Chapter 1

An Overview of the AP Biology Exam

This chapter introduces you to the AP Biology exam. You'll learn how this book can aid you in your preparation and what to bring on exam day. It also details the format of the exam and how it is scored. The "What's on the Exam" section outlines the topics that are covered on the exam and offers strategies for answering the two question types: multiple-choice and free-response. The last section of this chapter details how to best use the practice exams in this book to enhance your study.

How You Should Use This Book

The Advanced Placement program is designed to encourage students to take challenging courses in high school and receive college credit for their efforts. Many high schools offer classes especially designed for the AP program, but any course or program of study, whatever it is called, is appropriate preparation for taking the AP exam if the content is at the college level. This book helps you to prepare for the Advanced Placement Examination in Biology. It does this in three ways:

- It reviews the important material that you need to know for the actual AP exam. These reviews are detailed but written in an organized and condensed format, making them especially useful for studying.
- It provides you with review questions that reinforce the review. Many of the review questions, like those on the AP exam, require considerable thought to determine the correct answer. In addition, some of the review questions ask you to apply the reviewed material to new situations and, as a result, increase your breadth of understanding. Answers with complete explanations provide additional opportunities to understand the material.
- It offers two complete practice exams, giving you the opportunity to evaluate your knowledge and your test-taking skills. Taking these practice exams helps to improve your AP exam score because they are similar in content and format to the actual AP exam. Answers with complete explanations are given for each question, and a scoring worksheet is provided to help you determine your score.

When preparing for a test, have you ever wished that you had a copy of your teacher's lecture notes? The review sections in this book are very much like lecture notes. Each section contains all of the important terminology with brief descriptions. All of the important biological processes are outlined with a key word or phrase, listed in an easy-to-remember sequence. After each key word or phrase, a short explanation is given. When you study the material the first time, you can read the key words and the short explanations. When you review, you can just study the key words, rereading the explanations only as needed.

You should consider this book, however, as a supplement to your textbook, your laboratory exercises, and your teacher's lectures. Much of the excitement and adventure of biology can be obtained only through hands-on activities and discussions with teachers. In addition, textbooks provide background information, extensive examples, and thought-provoking questions that add depth to your study of biology. Each time you study a topic in class, after listening to the lectures and reading the textbook, use this book to review. Underline or highlight material to help you remember it. Write in the margins, noting any additional material that you heard in lectures or read in your textbook that you or your teacher thinks is important. Then answer the review questions and read the answer explanations at the end of each chapter. This will reinforce your learning.

At the end of your biology course, this book will be a single, condensed source of material to review before the AP exam. Begin your final preparation several weeks before the AP exam by reviewing the material in each chapter. Then take the two practice exams at the end of this book.

What to Bring to the Exam

1. A No. 2 pencil and an eraser are required for the multiple-choice section.
2. A pen with black or dark-blue ink is required for the free-response section.
3. A calculator with a 4-function (+, –, ×, ÷) and square-root capability is allowed for the entire exam. Programmable, graphing, and cell-phone calculators are not permitted. A calculator will be especially useful for the free-response questions but may be used for multiple-choice questions as well. Buy this calculator as soon as possible so that you can begin using it early in your biology course. Practice with the calculator frequently so that you are as familiar with it as you are with your cell phone. You don't want to spend time figuring out how to take a square root for the first time during the AP exam.
4. You are not allowed to bring your own scratch paper. For the multiple-choice section, you can use the margins of your exam booklet. For the free-response section, scratch paper is provided.
5. Obviously, you are not allowed to use any prepared notes. However, you will be provided with a list of equations and formulas. The Equations and Formulas pages are provided in this book at the beginning of "Part 3: AP Biology Practice Exams."

Exam Format

The AP Biology exam consists of two sections. Section I consists of 60 multiple-choice questions. These questions are often presented in sets of three to five related questions that refer to a descriptive paragraph, a set of data, or a figure. Each multiple-choice question provides four answer choices. Section II consists of six free-response questions. Two of these questions are long and evaluate your understanding and ability to interpret experimental data. One of these two questions may require graphing. The other four are short-answer questions. All questions, long and short, have four parts, each of which provides focus for your answer. Before you begin a free-response question, read the question carefully to organize your thoughts—underline or circle key words, record notes, or create an outline on provided paper. You have 90 minutes to complete each section of the exam, and each section counts toward 50% of your exam score. The exam is administered in May of each year, along with AP exams in other subjects.

