TT TEXTBOOK TESTBANKS

Solutions Manual for Campbell Biology 12th Urry

SOLUTIONS MANUAL SAMPLE PREVIEW

PUBLISHER
Pearson

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2021

RESOURCE TYPE
Solutions Manual

ISBN
9780135858141

Answers for Instructors
Campbell BIOLOGY, Twelfth Edition

by Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, and Rebecca B. Orr

Appendix A of the book includes answers for students for Figure Questions, Concept Check Questions, Summary of Key Concepts Questions, end-of-chapter multiple-choice questions, and Draw It Questions. This document for instructors includes suggested answers and teaching tips for the Scientific Skills Exercises and suggested answers for the Problem-Solving Exercises, Interpret the Data Questions, and the short-answer essay questions at the end of each chapter.

The Scientific Skills Exercises, Problem-Solving Exercises, Interpret the Data Questions, and additional questions for the Visualizing Figures can be assigned in Mastering Biology, where they are graded automatically.

Tips for Grading Short-Answer Essays

The ability to communicate clearly in writing is essential for almost any profession your students choose to pursue. As instructors, it is often frustrating to be faced with a large class full of students who have had inadequate preparation in writing skills, knowing that you don't have the resources to help your students develop these skills.

The **Write About a Theme** questions at the end of each chapter are an attempt on the part of the authors to partner with you in this endeavor. At the end of each chapter, we ask the student to write a short essay of 100-150 words that relates the material they learned in the chapter to one of the themes introduced in Chapter 1 and featured throughout the book. The **Write About a Theme** questions can be used as in-class or outside-of-class assignments.

For ease of grading, sample key points and sample top-scoring answers for the **Write About a Theme** questions are provided for instructors and TAs in this document. The list of key points provides a guide to the ideas that students should include in their essays. In addition, suggested answers to all of the end-of-chapter essay questions can be found in this document.

The time necessary to grade writing exercises has prohibited many instructors from assigning them. Using a grading rubric, however, can streamline the process. Some instructors have found they can train TAs or even students to grade short essays accurately. (Students can grade their own essays or those of their classmates.) A suggested grading rubric for the **Write About a Theme** essays is shown at the end of these tips and in the Study Area of Mastering Biology. This rubric can also be modified to use with the other end-of-chapter essay questions.

The simplest way to use the rubric is to read through each essay and determine how well the writer has accomplished the four aims listed at the top of the columns. The essay can then be graded as a 4, 3, 2, 1, or 0 based on the overall quality of the essay. Alternatively, you could assign 0 to 4 points for *each* of the aims, and then total the points out of 16 possible points.

You can also weight one of the aims more highly. For example, if you want to focus primarily on writing skills (aim #4: Quality of Writing) with the other aims weighted equally, the score for each aim can be multiplied by a "weighting factor." Aim #4 could be assigned 40% of the total points, with aims # 1, 2, and 3 each worth 20%. The score (out of 4) obtained for aim #4

is multiplied by 40, and each of the others multiplied by 20, giving a total of 400 points (160 + 80 + 80 + 80 = 400).

To train TAs to grade essays in a large class, the instructor should first read through some of the essays, looking for a representative example of each of the five scores (4, 3, 2, 1, and 0 for the simplest grading scheme described above). Copies of the five representative essays (with scores hidden) can be passed out to TAs, asking them to grade the essays based on the rubric and a 0-4 grading scheme. Subsequent discussion with the TAs about their essay rankings should clarify the standards, after which they can be given a few "test" essays to grade to ensure consistency in grading practices. This training exercise should take no more than 30-45 minutes. Using a similar rubric and training scheme, the Montgomery County Public School System in Maryland has been able to train a team of instructors to grade thousands of short essays consistently in a relatively short time.

There is also a web-based program called Calibrated Peer Review (CPR) (developed at UCLA with funding from the National Science Foundation and the Howard Hughes Medical Institute) that trains students to evaluate their own work or that of their classmates ("peers"). The program is described at **http://cpr.molsci.ucla.edu/**.

When assigning essays, the instructor should point out the rubric to students (in the Study Area of Mastering Biology) or provide a customized rubric to students. Students can then refer to the rubric before writing to see what is expected of them. They can also check their essay before submitting it to make sure they have met all the criteria in the rubric. Instructors should also encourage students to read the Writing Tips provided under "Additional Resources / Writing Tips and Rubric" in the Study Area of Mastering Biology, which also includes the suggested grading rubric.

Suggested Grading Rubric for "Write About a Theme" Short-Answer Essays				
	Understanding of Theme and Relationship to Topic	**Use of Supporting Examples or Details**	**Appropriate Use of Terminology**	**Quality of Writing**
4	Evidence of full and complete understanding	Examples well chosen, details accurate and applied to theme	Accurate scientific terminology enhances the essay	Excellent organization, sentence structure, and grammar
3	Evidence of good understanding	Examples or details are generally well applied to theme	Terminology is correctly used	Good sentence flow, sentence structure, and grammar
2	Evidence of a basic understanding	Supporting examples and details are adequate	Terminology used is not totally accurate or appropriate	Some organizational and grammatical problems
1	Evidence of limited understanding	Examples and details are minimal	Appropriate terminology is not present	Poorly organized; grammatical and spelling errors detract from essay
0	Essay shows no understanding of theme	Examples lacking or incorrect	Terminology lacking or incorrect	Essay is very poorly written

Suggested Answers and Teaching Tips

CHAPTER 1 EVOLUTION, THE THEMES OF BIOLOGY, AND SCIENTIFIC INQUIRY

Scientific Skills Exercise

Teaching objective: Students build scientific skills by interpreting data in a pair of bar graphs and relating the data to the biological system it came from.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

If this is the first exercise the students are doing related to interpreting graphs, then you will need to spend time reviewing independent and dependent variables. If the students are confused by having two independent variables on one graph, have them cover one set of data while they look at the other (for example, cover the "full moon" portion of graph A while analyzing the "no moon" portion of it).

In these graphs, there are no statistical significance values given for comparisons between treatments. In the original paper, there was a statistical difference between predation levels of light brown versus dark brown mice in light-colored soil enclosures with no moon and in dark-colored soil enclosures under a full moon. The other two combinations, light-colored soil under a full moon and dark-colored soil with no moon, had no statistically significant difference between light and dark mice.

Answers:

1. (a) The independent variables for each graph are the coat color of the mice (light or dark brown) and the presence or absence of moonlight (full moon or no moon). These are on the *x*-axis. Taking both graphs together, a third independent variable is the color of soil in the enclosure. **(b)** The dependent variable is the amount of predation, measured as the number of mice caught. The dependent variable is on the *y*-axis of the two graphs.

2. (a) About 19. **(b)** About 12. **(c)** Based on the data, the mouse would be more likely to escape on dark soil. This might be because in the moonlight, a dark mouse on light soil would be more noticeable than one on dark soil.

3. (a) Under a full moon (12 were caught vs. 20 under no moon). **(b)** Under no moon (11 were caught vs. 18 under a full moon).

4. (a) Dark soil field with a full moon. **(b)** Light soil with no moon.

5. (a) No moon plus dark brown coat had the highest predation level in the light soil enclosure (38 mice were caught). **(b)** Full moon plus light brown coat had the highest predation level in the dark soil enclosure.

6. Being on the contrasting soil is most deadly for both colors of mice.

7. The total number of mice caught on moonlit nights was about 77, while the total caught on nights without moonlight was about 95. This suggests that owls hunting on moonlit nights are slightly less successful than are owls hunting on nights without moonlight.

Interpret the Data

Figure 1.25 In the beach habitat, approximately 27 light models and 73 dark models were attacked. In the inland habitat, approximately 76 light models and 24 dark models were attacked. Yes, mouse models with camouflage coloration were preyed on *less* often than non-camouflaged mouse models. In both habitats, the models whose pattern did not match their surroundings suffered much higher "predation" than did the camouflaged models. The results are consistent with the researchers' prediction: that mouse models with camouflage coloration would be preyed on less often than non-camouflaged mouse models. Thus, the experiment supports the camouflage hypothesis.

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and a suggested rubric at the beginning of this document.

9. Evolution Connection
Common ancestry explains this observation. The thousand-some-odd genes shared by humans and prokaryotes originated in early prokaryotes. They have been retained, with some modification, over the billions of years of eukaryotic evolution. These genes no doubt code for proteins and RNAs whose functions are essential for survival—for example, the genes that code for ribosomal RNA, which is important for protein synthesis in both prokaryotes and eukaryotes.

10. Scientific Inquiry
Many legitimate hypotheses could be proposed to extend the investigation. Here is one example. If the camouflage color has arisen through the processes of natural selection due to visual predators, then you might wonder what would happen if a population of beach mice lived in an area where predators were absent. It might be possible to do a long-term study in an area where you excluded predators. Mice have fairly short generation times, so if predation is "naturally selecting" lighter colored mice, then in the absence of predation you might predict the fur color would not remain predominantly light in such an experimental population.

11. Scientific Inquiry
Students are asked to use a PubMed search to identify an abstract of an article authored or co-authored by Hopi Hoekstra from 2017 forward. The range of abstracts from which students might choose will grow as the Hoekstra Lab generates additional publications.

12. Write About a Theme: Evolution

Sample key points:

- Darwin used reasoning based on observations to develop his theory of natural selection as a mechanism for evolution.
- His observations included:
  - Heritable variations exist in each population.
  - A population has more individuals than can be supported by the environment.
  - Each species seems suited for its particular environment.
- He proposed that the best-adapted individuals in a population would outcompete others for resources and disproportionately survive and produce more offspring, leading to an increase in the adaptations seen in the population.

Sample top-scoring answer:

Based on many observations of different species, Darwin proposed his theory that evolution by means of natural selection accounts for both the unity and diversity of life on Earth. He noticed that variations existed among the individuals in a population and that these variations seemed to be heritable. He also saw that populations could grow larger than could be supported by the resources around them. Finally, he observed that species (like the different species of finches) seemed to suit their environment. He proposed that the best-suited individuals in a population would survive and reproduce more successfully that those less adapted to their environment, and he called this "natural selection." In Darwin's view, this mechanism could account for both the unity and diversity of features among species. The descent of organisms from a common ancestor explains similar features, while the force of natural selection in different environments accounts for differences between organisms.

13. Synthesize Your Knowledge

It's difficult to pick out this gecko against the background of the tree trunk, because the gecko itself looks like mossy bark. This coloration likely makes it harder for the gecko to be seen by predators, thus enhancing its survival. This cryptic coloration pattern probably evolved over generations. The members of a gecko population that more closely resembled their background would have been less visible to predators, thus more likely to survive, reproduce, and leave offspring. The offspring would inherit the genes that generated the mossy bark coloration, and the offspring that blended in better would survive better and reproduce more successfully. Over generations, the coloration would become a closer and closer match to the tree bark. (The mossy leaf-tailed gecko is endemic to Madagascar, meaning it is found only there and nowhere else in the world. Many endemic species live in Madagascar. This is because it is an island with land features and climatic factors that have allowed evolution of many species in isolation.)

CHAPTER 2 THE CHEMICAL CONTEXT OF LIFE

Scientific Skills Exercise

Teaching objective: Students will apply the principle of radioactive isotope half-life to calibrate a graph of carbon-14 decay with time and estimate the age of a fossil.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

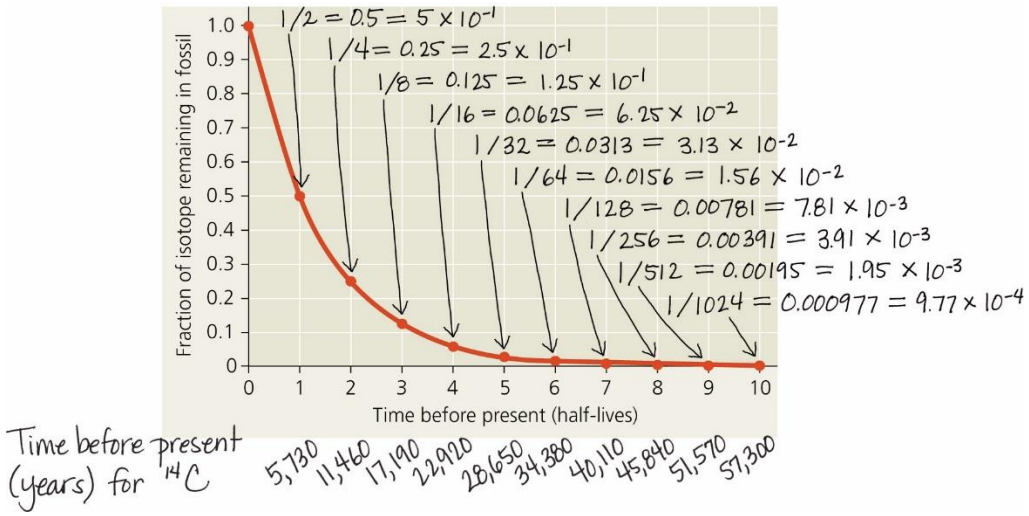
The fact that elements can be converted into different forms, like carbon and nitrogen, may go against student preconceptions about the immutability of the periodic table and the definition of an "element." It takes a high-energy source to create an isotope from a stable atom, but the decay of an unstable (radioactive) atom happens spontaneously. Helpful website activities are found at http://www.sciencecourseware.org/VirtualDating/.

