in an experiment we should observe behavior of the type shown in Figure A.22, we would immediately begin to suspect that something is wrong with our thermostat! Thus, although it may be that the shape of the rate-temperature curve for Process I is somewhat different from the way we drew it in Figure A.21, we can be reasonably certain that it is not radically different.

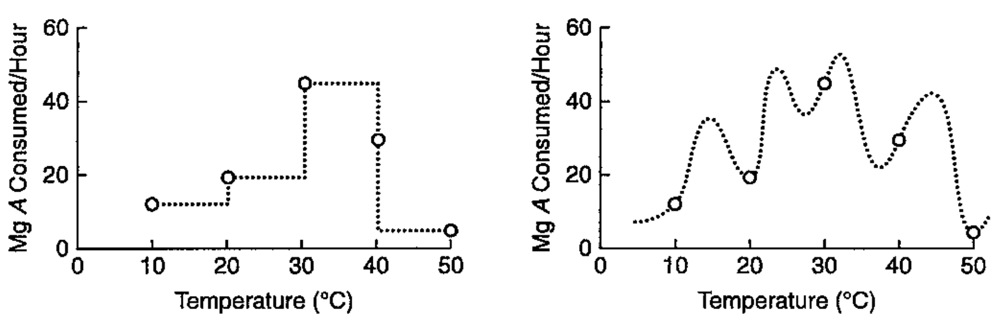


Figure A.22

In addition, we may also tend to be suspicious of a graph if we see a sharp peak, unless the experimental points were taken very close together. For example, common sense would tell us to be careful about accepting the rate curve shown in Figure A.23.

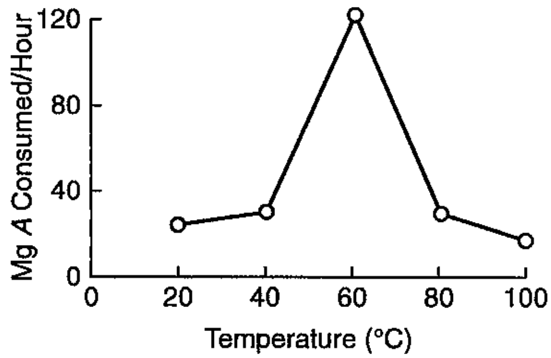


Figure A.23

Obviously, most of the shape is given to the profile by the one measurement at 60°. In biology, as in everything else, mistakes can be made, so the experimenter would have to check the validity of that measurement very carefully. The easiest way to do that would be to make more measurements slightly above and slightly below 60° to see whether these would fall on the line the experimenter has drawn. Alternatively, the experimenter could play it safe and draw only a bar graph for these spaced temperatures. Another useful dodge would be to connect the points with a smooth but broken line rather than a continuous line. As always, the broken line would suggest the tentative and provisional nature of the curve as drawn.