	Type of Question	Number of Questions	Question Weight	Section Weight	Approximate Time Recommended per Question	Time Allowed
Section I	Multiple-Choice	60	1 point each	50%	1½ minutes	90 minutes
Section II	Long Free-Response	2	8–10 points each	50%	20 minutes	90 minutes
	Short Free-Response	4	4 points each		12 minutes	

Exam Grading

Exams are graded on a scale of 1 to 5, with 5 being the best. Most colleges accept a score of 3 or better as a passing score. If you receive a passing score, colleges give you college credit (applied toward your bachelor's degree), advanced placement (you can skip the college's introductory course in biology and take an advanced course), or both. You should check with the biology department at the colleges you're interested in to determine how they award credit for the exam.

The distribution of student scores for some recent AP Biology exams is shown here.

			Student Performance*			
	Exam Grade	College Grade Equivalent	2016	2017	2018	2019
Extremely well qualified	5	A+, A	6.6%	6.4%	7.2%	7.2%
Well qualified	4	A–, B+, B	21.0%	21.0%	21.6%	22.2%
Qualified	3	B–, C+, C	33.6%	36.7%	32.8%	35.3%
Possibly qualified	2	n/a	28.8%	27.5%	28.3%	26.6%
No recommendation	1	n/a	10.1%	8.4%	10.2%	8.8%
Mean score (1 to 5)			2.85	2.90	2.87	2.92

**Percentages may not total 100 due to rounding.*

The multiple-choice section is designed with a balance of easy and difficult questions to produce a mean score of 50%. Scores for free-response questions vary significantly with individual questions and from year to year. On recent exams, mean scores ranged from 2.01 to 5.20 for the 10-point free-response questions and 0.96 to 2.66 for the 4-point free-response questions. Clearly, both sections of the exam are difficult. They are deliberately written that way so that the full range of students' abilities can be measured. In spite of the exam difficulty, however, more than 63% of the students taking recent exams received a score of 3 or better. Therefore, the AP exam is difficult, but most (prepared) students do well.

What's on the Exam

Theodosius Dobzhansky, a famous geneticist, once wrote an essay entitled "Nothing in Biology Makes Sense Except in the Light of Evolution." Similarly, many diverse topics in biology cannot be fully appreciated without studying them through the multiple lenses of other biology topics. Biology is not just a set of individual concepts or processes to be studied in isolation. Biology is a web of interconnecting themes. To fully grasp a theme, you must understand how it is shaped and influenced by other themes.

To address this web of interconnecting themes, the College Board has organized the course around four broad principles, called "Big Ideas," each of which encompasses a variety of unifying concepts. These are the four Big Ideas:

Big Ideas	Topics
Big Idea 1: Evolution	Evolution, Heredity, Gene Expression, Ecology
Big Idea 2: Energetics	Chemistry, Cells, Respiration, Photosynthesis, Cell Communication, Ecology
Big Idea 3 Information Storage and Transmission	Chemistry, Cells, Cell Communication, Heredity, Gene Expression, Ecology
Big Idea 4: Systems Interactions	Chemistry, Cells, Respiration, Photosynthesis, Heredity, Evolution, Ecology

As you can see, each Big Idea has multiple overlapping topics. That's why they are called *Big* Ideas. Although each chapter of this book focuses on an individual topic, as you progress through your study of the topics, each Big Idea will begin to take shape.

This book reviews every concept included in the AP Biology curriculum framework and its accompanying lab manual (*AP Biology Investigated Labs, An Inquiry-Based Approach*). It carefully *excludes* those concepts that are omitted from the framework and lab manual (but are often included in college biology textbooks). This book is what you need to know—no more, no less. Keep in mind, however, that the AP exam varies from year to year and will have questions that only cover a select portion of all the framework concepts.

The table that follows outlines the major topics that are covered on the exam and how much of that topic is represented. Depending on the exam, the weight of each topic varies. But realistically, except for evolution, they are all fairly equally represented. Evolution gets a slightly higher weight. The take-home message here is you need to know all of the topics.