The graph in this exercise uses fractions of the original ^{14}C on the *y*-axis, providing an opportunity for students to practice converting between fractions and decimals. You can also use this exercise to have them practice converting decimals to scientific notation.

The longest-lived radioactive isotope is tellurium-128 with a half-life of $2.2 \pm 0.3 \times 10^{24}$ years, and the shortest is hydrogen-7 with a half-life of 23×10^{-24} seconds. Uranium-238 (half-life 4.5 billion years) and uranium-235 (half-life 704 million years) are commonly used for dating very old fossils and rocks. Uranium isn't typically incorporated into living tissue but often enters dead material during the fossilization process. When direct dating of fossils isn't possible, archeologists date mineral materials found around the fossils with the assumption that they have been together since the animal died.

Answers:

1. and **2.**



3. (a) 7 half-lives have passed. **(b)** 40,000 years. **(c)** 40,000 years ago. **(d)** Neanderthals and modern humans may have overlapped for just a few thousand years or less, or perhaps did not overlap at all. Given the probable close timing of the extinction of the Neanderthals and the influx of modern humans, perhaps Neanderthals became extinct because of the presence of modern humans.

4. (a) No, ^{14}C decay cannot be used to date fossils that old because dead organisms cannot take up new ^{14}C, and the pool of ^{14}C present in the bones when the dinosaurs died will be completely decayed (for all practical purposes) by present time. **(b)** Uranium-235 can be used because only

about one-tenth of its half-life would pass in 65.5 million years, leaving a large fraction of the decaying atoms present in the fossils to be counted.

Interpret the Data

Table 2.1 As you probably know, the human body is made up in large part of water, H_2O. The atoms of oxygen in water, one per water molecule, likely account for the high percentage of oxygen (65%) found in the human body.

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and the suggested rubric at the beginning of this document.

10. Evolution Connection
It would be surprising if the percentages of naturally occurring elements in most organisms were *not* roughly the same, because all organisms evolved on Earth (with its unique elemental composition) and all are genetically related to one another. (Species living under unusual conditions might differ more than others, though.) Further, we might predict that the more similar the percentages of naturally occurring elements are in two species, the more closely related those two species are.

11. Scientific Inquiry
The complex shapes of biological molecules determine the great specificity with which they interact with one another and form weak or strong bonds.

Hypothesis: Receptor cells on the filaments of the male luna moth's antennae contain cell-surface molecules that are complementary in shape to sex attractant molecules (pheromones) produced by the female luna moth.

This hypothesis leads to several testable predictions. (1) Luna moth pheromones will bind to specific sites on the cells of the filaments of the male's antennae. (2) If it is possible to synthesize molecules that are very similar in shape to luna moth pheromones, these molecules will also attract male luna moths. (3) Chemical or temperature treatments that modify the molecular shape of luna moth pheromones will reduce the attractiveness of these molecules to male luna moths.

An experiment could be designed to test the third prediction. A number of male luna moths could be exposed to two separate treatments. In the first treatment, unaltered pheromones would be released near male luna moths, and the response of the moths would be noted. The second treatment would be identical in every way except that the pheromone would be treated in some way (for example, with heat; you'll read about this more in Chapter 5) to modify its molecular shape before it was released.

12. Write About a Theme: Organization
Sample key points:

- The chemical reactivity of an atom depends on the number of valence electrons.
- The properties of a compound emerge from the bonding of its atoms.

- Molecules have distinctive sizes, shapes, and charge distributions that determine their properties.
- Wastes may contain harmful compounds consisting of different arrangements of the same atoms found in safe compounds.

Sample top-scoring answer:
Industrial or agricultural wastes may contaminate the environment because of the compounds they contain. The atoms of each element have a characteristic number of electrons arranged in electron shells. The number of valence electrons determines what types of bonds or ions the atoms may form, so the chemical reactivity of an atom arises from its electron distribution. The properties of compounds emerge from the arrangement of their constituent atoms and of the bonds between them. Thus, a wide variety of molecules with very different chemical properties can be made from the same basic atoms. Each molecule has a distinctive size, shape, and charge distribution, which determine its highly specific ability to interact with other molecules. Although their constituent atoms may be the same as those in environmentally safe molecules, compounds in chemical wastes may contaminate the environment if their atoms are combined in new arrangements that harm living organisms.

13. Synthesize Your Knowledge
The two chemicals are harmless when stored separately, and so the bombardier beetle is not injured when the reactants are kept apart. When the beetle is threatened, structures in its body allow the two chemicals to combine in a way that protects its internal organs. (In fact, the beetle has a specialized "mixing chamber" that protects its internal organs.) The resulting chemical reaction causes a small explosion and produces irritating chemicals. (The reaction actually produces intense heat and an audible pop!)

CHAPTER 3 WATER AND LIFE

Scientific Skills Exercise

Teaching objective: This exercise is designed to give students practice in figuring out what is shown on a graph, how to describe the major trend(s) in the data, and extracting values from the graph to calculate related information. The student is then led back to the biological context of the data to draw a conclusion.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

Most students can look at a graph and describe the slope of the data line. However, many struggle with writing out what the trend means in terms of the relationship between what was reported on one axis relative to the other axis. Thus, while a student may respond that the data line has a positive slope, they may also respond that a higher calcification rate results in a higher carbonate ion concentration. Helping them sort out dependent and independent variables in this simple experiment should clear up some misunderstandings. Students will benefit from drawing a mock-up of 1 square meter of the reef, with dots in the water to represent carbonate ions and arrows to indicate calcification.

In this example, students will need to make the additional mental step of reading the trend line right to left, instead of left to right (the natural tendency), to reach a conclusion about the effect of *decreased* carbonate ion concentration on calcification rate and reef growth.

Answers:

1. (a) The *x*-axis shows the concentration of carbonate ions in units of micromoles (µmol) of carbonate ions per kilogram of seawater. **(b)** The *y*-axis shows the calcification rate in units of millimoles of calcium carbonate accumulated per square meter of reef per day. **(c)** Carbonate ion concentration is the independent variable in this experiment. **(d)** Calcification rate is the dependent variable.

2. The data show that the rate of calcification is positively related to the concentration of carbonate ions in the seawater. As the concentration of carbonate ions increases, the rate of calcification increases.

3. (a) If the seawater carbonate ion concentration was 270 µmol/kg, the calcification rate would be approximately 19 mmol $CaCO_3/m^2 \cdot$day. It would take 1 square meter of reef approximately 1.6 days to accumulate 30 mmol of $CaCO_3$ [(30 mmol of $CaCO_3/m^2$) / (19 mmol $CaCO_3/m^2 \cdot$day) = 1.6 days]. **(b)** If the seawater carbonate ion concentration was 250 µmol/kg, the calcification rate would be approximately 12 mmol $CaCO_3/m^2 \cdot$day. It would take 1 square meter of reef 2.5 days to accumulate 30 mmol of $CaCO_3$ [(30 mmol of $CaCO_3/m^2$) / (12 mmol $CaCO_3/m^2 \cdot$day) = 2.5 days]. **(c)** If carbonate ion concentration decreases, the rate of calcification decreases, and it takes coral longer to grow.

4. (a) The final step of the process shown in Figure 3.12, the rate of conversion of CO_3^{2-} and Ca^{2+} into $CaCO_3$, is measured in this experiment. **(b)** The results are consistent with the hypothesis that increased concentration of atmospheric CO_2 could lead to slower growth of coral reefs. According to the chemical reactions shown in Figure 3.11, more CO_2 entering the ocean will push the reactions toward formation of more bicarbonate ions, decreasing the amount of CO_3^{2-} available for formation of $CaCO_3$. Consistent with the reactions in the figure, the data displayed in the graph show that, under the experimental conditions, the lower the concentration of CO_3^{2-}, the lower the rate of calcification, and thus the slower the growth of coral reefs (for example, 2.5 days versus 1.6 days to accumulate the same amount of calcium carbonate at a lower carbonate ion concentration, calculated in question 3).

Interpret the Data

Figure 3.5 The inland temperatures (100°F, 96°F, 106°F) are much higher than those along the coast (73°F, 75°F, 72°F) because oceans are large bodies of water that can absorb or release heat, moderating the climate nearer the coast.

Concept Check 3.2 #5 A liter of blood would contain 7.8×10^{13} molecules of ghrelin (1.3×10^{-10} moles per liter $\times$ 6.02×10^{23} molecules per mole).

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and the suggested rubric at the beginning of this document.

9. Evolution Connection

These extreme environments may be similar to those found on other planets. The fact that life probably evolved and continues to flourish in such extreme environments here on Earth suggests that some form of life may have evolved on other planets. Astrobiologists would want to study these extreme habitats and the adaptations to such challenging conditions that have evolved in extremophiles. In addition to seeking evidence for the past or current presence of water on Mars or other celestial bodies, scientists now know to search in environments that previously would have been thought incapable of supporting life.

10. Scientific Inquiry

Hypothesis: The growth rate of the freshwater plant *Elodea* declines as water pH declines from 7 (neutral) to 3 (fairly acidic). (The low pH can be any acidic pH number.)

Experiment: Set up a number of water baths for each pH value. The water baths vary only in pH. All other relevant variables (such as temperature, light intensity and wavelength, and nutrient availability) are identical in each water bath. The same mass of *Elodea* is added to each water bath at the beginning of the experiment. The mass of *Elodea* in each water bath is measured weekly. At the end of the experiment, the average growth rate of *Elodea* is calculated for each pH treatment, and growth rates at different pH values are compared.

11. Write About a Theme: Organization

Sample key points:

- Water's versatility as a solvent arises from the polar covalent bonds of water molecules.
- Water molecules form hydrogen bonds with atoms that are part of polar covalent bonds in other molecules.
- The partially charged regions of water molecules are attracted to oppositely charged ions.

Sample top-scoring answer:

Water is the solvent of life, a function emerging from the polar covalent bonds of water molecules. A water molecule consists of an oxygen atom bonded to two hydrogen atoms. Due to oxygen's high electronegativity, the shared electrons are attracted closer to the oxygen at the apex of this V-shaped molecule. The resulting partial negative charge associated with oxygen and partial positive charge associated with each hydrogen result in hydrogen bonding between adjacent water molecules.

Water molecules also form hydrogen bonds with atoms in polar covalent bonds in other molecules, dissolving those molecules. The partial positive and negative regions of water molecules are also attracted to negatively and positively charged ions, respectively, forming hydration shells around ions that separate them from each other and dissolve them. Most of the chemical reactions of life involve solutes that are dissolved in water, so the properties of water that allow it to form hydrogen bonds are crucial to life on Earth.

12. Synthesize Your Knowledge

The water adheres to the molecules on the cat's tongue, drawing it upward. The column of water forms due to both cohesion of water molecules within the column and the surface tension along

the sides of the column. Adhesion, cohesion, and surface tension are possible because of extensive hydrogen bonding that takes place between water molecules, which in turn is because of the structure of the water molecule. The oxygen region of the water molecule has a partial negative charge while the hydrogens each carry a partial positive charge. This leads to an attraction between the hydrogen of one water molecule and the oxygen of an adjacent molecule. Hydrogen bonds constantly break and reform between water molecules. Although they are individually weak, the large number of them means that water sticks together very well—as well as to other hydrophilic molecules, such as those on a cat's tongue—allowing cats to drink in this way.

CHAPTER 4 CARBON AND THE MOLECULAR DIVERSITY OF LIFE

Scientific Skills Exercise

Teaching objective: Students gain practice working with moles of chemicals, including calculations requiring manipulation of large exponents.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

Thinking about moles of elements versus moles of molecules that make up those elements is like thinking about ingredients going into a dozen cookies. Ask students to imagine they want to make a dozen oatmeal raisin cookies: 12 oatmeal cookies (Ot) with 5 raisins (R) per cookie (OtR_5). If "a dozen" were a mole, they would need 5 "moles" of (5 dozen) raisins in the batter. This would be 60 raisins total (5 moles of R) to result in 1 mole of oatmeal raisin cookies (OtR_5).

It is a fun exercise to have students look up the metric, or SI, prefix for 10^{23}. There isn't one for exactly the 23rd power, but there is for 10^{21} (sextillion) and 10^{24} (septillion), so they can practice expressing Avogadro's number in either or both of these units by moving the decimal over to the correct place (602 sextillion molecules and 0.602 septillion molecules, respectively).

You may want to have students review Figure 4.2 before doing this exercise. Note that the Tesla-coils used to generate the spark discharged into the experiment's "atmosphere" are a favorite feature of the current "Steampunk" culture, in addition to being a common hair-raising activity at science museums.

Answers:

1. (a) The molar ratio of methionine is 1.8×10^{-3}, meaning there is 1.8×10^{-3} mole of methionine for every 1.0 mole of glycine. **(b)** There are 6.02×10^{23} molecules of glycine in a mole. **(c)** There are $(1.8 \times 10^{-3}) \times (6.02 \times 10^{23}) = (1.8 \times 6.02) \times (10^{-3+23}) = 10.84 \times 10^{20} = 1.08 \times 10^{21}$ molecules of methionine.