Chapter	Topic	Exam Weighting
2	Chemistry of Life	8–11%
3	Cell Structure and Function	10–13%
4	Cellular Respiration	12–16%
5	Photosynthesis	
6	Cell Communication	10–15%
7	Cell Cycle	
8	Heredity	8–11%
9	Gene Expression and Regulation	12–16%
10	Evolution	13–20%
11	Ecology	10–15%

As you probably have already discovered, biology consists of a lot of technical words, concepts, and processes. It is often much easier to study a topic in detail, when the connections among the words, concepts, and processes are presented together, before going on to the next topic. As you read your textbook and review with this book, it is important to remember that the AP exam will test not just your knowledge of individual topics, but how various topics contribute to overlapping themes. Multiple-choice questions, and especially free-response questions, will evaluate how well you understand this big picture of biology.

Keep in mind that the big picture is supported by content. For free-response questions, the quality of your content is often determined by the detail that you provide. That detail is in this book. But the AP curriculum also indicates certain material that you do not need to know for the exam. If that material appears in this book, it does so to help you understand a concept or to connect the material with your textbook. That information, however, what you are *not* expected to know for the exam, is clearly identified.

Strategies for Multiple-Choice Questions

On the AP exam, questions for the multiple-choice section are provided in a booklet. While reading the questions in the booklet, feel free to cross out answer choices you know are wrong or underline important words. After you've selected the answer from the various choices, you carefully fill in bubbles labeled A, B, C, or D on an answer sheet. Mark only your answers on the answer sheet. Since unnecessary marks can produce machine-scoring errors, be sure to fill in the bubbles carefully and erase errors and stray marks thoroughly.

Some specific strategies for answering the multiple-choice questions follow:

1. **Don't leave any answers blank.** There is no penalty for guessing. You get 1 point for each correct answer. If you leave it blank or if you get it wrong, you get 0 points. If you're not sure of the answer to a question, eliminate any answer choices you think are wrong and then select one of the remaining answer choices. If you can't eliminate any wrong answers, you still have a 25% probability (1 chance in 4) of choosing the correct answer by guessing. If you can eliminate one or more wrong answers, your probability of getting it right increases.
2. **Don't let easy questions mislead you.** The multiple-choice questions range from easy to difficult. On one exam, 92% of the candidates got the easiest question right, but only 23% got the hardest question right. Don't let the easy questions mislead you. If you come across what you think is an easy question, it probably is. Don't suspect that it's a trick question.

3. **Budget your time.** You have 90 minutes to answer 60 multiple-choice questions; that's about 1½ minutes per question. Read the question and consult any diagrams or graphs. Read all the answer choices, crossing out any you think are wrong. Then choose or, if necessary, guess the correct answer and mark your answer sheet. Remember, there's no penalty for wrong answers! It's better to move on to the next question so that you will have the opportunity to try all of the questions.
4. **Skip hard questions.** If you come across a hard question that you can't answer quickly, skip it, and mark the question to remind you to return to it if time permits. If you can eliminate some of the answer choices, mark those also so that you can save time when you return. It's important to skip a difficult question, even if you think you can eventually figure it out, because for each difficult question you spend 3 minutes on, you could have answered two easy questions. If you have time at the end of the exam, you can always go back. If you don't have time, at least you will have had the opportunity to try all of the questions. Also, if you don't finish the section, don't be overly concerned. Since the exam is designed to obtain a mean score of 50%, it is not unusual for a student to run out of time before reaching the end of the section. But don't leave any answers blank (see #8, below).
5. **Judge time requirements for questions.** Some multiple-choice questions begin with a long description followed by three to five associated questions. These questions make good use of your time because once you've read the introduction, you're ready to answer all of the associated questions. On the other hand, some multiple-choice questions with long introductory descriptions are followed by a single question. These questions require proportionately more time than if followed by multiple questions. Skip these questions with long introductions and a single question if you think you're running low on time. Return to them if time is available.
6. **Carefully answer reverse multiple-choice questions.** In a typical multiple-choice question, you need to select the answer choice that is true. On the AP exam, you may find a *reverse* multiple-choice question where you need to select the *false* answer choice. These questions usually use the word "EXCEPT" in sentences such as "All of the following are true EXCEPT . . ." or "All of the following occur EXCEPT. . . ." A reverse multiple-choice question is more difficult to answer than regular multiple-choice questions because it requires you to know three true pieces of information about a topic before you can select the false answer choice. It is equivalent to correctly answering four true-false questions to get 1 point; and if you get one of the four wrong, you get them all wrong. Reverse multiple-choice questions are also difficult because halfway through the question you can forget that you're looking for the false answer choice. To avoid confusion, do the following: After reading the opening part of the question, *read each answer choice and mark a T or an F next to each one to identify whether it is true or false.* If you're able to mark a T or an F for each one, then the correct answer is the choice marked with an F. Sometimes you won't be sure about one or more choices, or sometimes you'll have two choices marked F. In these cases, concentrate on the uncertain choices until you can make a decision.
7. **Return to difficult questions *only* if you have time.** Here's one thing to consider when skipping a question: If you return to a question, you will need to read the question, read the answer choices, and consult the diagrams. This is a costly strategy because you already spent time doing that once. Only do this if you've already tried to answer all of the other questions in Section I.
8. **Save the last minute to mark all unanswered questions.** Because the exam is designed to obtain a mean score of 50%, some students may not have enough time to read all of the questions. Should this happen to you, be sure to mark answers for all of your remaining unanswered questions. Remember, there's no penalty for wrong answers!