2. (a) Alanine—there are 1.1 moles of alanine for every 1.0 mole of glycine. **(b)** Molecules of alanine = 1.1 moles x 6.02×10^{23} molecules/mole = 6.62×10^{23} molecules of alanine. Molecules of alanine − molecules of glycine = $6.62 \times 10^{23} - 6.02 \times 10^{23} = 0.60 \times 10^{23} = 6.0 \times 10^{22}$ more molecules of alanine compared to the number of molecules in 1 mole of glycine. Alternate

approach: There are 0.1 more moles of alanine than glycine. Converting moles to molecules, 0.1 mole x 6.02 x 10^{23} molecules/mole = 6.02 x 10^{22} more molecules of alanine compared to the number of molecules in 1 mole of glycine.

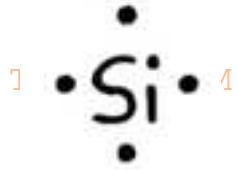
3. (a) There would be 120 moles of hydrogen [9 + 2(55.5)], 2 moles of carbon, 57.5 moles of oxygen (2 + 55.5), 1 mole of nitrogen, and 1 mole of sulfur. **(b)** 1 mole of glycine requires 2 moles of carbon, 5 moles of hydrogen, 1 mole of nitrogen, and 2 moles of oxygen. **(c)** 1 mole of glycine can be made. All of the carbon and nitrogen will be used up to make 1 mole of glycine, leaving some hydrogen, oxygen, and sulfur in the reaction flask. **(d)** Serine requires 3 carbons and 1 nitrogen, so the carbon would be used up first. The same is true of methionine, which requires 5 carbons and 1 nitrogen. In the flask, 0.67 (2/3) of a mole of serine could be made, and 0.4 (2/5) of a mole of methionine, limited in both cases by the amount of carbon atoms.

4. Methionine, which contains a sulfur.

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and the suggested rubric at the beginning of this document.

9. Evolution Connection/Draw It



Si has 4 valence electrons, the same number as carbon. Therefore, silicon would be able to form long chains, including branches, that could act as skeletons for large molecules. It would clearly do this much better than neon (with no valence electrons) or aluminum (with 3 valence electrons).

10. Scientific Inquiry

The observation that the harmful thalidomide enantiomer can be detected in the patient even if only the beneficial enantiomer is taken as a drug suggests that the body must have an enzyme that is able to convert one form into the other. (In fact, this has been shown to be the case.)

11. Write About a Theme: Organization

Sample key points:

- A molecule's shape results from the geometry of the bonds between its atoms.
- A molecule's shape largely determines its interactions—that is, its function.
- Enantiomers differ because of the tetrahedral, nonsuperimposable arrangement of four different atoms or groups of atoms around an asymmetric carbon.
- L-dopa is effective because its structure allows it to interact with a receptor molecule.
- D-dopa is ineffective because it does not fit the receptor.

Sample top-scoring answer:
An organic molecule has a specific three-dimensional shape, which is determined by the geometry of the bonding pattern between its atoms. This shape—the molecule's structure—largely determines how it interacts with other molecules—its function. Enantiomers are isomers that differ in structure and function because of the arrangement of atoms or groups of atoms around an asymmetric carbon. Because of the tetrahedral shape of the covalent bonds formed by carbon, the four different atoms or groups can occur in two non-superimposable arrangements. Presumably, the shape of L-dopa enables it to fit into and interact with a specific biological molecule, possibly a receptor protein on the surface of a brain cell. In this way, L-dopa might have restored a normal function lost by those patients. The other enantiomer, D-dopa, would have a different three-dimensional arrangement and therefore would not be expected to interact with a receptor in the same way. Thus, the structure of the effective enantiomer determines its function.

12. Synthesize Your Knowledge
Because carbon has a valence of 4, it can form four covalent bonds with other atoms. These can be carbons, building the skeletons of organic molecules, and other atoms as well. The versatility of carbon is the basis of the diversity of compounds that make up important biomolecules. Carbon skeletons in the shape of four fused rings make up organic molecules called steroids, some of which are sex hormones. Estradiol (a form of estrogen) and testosterone are very similar in structure, differing only in the biochemical groups located at two places on the steroid molecule. In one position, testosterone has a methyl group (a group that also depends on the chemistry of carbon) that is absent on estradiol. In another location, a carbonyl on testosterone is a hydroxyl group on estradiol. Although the chemical structures of these two sex hormones look very similar, their function is quite different, with testosterone being able to bind to other molecules that ultimately cause formation of the larger size and dense mane of the male lion. The slightly different chemical groups lead to different shapes and chemical characteristics, allowing them to bind to molecules on the surface of different target cells and result in these different effects.

CHAPTER 5 THE STRUCTURE AND FUNCTION OF LARGE BIOLOGICAL MOLECULES

Scientific Skills Exercise

Teaching objective: In this exercise, students will examine aligned amino acid sequences from three different species to find any and all differences between them. They will calculate percent identity and create supportable hypotheses about relatedness among the species.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

The sequences are too long to fit on one line, so some students may get confused and think there are three different sequences shown in the data, although you can point out that this is explained in the paragraph introducing the data. Also, a review of how to calculate percentage may be needed.

A key aspect of this exercise is using the data to support a hypothesis about evolutionary relationships. The "molecular genealogy" approach introduced in Chapter 5, and used in this

exercise, may not be intuitive for students who have not yet studied evolution. The group game "Telephone" is an analogy that might help them understand. In this game, one person whispers a sentence to the next person, and so on down the line, until the last person says it out loud. The farther away a person is from the source, the more errors will have been introduced into the sentence. Similarly, the more generations between species separations, the more changes there will be to the DNA and protein sequences.

If you would like to show your students the gorilla sequence of β globin (mentioned in the text), it is at http://www.ncbi.nlm.nih.gov/protein/P02024.2.

Answers:

1. (a) There are eight amino acid differences between the human and monkey sequences (S/N, A/T, V/L, T/S, A/N, T/Q, R/K, P/Q). **(b)** There are two amino acid differences between the gibbon and the human (T/Q, P/Q).

2. For the rhesus monkey, 94.5% (138/146) of its amino acids are identical to the human sequence of β globin. For the gibbon, 98.6% (144/146) of its amino acids are identical to the human sequence.

3. Based solely on the β-globin amino acid sequences, one can hypothesize that gibbons are more closely related to humans than rhesus monkeys are. The reasoning is that the more similar the amino acid sequences, the more closely related two species are. This is based on the premise that there has been less evolutionary change since gibbons and humans shared a common ancestor—in other words, fewer mutations have occurred and thus there has been less divergence of the DNA and polypeptide sequences of these species. Conversely, a more distantly related pair of species (here, human and monkey) would have a more divergent sequence because there has been more time for evolutionary change since they shared a common ancestor.

4. Other evidence could include amino acid sequences of other proteins, DNA sequences, and morphological and biochemical similarities and differences. The same principles of similarity/divergence and relatedness would apply.

Problem-Solving Exercise

Teaching objective: In this exercise, students will use short DNA sequences from three species of salmon to try to determine the species identification of a sample.

Teaching tip: A version of this Problem-Solving Exercise can be assigned in Mastering Biology.

1.

	Sample labeled as *O. kisutch* (coho salmon)	5′-CGGCACCGCCCTAAGTCTCT-3′
Standard sequences	Sequence for *O. kisutch* (coho salmon)	5′-AGGCACCGCCCTAAGTCTAC-3′
	Sequence for *O. keta* (chum salmon)	5′-AGGCACCGCCCTGAGCCTAC-3′
	Sequence for *Salmo salar* (Atlantic salmon)	5′-CGGCACCGCCCTAAGTCTCT-3′

2. **(a)** 3 **(b)** 5 **(c)** 0

3. **(a)** *O. kisutch* 17/20 = 85% identical to sample

(b) *O. keta*: 15/20 = 75% identical to sample

(c) *S. salar*: 20/20 = 100% identical to sample

4. Hypothesis: My fish sample is *Salmo salar*, Atlantic salmon, not *O. kisutch* as it was labeled. Reasoning: The DNA sequence of the sample matches the standard sequence of *S. salar* but not the standard sequences of *O. kisutch* or *O. keta*. The DNA from individuals of the same species will have more similar DNA than the DNA from individuals of different species. Therefore, it appears that the sample is *S. salar,* based on these data alone.

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and the suggested rubric at the beginning of this document.

10. Evolution Connection

Some cellular functions are more essential than others to the survival of the organism. Proteins perform most cellular functions, so some proteins could be considered more essential than others. You should therefore expect the amino acid sequences of more essential proteins to be more highly conserved (retained with little or no change) than those of less essential proteins. Moreover, different species often live in different habitats and experience different selection pressures. Consequently, you should expect different degrees of divergence among the proteins shared by species that live in different habitats.

11. Scientific Inquiry

DNA has many phosphate groups along the backbone of each strand, so the molecule has many negative charges. Therefore, you might expect a DNA-binding protein to have many amino acids with positively charged side chains. These are the basic amino acids in Figure 5.14: lysine, arginine, and histidine. (In fact, DNA-binding proteins do have regions that are rich in these three amino acids.)

12. Write About a Theme: Organization

Sample key points:

- Amino acids share common chemical groups but have unique side chains that allow for variation.
- Common components allow the formation of polypeptides, whose repeating units interact to establish secondary structure.
- Interactions of the varying side chains determine tertiary structure.
- The combination allows for an almost infinite number of possible different structures, each with a different function.

Sample top-scoring answer:

The structure of an amino acid, including both common and varying groups, is key to its function. The common groups (amino and carboxyl groups attached to an α carbon) allow amino acids to link together into a polypeptide of any length via peptide bonds. The repeating subunits

of the polymer can interact with each other, forming α helices and β pleated sheets that establish secondary structure. The varying groups are the amino acid side chains. Each polypeptide therefore has a unique sequence of side chains attached to the common backbone. Interactions between the side chains determine the tertiary structure of the polypeptide. A combination of secondary and tertiary structure establishes the overall 3-D structure of a protein (or one of its subunits), which determines its function. Amino acid structure thus allows for an almost infinite number of possible protein structures, accounting for the diversity of proteins functioning in a cell.

13. Synthesize Your Knowledge
A developing chick is growing rapidly, increasing its number of cells. To build new cells it needs large stores of cell membrane components, including cholesterol and lipids, and other cell components such as proteins. It also requires energy to fuel all this construction, and that is available in the form of fats. Fat molecules are a rich source of energy when metabolized.

CHAPTER 6 A TOUR OF THE CELL

Scientific Skills Exercise

Teaching objective: This exercise is designed to give students practice using a scale bar to measure the size of a cell in a micrograph and to use the measurement to calculate volume and surface area of the cell.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

Most students have difficulty grasping the relationship between the scale bar and the size of the object shown in the image. It may help to sketch (or photocopy) the picture at one size, then again in a larger size, to emphasize that the scale bar is enlarged along with the object. For both sizes, you can have the student make a small "ruler" the same size as the scale bar and use it to manually measure the cell. This will illustrate that even though the image size and ruler length have changed, the cell remains the same size. There will be some variation in measurements using the scale bar, according to where students delineate the edges of the cells in the image. As long as they are consistent between the two cells, the relationships will hold.

Answers:

1. If the 1-µm scale bar is 5 mm long and the diameter of the image of the parent cell is 20 mm, dividing 20 by 5 yields a cell diameter of 4 µm. Since the diameter of the image of the new cell is 15 mm, the actual diameter of that cell is 15 ÷ 5 = 3 µm. Another way to put it is that the diameter of the parent cell is 4 scale bars long, and the scale bar is 1 µm long, so 4 x 1 µm = 4 µm. The diameter of the new cell is 3 scale bars long, and 3 x 1 µm = 3 µm.

2. (a) For the parent cell with radius 2 μm, the volume is $\frac{4}{3}\pi(2\ \mu m)^3 = 33.5\ \mu m^3$. For the new cell with radius 1.5 μm, the volume is $\frac{4}{3}\pi(1.5\ \mu m)^3 = 14.1\ \mu m^3$. **(b)** The new cell will need to synthesize 19.4 μm^3 of cytoplasm to reach its mature volume (33.5 μm^3 – 14.1 μm^3 = 19.4 μm^3).

3. (a) For the parent cell with radius 2 μm, the surface area is $4\pi(2\ \mu m)^2 = 50.2\ \mu m^2$. For the new cell with radius 1.5 μm, the surface area is $4\pi(1.5\ \mu m)^2 = 28.3\ \mu m^2$. **(b)** The new cell will need to synthesize 21.9 μm^2 of plasma membrane to reach its mature size (50.2 μm^2 – 28.3 μm^2 = 21.9 μm^2).

4. When it is mature, the new cell will be approximately 2.4 times its current volume (33.5 $\mu m^3 \div 14.1\ \mu m^3 \approx 2.4$) and 1.8 times its current surface area (50.2 $\mu m^2 \div 28.3\ \mu m^2 \approx 1.8$).

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and the suggested rubric at the beginning of this document.

7. Evolution Connection

(a) Unity is best revealed by cell structures that are shared. Almost all biological membranes are phospholipid bilayers. This feature arose early in the evolution of life on Earth and has been consistently retained by all subsequent life-forms. Ribosomes also originated early and are found in all cells. Mitochondria arose early in the origin of eukaryotic cells, all of which seem to contain mitochondria or related organelles.

(b) The less commonly shared a structure is, the more likely it is a specialized adaptation. Cilia and flagella of the "9 + 2" variety are seen only in motile eukaryotes and in eukaryotic cells that move fluid substances past them. A very specialized adaptation seen in the fat-storing tissues of plant seeds is the glyoxysome, which contains enzymes that break down fatty acids, providing an energy source for the developing plant embryo (seedling).

8. Scientific Inquiry

Protein X was produced by ribosomes attached to the rough endoplasmic reticulum. As it was synthesized, protein X was inserted into the rough ER membrane, anchored by its own hydrophobic regions. The membrane with embedded protein X was released from the rough ER in the form of a transport vesicle, which traveled to the Golgi apparatus. Following possible modification, protein X left the Golgi apparatus embedded in another transport vesicle, which moved to and fused with the plasma membrane.

Following cell fractionation, protein X would be found in the pellet that is rich in microsomes: pieces of plasma membrane and internal membranes from the cell. All of the organelles mentioned in the transit of protein X (rough ER, transport vesicles, Golgi apparatus, and plasma membrane) would be found in this pellet.

9. Write About a Theme: Organization

Sample key points:

- Life emerges from the integration of the functions performed by individual cell components.
- Organelles and cellular structures are not alive on their own; their activities must be integrated with those of other components.
- Some of the characteristics of life include the ability to transform energy, to respond to the environment, and to reproduce and pass along characteristics to offspring.
- Although the nucleus contains instructions for all cell components, other cell components are required to carry them out.
- "Life" as a phenomenon is an emergent property of the parts of a cell.

Sample top-scoring answer:
The phenomenon we call "life" emerges from the integration of all the functions performed by the individual structures and organelles of a cell. Not one of the cellular components could exist indefinitely on its own. Integrating the activity of all cellular components allows a cell to display the fundamental characteristics of life: the ability to transform energy, to respond to the environment and interact with other organisms, and ultimately to reproduce and pass along characteristics to offspring. The nucleus houses the genetic instructions for the proteins needed for a cell's functions, but it could not carry out those instructions without the cooperation of ribosomes on which to build proteins, the endoplasmic reticulum and Golgi apparatus to modify them, and mitochondria to convert fuel energy to ATP to drive the process. Furthermore, the arrangement of all these organelles in relation to each other is crucial. Life is an emergent property that results from the intricate organization and orchestrated functioning of these and other cellular components.

10. Synthesize Your Knowledge
Epithelial cells in the small intestine function both in absorption of nutrients from partially digested food and as a barrier between the substances in the small intestine and the blood supply. The microvilli—the many hair-like projections of the plasma membrane at the top of each cell in the SEM—function to increase the surface area of the cell to allow more area for absorption (see Figure 6.25). The microvilli are supported internally by microfilaments, filaments made of actin monomers. The cells in the epithelial sheet must be tightly joined to each other so that the sheet can act as a barrier. This is accomplished by tight junctions, specialized regions on each cell where it is bound by proteins to cells surrounding it (see Figure 6.30; the red dashed arrow at the top of cell shows that substances can't get across). Tight junctions among the entire sheet of cells hold together the whole sheet. The cells are also anchored together by desmosomes, further strengthening the sheet.

CHAPTER 7 MEMBRANE STRUCTURE AND FUNCTION

Scientific Skills Exercise

Teaching objective: The main objective of this exercise is to give students practice in interpreting a graph, especially in regard to recognizing and comparing the major trends in two sets of data. Secondary objectives include encouraging students to deal with a real-life activity of one of the membrane transport proteins they read about in this chapter and, as they're thinking about hypothesis formulation and testing, to realize that what they're learning in this chapter connects to topics in other chapters.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

The instructor may want to point out that the rate of glucose "uptake" was not being measured directly; rather, the experimenters were measuring the concentration of radioactive glucose in the cells at successive time points, with the results reflecting the differing rates of glucose uptake. In answering question 3, some students may observe that, for both data sets, the uptake of glucose increases more slowly as incubation time increases—that is, the slopes of the curves are decreasing with time—and that the uptake by cells from the older animal is leveling off sooner than uptake by the cells from the younger animal. This could be explained by invoking the hypothesis in the question 4 answer, that the older cells have fewer glucose transporter molecules: Presumably the lower number of such protein molecules on the older cells are more quickly saturated with glucose. Regarding question 5, at this point in the book students don't yet have the background to design an experiment in detail, but the allusions to studying specific (purified) proteins in Concept 5.4 and the mentions of labeling in Chapter 2 (radioactive tracers in Concept 2.2) and Chapter 6 (fluorescent labeling of molecules for microscopy; see Figure 6.3) should enable them to come up with a general answer.

Answers:

1. (a) Incubation time (in minutes) is the independent variable. **(b)** Concentration of radioactive glucose (in millimoles) is the dependent variable. **(c)** The red dots indicate the data points for red blood cells from a 15-day-old guinea pig. **(d)** The blue dots indicate data points for red blood cells from a 1-month-old guinea pig.

2. Note: Numbers for concentration will vary slightly in student answers since these numbers are estimates from the graph.

Incubation Time (min)	Concentration of Radioactive Glucose (m*M*) in Red Blood Cells from a 15-Day-Old Guinea Pig	Concentration of Radioactive Glucose (m*M*) in Red Blood Cells from a 1-Month-Old Guinea Pig
10	50	22
20	72	33
30	85	40
45	97	48
60	104	53

3. The increasing concentrations of radioactive glucose at successive time points indicate that glucose is being taken up by the cells throughout the experiment. Careful study of how much the numbers are increasing reveals that the rate of glucose uptake is slowing down as time progresses. The graph shows that the cells from the older guinea pig took up less glucose and took it up less rapidly than the cells from the younger animal, at all incubation times.

4. Answers will vary but should involve the idea that glucose enters cells through glucose transporter proteins, which must be different in some way between the cells of 15-day-old guinea pigs and 1-month-old guinea pigs. One possible hypothesis for the lower glucose uptake by the

cells from the older guinea pig is that the red blood cells of older guinea pigs have fewer molecules of glucose transporter protein. (This trait may have evolved due to natural selection because the cells of older animals need less glucose, and there is a cost to making more glucose transporter proteins than needed.)

5. Answers will vary. One way to test the first hypothesis mentioned in answer 4 would be to isolate glucose transporter protein from the two kinds of cells and compare the amounts. More practically, one could tag the transporter proteins with radioactive or fluorescent labels and measure levels of the labels to compare the amounts of protein in cells from animals of the two ages.

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and the suggested rubric at the beginning of this document.

7. Evolution Connection

One might expect protists that live in hypertonic environments to have the opposite sort of adaptations from those seen in *Paramecium.* An example would be membranes that impede water loss to the environment. An organism that regularly experiences fluctuations in environmental salt concentrations (such as organisms in shallow tide pools) might be expected to have both types of adaptations, plus the ability to activate and inhibit them as its needs change.

8. Scientific Inquiry

(a) Evaluating the data reveals that the proton pump builds up an H^+ gradient across the membrane by pumping protons out of the cell, represented by the initial decrease in pH (increase in H^+ concentration) seen in the solution. Once the gradient is sufficient, H^+ can move down its electrochemical gradient into the cell, and sucrose appears to move with it. The proton pump, using ATP, continues to pump protons out of the cell, maintaining a steady gradient with a higher concentration of H^+ outside (lower pH than the starting pH). This leads to the following hypothesis: Sucrose and H^+ move together into the plant cell through a cotransport protein, with sucrose moving up a concentration gradient and H^+ moving down an electrochemical gradient. The H^+ gradient is maintained by a proton pump, which requires ATP. This hypothesis is consistent with the data.

(b) If an inhibitor of ATP regeneration were added, the proton pump would no longer be able to work, and the surplus of H^+ outside the cell would continue to drive cotransport until the gradient ran down and the outside H^+ concentration was the same as that inside the cell. Thus, you would see the pH in the solution rise, as $[H^+]$ decreases, until the gradient was no longer sufficient to drive cotransport, at which point sucrose transport would cease and the pH would remain steady.

9. Science, Technology, and Society

If a plant cell is placed in a hypertonic solution such as that found in wet saline soils, water will be lost by osmosis from the cytoplasm and central vacuole of the cell. The cell may plasmolyze as the plasma membrane pulls away from the cell wall, causing the cell to shrivel and die. Even if soil salinity is not at lethal levels, water becomes less available to plants as soil salinity increases because of the tendency of water to leave the plants' cells.

10. Write About a Theme: Interactions

Sample key points:

- The plasma membrane is selectively permeable and regulates the passage of materials.
- Nonpolar molecules diffuse through the lipid bilayer.
- Polar molecules require transport proteins.
- Cholesterol enters by receptor-mediated endocytosis.
- Hormones bind to receptors and trigger the secretion of enzymes by exocytosis.
- Ions move through specific ion channels, which may be gated.
- The sodium-potassium pump actively transports Na^+ and K^+.
- All of these mechanisms enable a cell to exchange materials with its environment.

Sample top-scoring answer:

The selectively permeable plasma membrane mediates the passage of substances into and out of the cell via several mechanisms. Small nonpolar molecules, such as O_2 and CO_2, can diffuse easily through the hydrophobic interior of the lipid bilayer, which interferes with entry of other substances, even very small ones. Larger polar molecules, such as glucose and amino acids, require specific carrier proteins that bind and move them across the membrane. Cholesterol (carried by LDLs) is brought in by receptor-mediated endocytosis. Hormones bind to cell surface receptors that trigger the secretion of digestive enzymes: the enzymes are packaged in vesicles and released by exocytosis. Ions move through specific ion channels, which may be gated. The energy-requiring sodium-potassium pump actively transports Na^+ and K^+. Together, the hydrophobic interior of the lipid bilayer, the activities of transport proteins and receptor proteins on the cell surface, and the expenditure of ATP to drive active transport allow the plasma membrane to regulate the cell's exchange of materials with its environment.

11. Synthesize Your Knowledge

The water is hypotonic to the plant cells, so the plant cells take up water. Thus, the cells of the vegetable remain turgid rather than plasmolyzing, and the vegetable (for example, lettuce or spinach) remains crisp.

CHAPTER 8 AN INTRODUCTION TO METABOLISM

Scientific Skills Exercise

Note: In this document, inorganic phosphate is symbolized as "$(P)_i$" since we can't type a circled P as done in the text.

Teaching objective: Students will practice making a line graph in this exercise. The students are then encouraged to think of a biological explanation for the data pattern.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

Some students may have a difficult time understanding why the concentration of $(P)_i$ goes up over time. A common misconception is that the *y*-values represent the enzyme activity itself, such that the steep rise near the start of the line shows that the enzyme is becoming activated and

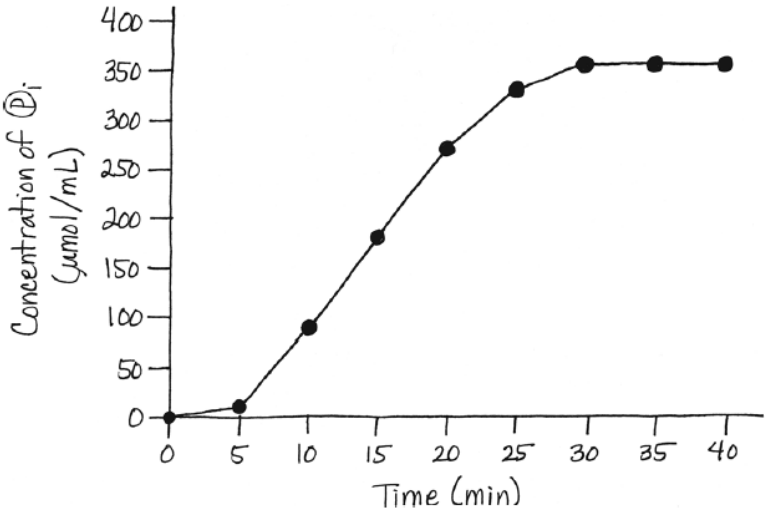
then it stays at a constant high level after the plateau. An analogy of snowfall rate versus snow accumulation may help them visualize what is going on in the buffer: the cells producing $(P)_i$ are analogous to the clouds dropping snowflakes, and the accumulation of the $(P)_i$ in the buffer over time is like having the snow get deeper over time. The snow started falling from the clouds high in the sky long before they eventually reached ground, analogous to the lag time for initial accumulation of $(P)_i$ in the buffer due to the time it takes for the substrate to enter the cells and the product to be leave the cells. And even after the snow clouds stop dropping flakes, the snow stays the same depth on the ground, like the $(P)_i$ concentration in the buffer stays the same after the enzyme has stopped functioning.