Strategies for Free-Response Questions

The free-response questions are provided in a separate booklet. Read each of the four parts of a question thoroughly, circling key words. Next, write a brief outline using key words to organize your thoughts. If you choose not to write an outline, go back and reread the question halfway through writing your answer. It's easy to get carried away, and by the end of your response you might be answering a different question. Also, make sure that you haven't written the same answer for more than one part; if so, choose the part most appropriate for your answer and write something different for the other part.

Each of the two long free-response questions is worth 8–10 points. Each of the four short free-response questions is worth 4 points.

Strategies for answering the free-response questions follow:

1. **Don't approach the free-response section with apprehension.** Most students approach the free-response section of the exam with more anxiety than they have when approaching the multiple-choice section. However, in terms of the amount of detail in the knowledge required, the free-response section is easier. On these questions, *you* get to choose what to write. You can get an excellent score without writing every relevant piece of information. Besides, you don't have time to write an entire book on the subject. A general answer that addresses the question with a limited number of specifics will get a good score. Additional details may (or *may not*) improve your score, but the basic principles are the most important elements for a good score. In contrast, a multiple-choice question focuses on a very narrow and specific body of knowledge, which you'll either know or you won't; it doesn't let you select from a range of correct information.
2. **Keep your answers brief for the short free-response questions.** Some short questions will be very general and seem to be asking for a whole lot of information, as if it were a long question. If you get a short question like this, don't freak out because you think that it will take 20 minutes to write down everything you know. Instead, try to answer each part of the question as concisely and briefly as possible. Come back and add more details if you have time. Other short questions will have parts that will require more specific answers and won't require a lengthy explanation.
3. **Give specific information in your answer.** You need to give specific information for each free-response question. Don't be so general that you don't really say anything. Give more than just terminology with definitions. You need to use the terminology to explain biological processes. The combination of using the proper terminology and explaining processes will convince an AP exam reader that you understand the answer. Give some detail when you know it—names of processes, names of structures, names of molecules—and then tell how they're related. The exam reader is looking for specific information. If you say it, you get the points. You don't have to say everything, however, to get the maximum number of points.
4. **Answer each part of a free-response question separately.** You should answer each part of the question in a separate paragraph, which helps the exam reader recognize each part of your answer. Questions are formally divided into parts, such as a, b, c, and d, so label your paragraphs a, b, c, and d.
5. **Answer all parts of a free-response question.** It is extremely important that you give a response for each part of the question. Don't overload the detail on one part at the expense of saying nothing in another part because you ran out of time. Each part of the question is apportioned a specific number of points. If you give abundant information in one part and nothing in the remaining parts, you receive only the maximum number of points allotted to the part you completed. Each part of a long question may earn between 1 and 4 points; in a short question, each part is worth 1 point. You won't get any extra points above the established maximum, even if what you write is Nobel Prize–quality.
6. **Don't answer more parts than required.** Some free-response questions may give you a choice of parts to answer. Choose the parts that you know the most about and answer only those parts. Do not answer extra parts. *There is no extra credit on this exam!* In general, an exam reader will not read beyond the required number of answers. In cases where the exam reader does read the extra parts, you may lose points if you contradict something you said correctly in an earlier required part.
7. **Budget your time.** You have 90 minutes to answer six free-response questions. Allow 20 minutes for each of the two long questions (40 minutes total) and about 12 minutes for each of the four short questions (48 minutes total). That's 5 minutes per part for the long questions and 3 minutes per part for the short questions. When you begin this section, identify the questions you think you can answer the best and answer those questions first. However, just as it's most important to answer all parts of a question, it's best to respond to ALL of the free-response questions and all of their parts instead of leaving blank parts. You'll probably know *something* about every part of each question, so be sure you get that information written. If you are nearing the end of the 90-minute period and you still have several questions to answer, use that time to write something for each of the remaining questions. One point, especially on a short free-response question, is a lot better than zero.