Answers:

1. (a) By taking samples every 5 minutes, the researchers intentionally varied the amount of time elapsed since the addition of substrate. Thus, time is the independent variable and should be on the *x*-axis. **(b)** The units for time are min (the abbreviation for minutes). **(c)** The variable that is being measured, which depends on the time since substrate addition, is the concentration of $(P)_i$ in the buffer due to its release by the cells. This is the dependent variable and should go on the *y*-axis. **(d)** The units for the concentration of $(P)_i$ are µmol/mL, which means micromoles of $(P)_i$ per milliliter of sampled buffer.

2. (a) The largest value to go on the *x*-axis is 40 min. It is reasonable to label tick marks every 5 min, and the highest should be at 40 min. (It is also acceptable to label ticks every 10 min—this is a matter of choice.) **(b)** The largest value to go on the *y*-axis is 355 µmol /mL. It is reasonable to label tick marks every 50 µmol /mL, so the highest tick should be at 400 µmol /mL. (You could also choose to label every 100 µmol /mL, but it would be more difficult to figure out where to place the points.)

3.



4. (a) The concentration of $(P)_i$ does increase over time, but not in a linear pattern. The concentration is low for the first 5 minutes, then increases steadily for the next 15 minutes, then the rate of increase slows down, and finally the concentration stays the same for the rest of the

experiment. **(b)** The highest rate of enzyme activity occurred where the line has the steepest slope, from 5 to 20 minutes. The slope is calculated as $\Delta y/\Delta x$; for the steepest region the slope is (270 − 10) µmol/mL divided by (20 − 5) minutes = 17.7 µmol/mL · min. **(c)** When the substrate is first added, there is a lag time before product appears in the buffer because the substrate has to be transported into the cells and processed by the enzyme, and then the product has to be released from the cells into the buffer. After the rate of transport becomes steady, the concentration of $(P)_i$ reflects the enzyme activity level. As the rate slows down (where the line plateaus), the concentration is unchanging—there is no additional $(P)_i$ being released into the buffer because the cells have used up the substrate.

5. If your blood glucose level is low, this reaction will occur in your liver cells:

$$\text{Glucose 6-phosphate} \xrightarrow{\text{Glucose 6-phosphatase}} \text{Glucose} + (P)_i$$

Your blood glucose level will increase as glucose is released from your liver cells into your bloodstream.

Interpret the Data

Figure 8.17(b) The optimal pH for pepsin is 2.0. Natural selection likely resulted in pepsin's optimal temperature because 2.0 is the pH inside the stomach, as seen in Figure 3.11. The optimal pH for trypsin is 8.0.

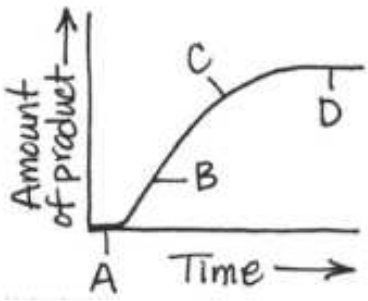
Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and the suggested rubric at the beginning of this document.

8. Evolution Connection

For a given metabolic pathway, its current function is accomplished by a complex series of reactions catalyzed by a specific set of enzymes. However, earlier versions of the pathway may have existed that accomplished the same or different functions. Organisms with cellular enzymes for carrying out the earlier pathway may have had mutations that allowed new enzymes to arise. These new enzymes could have participated in the earlier pathway, modifying the pathway in a way advantageous to the organism. If natural selection caused the new genes to be passed on because the organism survived better, this would represent one step in a gradual modification of a biochemical pathway. With additional steps taking place over long periods of time, this is a plausible model for how evolutionary processes could have resulted in any biochemical pathway seen in organisms today. This evolutionary process could have happened differently in distinct lineages of organisms. The existence of diverse pathways to produce the same or similar products provides support for this model.

9. Scientific Inquiry/Draw It



A. The substrate molecules are entering the pancreatic cells, so no product is made yet.
B. There is sufficient substrate, so the reaction is proceeding at a maximum rate.
C. As the substrate is used up, the rate decreases (the slope is less steep).
D. The line is flat because no new substrate remains and thus no new product appears.

10. Write About a Theme: Energy and Matter
Sample key points:

- Energy enters an animal cell in the form of the chemical potential energy of fuel molecules such as glucose.
- Energy enters a plant cell in the form of light, which is converted to the chemical energy of sugars like glucose.
- The transfer and transformation of energy increase entropy, and a cell returns heat and the low-energy molecules of CO_2 and H_2O to its surroundings.
- In energy coupling, the free energy released by exergonic chemical reactions is used to drive endergonic reactions.
- ATP represents a store of energy that links catabolic pathways to anabolic pathways.
- The hydrolysis of ATP also drives the mechanical and transport work of a cell.
- Enzymes are required for all the chemical reactions of a cell. By lowering the activation energy, enzymes enable specific reactions to occur more quickly.

Sample top-scoring answer:
The work of a cell requires energy. Energy enters an animal cell as the chemical energy of fuel molecules such as glucose. In a photosynthesizing cell, light energy drives the synthesis of sugars, which in turn provide the energy for metabolism. The free energy released by the exergonic reactions of catabolic pathways is stored in ATP. The energy released by the hydrolysis of ATP to ADP and $(P)_i$ drives the endergonic reactions of anabolic pathways, which synthesize the complex molecules of a cell. Also, during the hydrolysis of ATP in mechanical and transport work, potential energy is transformed into kinetic energy. In these transfers and transformations, some energy is lost as heat, and the cell returns the less ordered molecules of CO_2 and H_2O to its surroundings. All the reactions of a cell require enzymes, which ensure efficient cell function by binding substrates and lowering activation energy, thus speeding up metabolic reactions.

11. Synthesize Your Knowledge
On top of the glacier the penguins have potential energy, which is transformed into kinetic energy as they slide down the slope and dive into the water. Climbing back up the glacier and gaining potential energy requires the activity of muscles. To power the muscle function that drives their motion, the penguins burn fuel from food they consume, such as the proteins and

lipids in fish that they feed on while they are in the water. They digest the food by means of enzymes, which break down the large energy-rich biomolecules into smaller molecules with less free energy. Ultimately, the ATP molecules that are generated from catabolic food breakdown will be used to cause muscle contraction. In addition to producing ATPs, catabolic processes result in the generation of heat, which keeps the penguins' body temperatures elevated above the freezing polar temperatures.

CHAPTER 9 CELLULAR RESPIRATION AND FERMENTATION

Scientific Skills Exercise

Teaching objective: Students will practice making a bar graph with categorical data in this exercise. The students are then encouraged to think of a biological explanation for the data pattern.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

When faced with data that fall into categories instead of along a continuum, many students will "connect the dots" of data points instead of keeping them separate in bar graph format. Having them make the graph several times, changing the order that the categories align on the axis, will demonstrate that the pattern will change if points are connected but not if left separate. Some astute students may argue that in this example, the cells with low, normal, and elevated thyroid hormone levels represent a continuum of thyroid hormone levels and can be treated as continuous data. In this case, challenge them to assign numerical values to the hormone levels and they will see that in the absence of actual hormone data, the cell types must be treated as non-continuous categories. However, it is logical to put the categories in order from low to high hormone levels.

Answers:

1. (a) The researchers intentionally varied the thyroid hormone level, which is therefore the independent variable and should be put on the *x*-axis. The data should be shown in the categories Low, Normal, and Elevated. Putting the categories in the order Low, Normal, and Elevated is logical, but the categories could go in a different order. **(b)** The researchers measured the O_2 consumption rate, which is therefore the dependent variable and should be put on the *y*-axis. **(c)** The units on the *y*-axis are nanomoles of oxygen (O_2) gas per minute per milligram of cells (abbreviated as "nmol O_2/min · mg cells"). The largest value on the *y*-axis is 8.7, so numbers from 0.0 to 9.0 should be used as tick mark labels on the *y*-axis.

2.

Answers for Instructors
Campbell BIOLOGY IN FOCUS, Third Edition

by Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, and Rebecca B. Orr

Appendix A of the book includes answers for students for Figure Questions, Concept Check Questions, Summary of Key Concepts Questions, end-of-chapter multiple-choice questions, and Draw It Questions. This document for instructors includes suggested answers and teaching tips for the Scientific Skills Exercises and suggested answers for the Problem-Solving Exercises, Interpret the Data Questions, and the short-answer essay questions at the end of each chapter.

The Scientific Skills Exercises, Problem-Solving Exercises, Interpret the Data Questions, and additional questions for the Visualizing Figures can be assigned in Mastering Biology, where they are graded automatically.

Tips for Grading Short-Answer Essays

The ability to communicate clearly in writing is essential for almost any profession your students choose to pursue. As instructors, it is often frustrating to be faced with a large class full of students who have had inadequate preparation in writing skills, knowing that you don't have the resources to help your students develop these skills.

The Focus on a Theme Questions at the end of each chapter are an attempt on the part of the authors to partner with you in this endeavor. At the end of each chapter, we ask the student to write a short essay of 100-150 words that relates the material they learned in the chapter to one of the themes introduced in Chapter 1 and featured throughout the book. The Focus on a Theme Questions can be used as in-class or outside-of-class assignments.

For ease of grading, sample key points and sample top-scoring answers for the Focus on a Theme Questions are provided for instructors and TAs in this document. The list of key points provides a guide to the ideas that students should include in their essays. In addition, suggested answers to all of the end-of-chapter essay questions can be found in this document.

The time necessary to grade writing exercises has prohibited many instructors from assigning them. Using a grading rubric, however, can streamline the process. Some instructors have found they can train TAs or even students to grade short essays accurately. (Students can grade their own essays or those of their classmates.) A suggested grading rubric for the Focus on a Theme essays is shown at the end of these tips and in the Study Area of Mastering Biology. This rubric can also be modified to use with the other end-of-chapter essay questions.

The simplest way to use the rubric is to read through each essay and determine how well the writer has accomplished the four aims listed at the top of the columns. The essay can then be graded as a 4, 3, 2, 1, or 0 based on the overall quality of the essay. Alternatively, you could assign 0 to 4 points for *each* of the aims, and then total the points out of 16 possible points.

You can also weight one of the aims more highly. For example, if you want to focus primarily on writing skills (aim #4: Quality of Writing) with the other aims weighted equally, the score for each aim can be multiplied by a "weighting factor." Aim #4 could be assigned 40% of the total points, with aims # 1, 2, and 3 each worth 20%. The score (out of 4) obtained for aim #4

is multiplied by 40, and each of the others multiplied by 20, giving a total of 400 points (160 + 80 + 80 + 80 = 400).

To train TAs to grade essays in a large class, the instructor should first read through some of the essays, looking for a representative example of each of the five scores (4, 3, 2, 1, and 0 for the simplest grading scheme described above). Copies of the five representative essays (with scores hidden) can be passed out to TAs, asking them to grade the essays based on the rubric and a 0-4 grading scheme. Subsequent discussion with the TAs about their essay rankings should clarify the standards, after which they can be given a few "test" essays to grade to ensure consistency in grading practices. This training exercise should take no more than 30-45 minutes. Using a similar rubric and training scheme, the Montgomery County Public School System in Maryland has been able to train a team of instructors to grade thousands of short essays consistently in a relatively short time.

There is also a web-based program called Calibrated Peer Review (CPR) (developed at UCLA with funding from the National Science Foundation and the Howard Hughes Medical Institute) that trains students to evaluate their own work or that of their classmates ("peers"). The program is described at **http://cpr.molsci.ucla.edu/**.

When assigning essays, the instructor should point out the rubric to students (in the Study Area of Mastering Biology) or provide a customized rubric to students. Students can then refer to the rubric before writing to see what is expected of them. They can also check their essay before submitting it to make sure they have met all the criteria in the rubric. Instructors should also encourage students to read the Writing Tips provided under "Additional Resources / Writing Tips and Rubric" in the Study Area of Mastering Biology, which also includes the suggested grading rubric.

Suggested Grading Rubric for "Focus on a Theme" Short-Answer Essays				
	Understanding of Theme and Relationship to Topic	**Use of Supporting Examples or Details**	**Appropriate Use of Terminology**	**Quality of Writing**
4	Evidence of full and complete understanding	Examples well chosen, details accurate and applied to theme	Accurate scientific terminology enhances the essay	Excellent organization, sentence structure, and grammar
3	Evidence of good understanding	Examples or details are generally well applied to theme	Terminology is correctly used	Good sentence flow, sentence structure, and grammar
2	Evidence of a basic understanding	Supporting examples and details are adequate	Terminology used is not totally accurate or appropriate	Some organizational and grammatical problems
1	Evidence of limited understanding	Examples and details are minimal	Appropriate terminology is not present	Poorly organized; grammatical and spelling errors detract from essay
0	Essay shows no understanding of theme	Examples lacking or incorrect	Terminology lacking or incorrect	Essay is very poorly written

Suggested Answers and Teaching Tips

CHAPTER 1 INTRODUCTION: EVOLUTION AND THE FOUNDATIONS OF BIOLOGY

Scientific Skills Exercise

Teaching objective: Students build scientific skills by interpreting data in a pair of bar graphs and relating the data to the biological system it came from.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

If this is the first exercise the students are doing related to interpreting graphs, then you will need to spend time reviewing independent and dependent variables. If the students are confused by having two independent variables on one graph, have them cover one set of data while they look at the other (for example, cover the "full moon" portion of graph A while analyzing the "no moon" portion of it).

In these graphs, there are no statistical significance values given for comparisons between treatments. In the original paper, there was a statistical difference between predation levels of light brown versus dark brown mice in light-colored soil enclosures with no moon and in dark-colored soil enclosures under a full moon. The other two combinations, light-colored soil under a full moon and dark-colored soil with no moon, had no statistically significant difference between light and dark mice.

Answers:

1. (a) The independent variables for each graph are the coat color of the mice (light or dark brown) and the presence or absence of moonlight (full moon or no moon). These are on the *x*-axis. Taking both graphs together, a third independent variable is the color of soil in the enclosure. **(b)** The dependent variable is the amount of predation, measured as the number of mice caught. The dependent variable is on the *y*-axis of the two graphs.

2. (a) About 19. **(b)** About 12. **(c)** Based on the data, the mouse would be more likely to escape on dark soil. This might be because in the moonlight, a dark mouse on light soil would be more noticeable than one on dark soil.

3. (a) Under a full moon (12 were caught vs. 20 under no moon). **(b)** Under no moon (11 were caught vs. 18 under a full moon).

4. (a) Dark soil field with a full moon. **(b)** Light soil with no moon.

5. (a) No moon plus dark brown coat had the highest predation level in the light soil enclosure (38 mice were caught). **(b)** Full moon plus light brown coat had the highest predation level in the dark soil enclosure.
6. Being on the contrasting soil is most deadly for both colors of mice.

7. The total number of mice caught on moonlit nights was about 77, while the total caught on nights without moonlight was about 95. This suggests that owls hunting on moonlit nights are slightly less successful than are owls hunting on nights without moonlight.

Interpret the Data

Figure 1.21 In the beach habitat, approximately 14 light models and 36 dark models were attacked. In the inland habitat, approximately 38 light models and 12 dark models were attacked.

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and a suggested rubric at the beginning of this document.

7. Scientific Inquiry
Many legitimate hypotheses could be proposed to extend the investigation. Here is one example. If the camouflage color has arisen through the processes of natural selection due to visual predators, then you might wonder what would happen if a population of beach mice lived in an area where predators were absent. It might be possible to do a long-term study in an area where you excluded predators. Mice have fairly short generation times, so if predation is "naturally selecting" lighter colored mice, then in the absence of predation you might predict the coat color would not remain predominantly light in such an experimental population.

8. Scientific Inquiry
Students are asked to use a PubMed search to identify an abstract of an article authored or co-authored by Hopi Hoekstra from 2016 forward. The range of abstracts from which students might choose will grow as the Hoekstra lab generates additional publications.

9. Focus on a Theme: Evolution
Sample key points:
- Darwin used reasoning based on observations to develop his theory of natural selection as a mechanism for evolution.
- His observations included:
  - Heritable variations exist in each population.
  - A population has more individuals than can be supported by the environment.
  - Each species seems suited for its particular environment.
- He proposed that the best-adapted individuals in a population would outcompete others for resources and disproportionately survive and produce more offspring, leading to an increase in the adaptations seen in the population.

Sample top-scoring answer:

Based on many observations of different species, Darwin proposed his theory that evolution by means of natural selection accounts for both the unity and diversity of life on Earth. He noticed that variations existed among the individuals in a population and that these variations seemed to be heritable. He also saw that populations could grow larger than could be supported by the resources around them. Finally, he observed that species (like the different species of finches) seemed to suit their environment. He proposed that the best-suited individuals in a population would survive and reproduce more successfully that those less adapted to their environment, and he called this "natural selection." In Darwin's view, this mechanism could account for both the unity and diversity of features among species. The descent of organisms from a common ancestor explains similar features, while the force of natural selection in different environments accounts for differences between organisms.

10. Focus on a Theme: Information
Common ancestry explains this observation. The thousand-some-odd genes shared by humans and prokaryotes originated in early prokaryotes. They have been retained, with some modification, over the billions of years of eukaryotic evolution. These genes no doubt code for proteins and RNAs whose functions are essential for survival—for example, the genes that code for ribosomal RNA, which is important for protein synthesis in both prokaryotes and eukaryotes.

11. Synthesize Your Knowledge
It's difficult to pick out this gecko against the background of the tree trunk, because the gecko itself looks like mossy bark. This coloration likely makes it harder for the gecko to be seen by predators, thus enhancing its survival. This cryptic coloration pattern probably evolved over generations. The members of a gecko population that more closely resembled their background would have been less visible to predators, thus more likely to survive, reproduce, and leave offspring. The offspring would inherit the genes that generated the mossy bark coloration, and the offspring that blended in better would survive better and reproduce more successfully. Over generations, the coloration would become a closer and closer match to the tree bark. (The mossy leaf-tailed gecko is endemic to Madagascar, meaning it is found only there and nowhere else in the world. Many endemic species live in Madagascar. This is because it is an island with land features and climatic factors that have allowed evolution of many species in isolation.)

CHAPTER 2 THE CHEMICAL CONTEXT OF LIFE

Scientific Skills Exercise

Teaching objective: This exercise is designed to give students practice in figuring out what is shown on a graph, how to describe the major trend(s) in the data, and extracting values from the graph to calculate related information. The student is then led back to the biological context of the data to draw a conclusion.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

Most students can look at a graph and describe the slope of the data line. However, many struggle with writing out what the trend means in terms of the relationship between what was

reported on one axis relative to the other axis. Thus, while a student may respond that the data line has a positive slope, they may also respond that a higher calcification rate results in a higher carbonate ion concentration. Helping them sort out dependent and independent variables should clear up the problem. Visual learners will benefit from drawing a mock-up of 1 square meter of the reef, with dots in the water to represent carbonate ions and arrows to indicate calcification.

In this example, students will need to make the additional mental step of reading the trend line right to left, instead of left to right (the natural tendency), to reach a conclusion about the effect of *decreased* carbonate ion concentration on calcification rate and reef growth.

Answers:

1. (a) The *x*-axis shows the concentration of CO_3^{-2} (carbonate) ions in units of micromoles (μmol) of CO_3^{-2} per kilogram of seawater. **(b)** The *y*-axis shows the calcification rate in units of millimoles of $CaCO_3$ accumulated per square meter of reef per day. **(c)** Carbonate ion concentration is the independent variable. **(d)** Calcification rate is the dependent variable.

2. The data show that the rate of calcification is positively related to the concentration of CO_3^{-2} in the seawater. As the concentration of CO_3^{-2} increases, the rate of calcification increases.

3. If the seawater CO_3^{-2} concentration was 270 μmol/kg, the calcification rate would be approximately 19 mmol $CaCO_3/m^2 \cdot$ day. It would take 1 square meter of reef approximately 1.6 days to accumulate 30 mmol of $CaCO_3$ [(30 mmol of $CaCO_3/m^2$) / (19 mmol $CaCO_3/m^2 \cdot$ day) = 1.6 days].

4. (a) The final step of the process shown in Figure 2.25, the rate of conversion of CO_3^{2-} and Ca^{2+} into $CaCO_3$, is measured in this experiment. **(b)** The results do support the hypothesis that increased concentration of atmospheric CO_2 could lead to slower growth of coral reefs. It supports it because, according to the chemistry shown in Figure 2.25, more CO_2 entering the ocean will push the reactions toward formation of more HCO_3^- (bicarbonate) ions, decreasing the amount of CO_3^{2-} available for formation of $CaCO_3$. The results in the graph show that, under the experimental conditions, the lower the concentration of CO_3^{2-}, the lower the rate of calcification, and thus the slower the growth of coral reefs. (As an example, if you do the same calculation as in question 3 for a CO_3^{-2} concentration of 250 μmol/kg, you will see it takes 2.5 days instead of 1.6 days to accumulate the same amount of calcium carbonate at this lower CO_3^{-2} concentration.)

Interpret the Data

Table 2.1 As you probably know, the human body is made up in large part of water, H_2O. The atoms of oxygen in water, one per water molecule, likely account for the high percentage of oxygen (65.0%) found in the human body.

Figure 2.19 The inland temperatures (100°F, 96°F, 106°F) are much higher than those along the coast (73°F, 75°F, 72°F) because oceans are large bodies of water that can absorb or release heat, moderating the climate nearer the coast.

Concept Check 2.5 #5 A liter of blood would contain 7.8×10^{13} molecules of ghrelin (1.3×10^{-10} moles per liter $\times$ 6.02×10^{23} molecules per mole).

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and the suggested rubric at the beginning of this document.

11. Scientific Inquiry
The complex shapes of biological molecules determine the great specificity with which they interact with one another and form weak or strong bonds.
(a) Hypothesis: Receptor cells on the filaments of the male luna moth's antennae contain cell-surface molecules that are complementary in shape to sex attractant molecules (pheromones) produced by the female luna moth.
(b) This hypothesis leads to several testable predictions. (1) Luna moth pheromones will bind to specific sites on the cells of the filaments of the male's antennae. (2) If it is possible to synthesize molecules that are very similar in shape to luna moth pheromones, these molecules will also attract male luna moths. (3) Chemical or temperature treatments that modify the molecular shape of luna moth pheromones will reduce the attractiveness of these molecules to male luna moths.
(c) An experiment could be designed to test the third prediction. A number of male luna moths could be exposed to two separate treatments. In the first treatment, unaltered pheromones would be released near male luna moths, and the response of the moths would be noted. The second treatment would be identical in every way except that the pheromone would be heated to permanently modify its molecular shape before it was released.

12. Focus on a Theme: Evolution
It would be surprising if the percentages of naturally occurring elements in most organisms were *not* roughly the same, because all organisms evolved on Earth (with its unique elemental composition) and all are genetically related to one another. (Species living under unusual conditions might differ more than others, though.) Further, we might predict that the more similar the percentages of naturally occurring elements are in two species, the more closely related those two species are.

13. Focus on a Theme: Organization
Sample key points:
- Water's versatility as a solvent arises from the polar covalent bonds of water molecules.
- Water molecules form hydrogen bonds with atoms that are part of polar covalent bonds in other molecules.
- The partially charged regions of water molecules are attracted to oppositely charged ions.

Sample top-scoring answer:
Water is the solvent of life, a function emerging from the polar covalent bonds of water molecules. A water molecule consists of an oxygen atom bonded to two hydrogen atoms. Due to oxygen's high electronegativity, the shared electrons are attracted closer to the oxygen at the apex of this V-shaped molecule. The resulting partial negative charge associated with oxygen

and partial positive charge associated with each hydrogen result in hydrogen bonding between adjacent water molecules.

Water molecules also form hydrogen bonds with atoms in polar covalent bonds in other molecules, dissolving those molecules. The partial positive and negative regions of water molecules are also attracted to negatively and positively charged ions, respectively, forming hydration shells around ions that separate them from each other and dissolve them. Most of the chemical reactions of life involve solutes that are dissolved in water, so the properties of water that allow it to form hydrogen bonds are crucial to life on Earth.

14. Synthesize Your Knowledge

The water adheres to the molecules on the cat's tongue, drawing it upward. The column of water forms due to both cohesion of water molecules within the column and the surface tension along the sides of the column. Adhesion, cohesion, and surface tension are possible because of extensive hydrogen bonding that takes place between water molecules, which in turn is because of the structure of the water molecule. The oxygen region of the water molecule has a partial negative charge while the hydrogens each carry a partial positive charge. This leads to an attraction between the hydrogen of one water molecule and the oxygen of an adjacent molecule. Hydrogen bonds constantly break and re-form between water molecules. Although they are individually weak, the large number of them means that water sticks together very well—as well as to other hydrophilic molecules, such as those on a cat's tongue—allowing cats to drink in this way.

CHAPTER 3 CARBON AND THE MOLECULAR DIVERSITY OF LIFE

Scientific Skills Exercise

Teaching objective: In this exercise, students will examine aligned amino acid sequences from three different species to find any and all differences between them. They will calculate percent identity and create supportable hypotheses about relatedness among the species.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

The sequences are too long to fit on one line, so some students may get confused and think there are three different sequences shown in the data, although you can point out that this is explained in the paragraph introducing the data. Also, a review of how to calculate percentage may be needed.

A key aspect of this exercise is using the data to support a hypothesis about evolutionary relationships. The "molecular genealogy" approach introduced in Chapter 3, and used in this exercise, may not be intuitive for students who have not yet studied evolution. The group game "Telephone" is an analogy that might help them to understand. In this game, one person whispers a sentence to the next person, and so on down the line, until the last person says it out loud. The farther away a person is from the source, the more errors will have been introduced into the sentence. Similarly, the more generations between species separations, the more changes there will be to the DNA and protein sequences.

If you would like to show your students the gorilla sequence of β-globin (mentioned in the text), it is at http://www.ncbi.nlm.nih.gov/protein/P02024.2.