8. **Don't worry if you make a factual error.** What if you write something that is incorrect? The AP exam readers look for correct information. They search for key words and phrases and award points when they find them. If you use the wrong word to describe a process, or identify a structure with the wrong name, no formal penalty is assessed. If you're going to get any points, however, you need to write correct information. Also, you'll lose points if you contradict something you said correctly earlier.
9. **Don't be overly concerned about grammar, spelling, punctuation, or penmanship.** The AP exam readers don't penalize for incorrect grammar, spelling, or punctuation or for poor penmanship. They are interested in *content*. However, if your grammar, spelling, or penmanship impairs your ability to communicate, then the exam readers cannot recognize the content, and your score will suffer.
10. **Don't write a standard essay.** Don't spend your time writing a standard essay with an introduction, supporting paragraphs, and a conclusion. Just dive right in and answer the question directly. On the other hand, your response cannot be an outline; it must have complete sentences and be written in paragraph form.
11. **Don't repeat the question in your answer.** Or do so only briefly. The exam reader knows the question.
12. **Improve your score by incorporating drawings.** Drawings and diagrams may sometimes add as much as 1 point to your free-response score. But the drawings must be explained in your response, and the drawings must be labeled with supporting information. If not, the AP exam reader will consider them doodles, and you will get no additional points.
13. **Pay attention to direction words.** A direction word is the first word in a free-response question that tells you how to answer the question. The direction word tells you what you need to say about the subject matter that follows. Here are the most common direction words found on the AP exam:
    - *Describe* means to characterize or give an account in words.
    - *Explain* means to clarify or make understandable.
    - *Identify* means to name a structure, process, or concept (no explanation is required).
    - *Justify* means to provide evidence or reasoning to support a claim.
    - *Represent* means to provide information in a graph, drawing, table, or mathematical expression.
    - *Compare* means to discuss two or more items with an emphasis on their *similarities*.
    - *Contrast* means to discuss two or more items with an emphasis on their *differences*.

    Specialized direction words are used for questions that evaluate your quantitative skills. These words include *design* (an experiment), *calculate* or *determine* (a value), and *construct* and *label* (a graph). These words have specific meanings for laboratory analyses and are discussed in Chapter 12, "Review of Laboratory Investigations."

Taking the Practice Exams

For each of the practice exams, a scoring template is provided. Each exam is followed by an answer key for the multiple-choice questions, explanations for these questions, and scoring standards for the free-response questions (often called a rubric).

To get the full benefit of simulating a real AP exam, set aside at least 3 hours for each practice exam. Begin with the multiple-choice section (Section I), and after 90 minutes, stop and move on to the free-response section (Section II). Allow yourself 90 minutes to write out your full answers. By using the actual times that the real AP exam allows, you will learn whether the time you spend on each multiple-choice and free-response question is appropriate. When you're done taking a practice exam, score your exam using the multiple-choice answer key and the free-response scoring standards. Then go back and answer any multiple-choice questions that you were unable to complete in the allotted 90 minutes. When you are done, read all of the multiple-choice explanations, even those for questions you got right. The explanations are thorough and provide you with information and suggestions. Even if you know the answers, reading the provided explanations is good review.