Answers:

1. (a) There are eight amino acid differences between the human and monkey sequences (S/N, A/T, V/L, T/S, A/N, T/Q, R/K, P/Q). **(b)** There are two amino acid differences between the gibbon and the human (T/Q, P/Q).

2. For the rhesus monkey, 94.5% (138/146) of its amino acids are identical to the human sequence of β-globin. For the gibbon, 98.6% (144/146) of its amino acids are identical to the human sequence.

3. Based solely on the β-globin amino acid sequences, one can hypothesize that gibbons are more closely related to humans than rhesus monkeys are. The reasoning is that the more similar the amino acid sequences, the more closely related two species are. This is based on the premise that there has been less evolutionary change since gibbons and humans shared a common ancestor—in other words, fewer mutations have occurred and thus there has been less divergence of the DNA and polypeptide sequences of these species. Conversely, a more distantly related pair of species (here, human and monkey) would have a more divergent sequence because there has been more time for evolutionary change since they shared a common ancestor.

4. Other evidence could include amino acid sequences of other proteins, DNA sequences, and morphological and biochemical similarities and differences. The same principles of similarity/divergence and relatedness would apply.

Problem-Solving Exercise

Teaching objective: In this exercise, students will use short DNA sequences from three species of salmon to try to determine the species identification of a sample.

Teaching tip: A version of this Problem-Solving Exercise can be assigned in Mastering Biology.

1.

	Sample labeled as *O. kisutch* (coho salmon)	5′–CGGCACCGCCCTAAGTCTCT–3′
Standard sequences	Sequence for *O. kisutch* (coho salmon)	5′–AGGCACCGCCCTAAGTCTAC–3′
	Sequence for *O. keta* (chum salmon)	5′–AGGCACCGCCCTGAGCCTAC–3′
	Sequence for *Salmo salar* (Atlantic salmon)	5′–CGGCACCGCCCTAAGTCTCT–3′

2. **(a)** 3 **(b)** 5 **(c)** 0

3. **(a)** *O. kisutch* 17/20 = 85% identical to sample

(b) *O. keta*: 15/20 = 75% identical to sample

(c) *S. salar*: 20/20 = 100% identical to sample

4. Hypothesis: My fish sample is *Salmo salar*, Atlantic salmon, not *O. kisutch* as it was labeled. Reasoning: The DNA sequence of the sample matches the standard sequence of *S. salar* but not the standard sequences of *O. kisutch* or *O. keta*. The DNA from individuals of the same species will have more similar DNA than the DNA from individuals of different species. Therefore, it appears that the sample is *S. salar,* based on these data alone.

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and the suggested rubric at the beginning of this document.

12. Scientific Inquiry
DNA has many phosphate groups along the backbone of each strand, so the molecule has many negative charges. Therefore, you might expect a DNA-binding protein to have many amino acids with positively charged side chains. These are the basic amino acids in Figure 3.18: lysine, arginine, and histidine. (In fact, DNA-binding proteins do have regions that are rich in these three amino acids.)

13. Focus on a Theme: Evolution
Some cellular functions are more essential than others to the survival of the organism. Proteins perform most cellular functions, so some proteins could be considered more essential than others. You should therefore expect the amino acid sequences of more essential proteins to be more highly conserved (retained with little or no change) than those of less essential proteins. Moreover, different species often live in different habitats and experience different selection pressures. Consequently, you should expect different degrees of divergence among the proteins shared by species that live in different habitats.

14. Focus on a Theme: Organization
Sample key points:

- Amino acids share common chemical groups but have unique side chains that allow for variation.
- Common components allow the formation of polypeptides, whose repeating units interact to establish secondary structure.
- Interactions of the varying side chains determine tertiary structure.
- The combination allows for an almost infinite number of possible different structures, each with a different function.

Sample top-scoring answer:
The structure of an amino acid, including both common and varying groups, is key to its function. The common groups (amino and carboxyl groups attached to an α carbon) allow amino acids to link together into a polypeptide of any length via peptide bonds. The repeating subunits of the polymer can interact with each other, forming α helices and β pleated sheets that establish secondary structure. The varying groups are the amino acid side chains. Each polypeptide therefore has a unique sequence of side chains attached to the common backbone. Interactions between the side chains determine the tertiary structure of the polypeptide. A combination of

secondary and tertiary structure establishes the overall 3-D structure of a protein (or one of its subunits), which determines its function. Amino acid structure thus allows for an almost infinite number of possible protein structures, accounting for the diversity of proteins functioning in a cell.

15. Synthesize Your Knowledge
A developing chick is growing rapidly, increasing its number of cells. To build new cells it needs large stores of cell membrane components, including cholesterol and lipids, and other cell components such as proteins. It also requires energy to fuel all this construction, and that is available in the form of fats. Fat molecules are a rich source of energy when metabolized.

CHAPTER 4 A TOUR OF THE CELL

Scientific Skills Exercise

Teaching objective: This exercise is designed to give students practice using a scale bar to measure the size of a cell in a micrograph and to use the measurement to calculate volume and surface area of the cell.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

Most students have difficulty grasping the relationship between the scale bar and the size of the object shown in the image. It may help to sketch (or photocopy) the picture at one size, then again in a larger size, to emphasize that the scale bar is enlarged along with the object. For both sizes, you can have the student make a small "ruler" the same size as the scale bar and use it to manually measure the cell. This will illustrate that even though the image size and ruler length have changed, the cell remains the same size. There will be some variation in measurements using the scale bar, according to where students delineate the edges of the cells in the image. As long as they are consistent between the two cells, the relationships will hold.

Answers:

1. If the 1-µm scale bar is 5 mm long and the diameter of the image of the parent cell is 20 mm, dividing 20 by 5 yields a cell diameter of 4 µm. Since the diameter of the image of the new cell is 15 mm, the actual diameter of that cell is 15 ÷ 5 = 3 µm. Another way to put it is that the diameter of the parent cell is 4 scale bars long, and the scale bar is 1 µm long, so 4 × 1 µm = 4 µm. The diameter of the new cell is 3 scale bars long, and 3 × 1 µm = 3 µm.

2. (a) For the parent cell with radius 2 µm, the volume is $\frac{4}{3}\pi(2\ \mu m)^3 = 33.5\ \mu m^3$. For the new cell with radius 1.5 µm, the volume is $\frac{4}{3}\pi(1.5\ \mu m)^3 = 14.1\ \mu m^3$. **(b)** The new cell will need to synthesize 19.4 μm^3 of cytoplasm to reach its mature volume (33.5 μm^3 – 14.1 μm^3 = 19.4 μm^3).

3. (a) For the parent cell with radius 2 µm, the surface area is $4\pi(2\ \mu m)^2 = 50.2\ \mu m^2$. For the new cell with radius 1.5 µm, the surface area is $4\pi(1.5\ \mu m)^2 = 28.3\ \mu m^2$. **(b)** The new cell will need to

synthesize 21.9 μm^2 of plasma membrane to reach its mature size (50.2 μm^2 – 28.3 μm^2 = 21.9 μm^2).

4. When it is mature, the new cell will be approximately 2.4 times its current volume (33.5 $\mu m^3 \div$ 14.1 $\mu m^3 \approx 2.4$) and 1.8 times its current surface area (50.2 $\mu m^2 \div 28.3\ \mu m^2 \approx 1.8$).

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and the suggested rubric at the beginning of this document.

7. Scientific Inquiry
You could start by examining the organism and especially its mystery organelle by TEM at high magnification, looking closely for structural similarities with known organelles. Then, starting with a suspension of the organism in an aqueous solution, you could carry out cell fractionation: successive centrifugations at higher and higher speeds, saving the pellet at each stage. Using electron microscopy on material from the pellets, you could identify the pellet containing the organelles of interest. You could then re-suspend these organelles in solution, and test them for the activities of various enzymes, which might reveal the organelle's function in the cell. You could also attempt to isolate DNA from the organelles and compare any you find with DNA from normal mitochondria and chloroplasts. If, for example, the organelles contain enzymes known to participate in cellular respiration and also contain DNA similar to known mitochondrial DNA, you could conclude that the mystery organelle is most likely a mitochondrion. An organelle unrelated or more distantly related to known organelles might take much additional study to figure out.

8. Focus on a Theme: Evolution
(a) Unity is best revealed by cell structures that are shared. Almost all biological membranes are phospholipid bilayers. This feature arose early in the evolution of life on Earth and has been consistently retained by all subsequent life-forms. Ribosomes also originated early and are found in all cells. Mitochondria arose early in the origin of eukaryotic cells, all of which seem to contain mitochondria or related organelles.
(b) The less commonly shared a structure is, the more likely it is a specialized adaptation. Cilia and flagella of the "9 + 2" variety are seen only in motile eukaryotes and in eukaryotic cells that move fluid substances past them.

9. Focus on a Theme: Organization
Sample key points:
- Life emerges from the integration of the functions performed by individual cell components.
- Organelles and cellular structures are not alive on their own; their activities must be integrated with those of other components.
- Some of the characteristics of life include the ability to transform energy, to respond to the environment, and to reproduce and pass along characteristics to offspring.
- Although the nucleus contains instructions for all cell components, other cell components are required to carry them out.
- "Life" as a phenomenon is an emergent property of the parts of a cell.

Sample top-scoring answer:
The phenomenon we call "life" emerges from the integration of all the functions performed by the individual structures and organelles of a cell. Not one of the cellular components could exist indefinitely on its own. Integrating the activity of all cellular components allows a cell to display the fundamental characteristics of life: the ability to transform energy, to respond to the environment and interact with other organisms, and ultimately to reproduce and pass along characteristics to offspring. The nucleus houses the genetic instructions for the proteins needed for a cell's functions, but it could not carry out those instructions without the cooperation of ribosomes on which to build proteins, the endoplasmic reticulum and Golgi apparatus to modify them, and mitochondria to convert fuel energy to ATP to drive the process. Furthermore, the arrangement of all these organelles in relation to each other is crucial. Life is an emergent property that results from the intricate organization and orchestrated functioning of these and other cellular components.

10. Synthesize Your Knowledge
Epithelial cells in the small intestine function both in the absorption of nutrients from partially digested food and as a barrier between the substances in the small intestine and the blood supply. The microvilli—the many hair-like projections of the plasma membrane at the top of each cell in the SEM—function to increase the surface area of the cell to allow more area for absorption (see Figure 4.24). The microvilli are supported internally by microfilaments, filaments made of actin monomers. The cells in the epithelial sheet must be tightly joined to each other so that the sheet can act as a barrier. This is accomplished by tight junctions, specialized regions on each cell where it is bound by proteins to cells surrounding it (see Figure 4.27; the red dashed arrow at the top of the cell shows that substances can't get across). Tight junctions among the entire sheet of cells hold together the whole sheet. The cells are also anchored together by desmosomes, further strengthening the sheet.

CHAPTER 5 MEMBRANE TRANSPORT AND CELL SIGNALING

Scientific Skills Exercise

Teaching objective: The main objective of this exercise is to give students practice in interpreting a graph, especially in regard to recognizing and comparing the major trends in two sets of data. Secondary objectives include encouraging students to deal with a real-life activity of one of the membrane transport proteins they read about in this chapter and, as they're thinking about hypothesis formulation and testing, to realize that what they're learning in this chapter connects to topics in other chapters.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

The instructor may want to point out that the rate of glucose "uptake" was not being measured directly; rather, the experimenters were measuring the concentration of radioactive glucose in the cells at successive time points, with the results reflecting the differing rates of glucose uptake. In answering question 3, some students may observe that, for both data sets, the uptake of glucose increases more slowly as incubation time increases—that is, the slopes of the curves are

decreasing with time—and that the uptake by cells from the older animal is leveling off sooner than uptake by the cells from the younger animal. This could be explained by invoking the hypothesis in the question 4 answer, that the older cells have fewer glucose transporter molecules: Presumably, the lower number of such protein molecules on the older cells are more quickly saturated with glucose. Regarding question 5, at this point in the book students don't yet have the background to design an experiment in detail, but the allusions to studying specific (purified) proteins in Concept 3.5 and the mentions of labeling in Chapter 2 (radioactive tracers in Concept 2.2) and Chapter 4 (fluorescent labeling of molecules for microscopy; see Figure 4.3) should enable them to come up with a general answer.

Answers:

1. (a) Incubation time (in minutes) is the independent variable. **(b)** Concentration of radioactive glucose (in millimoles) is the dependent variable. **(c)** The red dots indicate the data points for red blood cells from a 15-day-old guinea pig. **(d)** The blue dots indicate data points for red blood cells from a 1-month-old guinea pig.

2. Note: Numbers for concentration will vary slightly in student answers since these numbers are estimates from the graph.

Incubation Time (min)	Concentration of Radioactive Glucose (m*M*) in Red Blood Cells from a 15-Day-Old Guinea Pig	Concentration of Radioactive Glucose (m*M*) in Red Blood Cells from a 1-Month-Old Guinea Pig
10	50	22
20	72	33
30	85	40
45	97	48
60	104	53

3. The increasing concentrations of radioactive glucose at successive time points indicate that glucose is being taken up by the cells throughout the experiment. Careful study of how much the numbers are increasing reveals that the rate of glucose uptake is slowing down as time progresses. The graph shows that the cells from the older guinea pig took up less glucose and took it up less rapidly than the cells from the younger animal, at all incubation times.

4. Answers will vary but should involve the idea that glucose enters cells through glucose transporter proteins, which must be different in some way between the cells of 15-day-old guinea pigs and 1-month-old guinea pigs. One possible hypothesis for the lower glucose uptake by the cells from the older guinea pig is that the red blood cells of older guinea pigs have fewer molecules of glucose transporter protein. (This trait may have evolved due to natural selection because the cells of older animals need less glucose, and there is a cost to making more glucose transporter proteins than needed.)

5. Answers will vary. One way to test the first hypothesis mentioned in answer 4 would be to isolate glucose transporter proteins from the two kinds of cells and compare the amounts. More practically, one could tag the transporter proteins with radioactive or fluorescent labels and

measure levels of the labels to compare the amounts of protein in cells from animals of the two ages.

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and a suggested rubric at the beginning of this document.

7. Scientific Inquiry
(a) Evaluating the data reveals that the proton pump builds up an H^+ gradient across the membrane by pumping protons out of the cell, represented by the initial decrease in pH (increase in H^+ concentration) seen in the solution. Once the gradient is sufficient, H^+ can move down its electrochemical gradient into the cell, and sucrose appears to move with it. The proton pump, using ATP, continues to pump protons out of the cell, maintaining a steady gradient with a higher concentration of H^+ outside (lower pH than the starting pH). This leads to the following hypothesis: Sucrose and H^+ move together into the plant cell through a cotransport protein, with sucrose moving up a concentration gradient and H^+ moving down an electrochemical gradient. The H^+ gradient is maintained by a proton pump, which requires ATP. This hypothesis is consistent with the data.
(b) If an inhibitor of ATP regeneration were added, the proton pump would no longer be able to work, and the surplus of H^+ outside the cell would continue to drive cotransport until the gradient ran down and the outside H^+ concentration was the same as that inside the cell. Thus, you would see the pH in the solution rise, as $[H^+]$ decreases, until the gradient was no longer sufficient to drive cotransport, at which point sucrose transport would cease and the pH would remain steady.

8. Science, Technology, and Society
If a plant cell is placed in a hypertonic solution such as that found in wet saline soils, water will be lost by osmosis from the cytoplasm and central vacuole of the cell. The cell may plasmolyze as the plasma membrane pulls away from the cell wall, causing the cell to shrivel and die. Even if soil salinity is not at lethal levels, water becomes less available to plants as soil salinity increases because of the tendency of water to leave the plants' cells.

9. Focus on a Theme: Evolution
One might expect protists that live in hypertonic environments to have the opposite sort of adaptations from those seen in *Paramecium.* An example would be membranes that impede water loss to the environment. An organism that regularly experiences fluctuations in environmental salt concentrations (such as organisms in shallow tide pools) might be expected to have both types of adaptations, plus the ability to activate and inhibit them as its needs change.

10. Focus on a Theme: Interactions
Sample key points:
- The plasma membrane is selectively permeable and regulates the passage of materials.
- Nonpolar molecules diffuse through the lipid bilayer.
- Polar molecules require transport proteins.
- Cholesterol enters by receptor-mediated endocytosis.
- Hormones bind to receptors and trigger the secretion of enzymes by exocytosis.

- Ions move through specific ion channels, which may be gated.
- The sodium-potassium pump actively transports Na^+ and K^+.
- All of these mechanisms enable a cell to exchange materials with its environment.

Sample top-scoring answer:
The selectively permeable plasma membrane mediates the passage of substances into and out of the cell via several mechanisms. Small nonpolar molecules, such as O_2 and CO_2, can easily diffuse through the hydrophobic interior of the lipid bilayer, which interferes with entry of polar substances, even very small ones. Larger polar molecules, such as glucose and amino acids, require specific carrier proteins that bind and move them across the membrane. Cholesterol (carried by LDLs) is brought into the cell by receptor-mediated endocytosis. Hormones bind to cell surface receptors that trigger the secretion of digestive enzymes: the enzymes are packaged in vesicles and released by exocytosis. Ions move through specific ion channels, which may be gated. The energy-requiring sodium-potassium pump actively transports Na^+ and K^+. Together, the hydrophobic interior of the lipid bilayer, the activities of transport proteins and receptor proteins on the cell surface, and the expenditure of ATP to drive active transport allow the plasma membrane to regulate the cell's exchange of materials with its environment.

11. Synthesize Your Knowledge
The water is hypotonic to the plant cells, so the plant cells take up water. Thus, the cells of the vegetable remain turgid rather than plasmolyzing, and the vegetable (for example, lettuce or spinach) remains crisp.

CHAPTER 6 AN INTRODUCTION TO METABOLISM

Scientific Skills Exercise

Note: In this document, inorganic phosphate is symbolized as "$(P)_i$" since we can't type a circled P as done in the text.

Teaching objective: Students will practice making a line graph in this exercise. The students are then encouraged to think of a biological explanation for the data pattern.

Teaching tips: A version of this Scientific Skills Exercise can be assigned in Mastering Biology.

Some students may have a difficult time understanding why the concentration of $(P)_i$ goes up over time. A common misconception is that the *y*-values represent the enzyme activity itself, such that the steep rise near the start of the line shows that the enzyme is becoming activated and then it stays at a constant high level after the plateau. An analogy of snowfall rate versus snow accumulation may help them visualize what is going on in the buffer: The cells producing $(P)_i$ are analogous to the clouds dropping snowflakes, and the accumulation of the $(P)_i$ in the buffer over time is like having the snow get deeper over time. The snow started falling from the clouds high in the sky long before they eventually reached ground, analogous to the lag time for initial accumulation of $(P)_i$ in the buffer due to the time it takes for the substrate to enter the cells and the product to be leave the cells. And even after the snow clouds stop dropping flakes, the snow

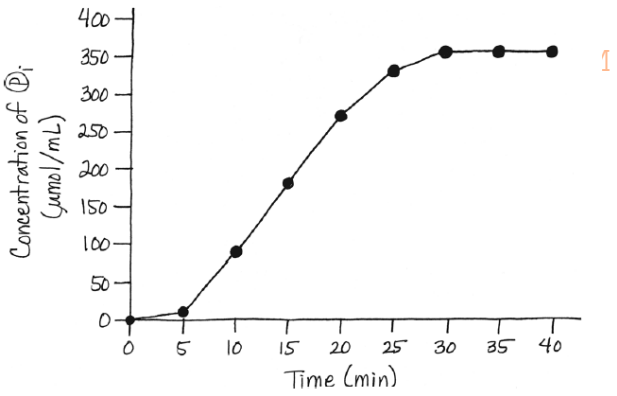
stays the same depth on the ground, like the $(P)_i$ concentration in the buffer stays the same after the enzyme has stopped functioning.

Answers:

1. (a) By taking samples every 5 minutes, the researchers intentionally varied the amount of time elapsed since the addition of substrate. Thus, time is the independent variable and should be on the *x*-axis. **(b)** The units for time are "min" (the abbreviation for minutes). **(c)** The variable that is being measured, which depends on the time since substrate addition, is the concentration of $(P)_i$ in the buffer due to its release by the cells. This is the dependent variable and should go on the *y*-axis. **(d)** The units for the concentration of $(P)_i$ are µmol/mL, which means micromoles of $(P)_i$ per milliliter of sampled buffer.

2. (a) The largest value to go on the *x*-axis is 40 min. It is reasonable to label tick marks every 5 min, and the highest should be at 40 min. (It is also acceptable to label ticks every 10 min—this is a matter of choice.) **(b)** The largest value to go on the *y*-axis is 355 µmol /mL. It is reasonable to label tick marks every 50 µmol /mL, so the highest tick should be at 400 µmol /mL. (You could also choose to label every 100 µmol /mL, but it would be more difficult to figure out where to place the points.)

3.



4. (a) The concentration of $(P)_i$ does increase over time, but not in a linear pattern. The concentration is low for the first 5 minutes, then increases steadily for the next 15 minutes, then the rate of increase slows down, and finally the concentration stays the same for the rest of the experiment. **(b)** The highest rate of enzyme activity occurred where the line has the steepest slope, from 5 to 20 minutes. The slope is calculated as $\Delta y/\Delta x$; for the steepest region the slope is (270 – 10) µmol/mL divided by (20 – 5) minutes = 17.3 µmol/mL · min. **(c)** When the substrate is first added, there is a lag time before product appears in the buffer because the substrate has to be transported into the cells and processed by the enzyme, and then the product has to be released from the cells into the buffer. After the rate of transport becomes steady, the concentration of $(P)_i$ reflects the enzyme activity level. As the rate slows down (where the line

plateaus), the concentration is unchanging—there is no additional $(P)_i$ being released into the buffer because the cells have used up the substrate.

5. If your blood sugar level is low, this reaction will occur in your liver cells:

$$\text{Glucose 6-phosphate} \xrightarrow{\text{Glucose 6-phosphatase}} \text{Glucose} + (P)_i$$

Your blood sugar level will increase as glucose is released from your liver cells into your bloodstream.

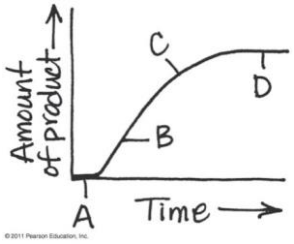
Interpret the Data

Figure 6.16(b) The optimal pH for pepsin is 2.0. Natural selection likely resulted in pepsin's optimal temperature because 2.0 is the pH inside the stomach, as seen in Figure 2.24. The optimal pH for trypsin is 8.0.

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and a suggested rubric at the beginning of this document.

8. Scientific Inquiry/Draw It



A. The substrate molecules are entering the pancreatic cells, so no product is made yet.
B. There is sufficient substrate, so the reaction is proceeding at a maximum rate.
C. As the substrate is used up, the rate decreases (the slope is less steep).
D. The line is flat because no new substrate remains and thus no new product appears.

9. Science, Technology, and Society
This answer depends on your personal viewpoint. Some might argue that improving crop yields is of paramount importance in a world where many are starving, considering that rapid breakdown of the compounds means the risk of harm to humans is low. Others might argue that although short-lived, organophosphates are highly toxic to humans who work in agriculture and not worth the risk. Also, other organisms, including bees and other pollinating insects, birds, and small mammals, could be affected. It is often impossible to predict the negative effects on ecosystems and therefore not worth the risk.

10. Focus on a Theme: Evolution

For a given metabolic pathway, its current function is accomplished by a complex series of reactions catalyzed by a specific set of enzymes. However, earlier versions of the pathway may have existed that accomplished the same or different functions. Organisms with cellular enzymes for carrying out the earlier pathway may have had mutations that allowed new enzymes to arise. These new enzymes could have participated in the earlier pathway, modifying the pathway in a way advantageous to the organism. If natural selection caused the new genes to be passed on because the organism survived better, this would represent one step in a gradual modification of a biochemical pathway. With additional steps taking place over long periods of time, this is a plausible model for how evolutionary processes could have resulted in any biochemical pathway seen in organisms today. This evolutionary process could have happened differently in distinct lineages of organisms. The existence of diverse pathways to produce the same or similar products argues in support of this model.

11. Focus on a Theme: Energy and Matter

Sample key points:

- Energy enters an animal cell in the form of the chemical potential energy of fuel molecules such as glucose.
- Energy enters a plant cell in the form of light, which is converted to the chemical energy of sugars.
- The transfer and transformation of energy increase entropy, and a cell returns heat and the low-energy molecules of CO_2 and H_2O to its surroundings.
- In energy coupling, the free energy released by exergonic chemical reactions is used to drive endergonic reactions.
- ATP represents a store of energy that links catabolic pathways to anabolic pathways.
- The hydrolysis of ATP also drives the mechanical and transport work of a cell.
- Enzymes are required for all the chemical reactions of a cell. By lowering the activation energy, enzymes enable specific reactions to occur more quickly.

Sample top-scoring answer:

The work of a cell requires energy. Energy enters an animal cell as the chemical energy of fuel molecules such as glucose. In a photosynthesizing cell, light energy drives the synthesis of sugars, which in turn provide the energy for metabolism. The free energy released by the exergonic reactions of catabolic pathways is stored in ATP. The energy released by the hydrolysis of ATP to ADP and $(P)_i$ drives the endergonic reactions of anabolic pathways, which synthesize the complex molecules of a cell. Also, during the hydrolysis of ATP in mechanical and transport work, potential energy is transformed into kinetic energy. In these transfers and transformations, some energy is lost as heat, and the cell returns the less ordered molecules of CO_2 and H_2O to its surroundings. All the reactions of a cell require enzymes, which ensure efficient cell function by binding substrates and lowering activation energy, thus speeding up metabolic reactions.

11. Synthesize Your Knowledge

On top of the glacier the penguins have potential energy, which is transformed into kinetic energy as they slide down the slope and dive into the water. Climbing back up the glacier and gaining potential energy requires the activity of muscles. To power the muscle function that