Although you've heard it so many times, practice *will* improve your test performance (although it's unlikely to make you perfect). So be sure to complete both practice exams and review all of the answer explanations. Good luck!

PART 1

SUBJECT AREA REVIEWS WITH REVIEW QUESTIONS AND ANSWERS

Chapter 2

Chemistry of Life

Review

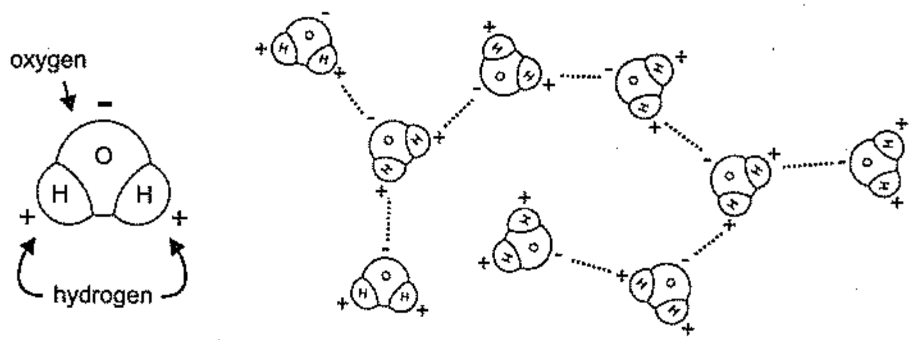
A major difference between an AP biology course and a regular high school biology course is the emphasis on detail. In many cases, that detail derives from a description of the molecular structure of molecules and the chemistry of metabolic reactions. It is the understanding of biological processes at the molecular level that provides you with a more thorough understanding of biology. The AP examiners want to know whether you have this kind of understanding. With that in mind, your studying should begin with a brief review of chemistry and the characteristics of major groups of biological molecules.

Although chemistry deepens your understanding of biology, the AP exam will not ask you to draw molecular structures, to distinguish fine differences between molecules, or to identify specific names of molecules. You will only need to be able to recognize very major distinctions between groups of similar types of molecules.

Atoms, Molecules, Ions, and Bonds

An **atom** consists of a nucleus of positively charged protons and neutrally charged neutrons. Negatively charged electrons are arranged outside the nucleus. **Molecules** are groups of two or more atoms held together by chemical bonds. Chemical bonds between atoms form because of the interaction of their electrons. The **electronegativity** of an atom, or the ability of an atom to attract electrons, plays a large part in determining the kind of bond that forms. There are three kinds of bonds, as follows:

1. **Ionic** bonds form between two atoms when one or more electrons are *transferred* from one atom to the other. This bond occurs when the electronegativities of the atoms are very different and one atom has a much stronger pull on the electrons (high electronegativity) than the other atom in the bond. The atom that gains electrons has an overall negative charge, and the atom that loses electrons has an overall positive charge. Because of their positive or negative charges, these atoms are **ions.** The attraction of the positive ion to the negative ion constitutes the ionic bond. Sodium and chlorine form ions (Na^+ and Cl^-), and the bond formed in a molecule of sodium chloride (NaCl) is an ionic bond.
2. **Covalent** bonds form when electrons between atoms are *shared,* which means that neither atom completely retains possession of the electrons (as happens with atoms that form strong ionic bonds). Covalent bonds occur when the electronegativities of the atoms are similar.
   - **Nonpolar covalent** bonds form when electrons are *shared equally.* When the two atoms sharing electrons are identical, such as in oxygen gas (O_2), the electronegativities are identical, and both atoms pull equally on the electrons.
   - **Polar covalent** bonds form when electrons are *shared unequally.* Atoms in this kind of bond have electronegativities that are different, and an unequal distribution of the electrons results. The electrons forming the bond are closer to the atom with the greater electronegativity and produce a negative charge, or **pole,** near that atom. The area around the atom with the weaker pull on the electrons produces a positive pole. In a molecule of water (H_2O), for example, electrons are shared between the oxygen atom and each hydrogen atom. Oxygen, with a greater electronegativity, exerts a stronger pull on the shared electrons than does each hydrogen atom. This unequal distribution of electrons creates a negative pole near the oxygen atom and positive poles near each hydrogen atom (Figure 2-1).
   - **Single covalent, double covalent,** and **triple covalent** bonds form when two, four, and six electrons are shared, respectively.
3. **Hydrogen** bonds are weak bonds between *molecules.* They form when a positively charged *hydrogen* atom in one covalently bonded molecule is attracted to a negatively charged area of another covalently bonded molecule. In water, the positive pole around a hydrogen atom forms a hydrogen bond to the negative pole around the oxygen atom of *another* water molecule (Figure 2-1).

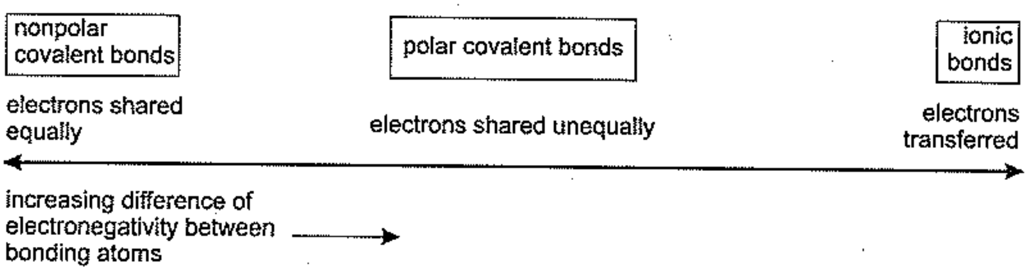


A space-filling model of a water molecule showing polarity created by covalent bonds

Hydrogen bonding between water molecules

Figure 2-1

When you think of chemical bonds, imagine a continuum based on the differences of electronegativities (Figure 2-2). The left end represents bonds that form when no differences exist in the electronegativities of the atoms. Electrons are shared equally, and nonpolar covalent bonds form. The right end represents bonds that form when very large differences in electronegativities exist. Electrons are transferred from one atom to another, and ionic bonds form. When the electronegativities of the atoms are different, but not strongly so, the electrons are shared unequally, and polar covalent bonds form; this activity is represented by the center of Figure 2-2. The kind of bond that forms between two atoms and the strength of that bond depend upon the difference of electronegativities of the atoms and might occur any place along the line shown in Figure 2-2.



Types of Chemical Bonds

Figure 2-2

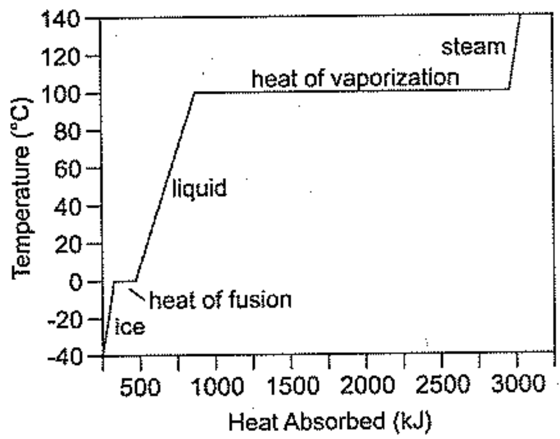
Properties of Water

The polarity of water molecules and the hydrogen bonds that result from that polarity contribute to some very special properties for water:

1. *Water is an excellent* **solvent.** Ionic substances are soluble (they dissolve) in water because the poles of the polar water molecules interact with the ionic substances and separate them into ions. Substances with polar covalent bonds are similarly soluble because of the interaction of their poles with those of water. Substances that dissolve in water are called **hydrophilic** ("water loving"). Because they lack charged poles, nonpolar covalent substances do not dissolve in water and are called **hydrophobic** ("water fearing"). Because so many kinds of molecules are soluble in water, water is often referred to as a universal solvent. In general, a **solute** is a substance that dissolves in a solvent. When that solvent is water, the solution is called an **aqueous** solution.
2. *Water has a high* **specific heat capacity.** Specific heat is the degree to which a substance changes temperature in response to a gain or loss of heat. Water has a high specific heat, changing temperature very slowly with changes in its heat content. You must add a relatively large amount of energy to warm (and boil) water or

remove a relatively large amount of energy to cool (and freeze) water. When sweat evaporates from your skin, a large amount of heat is taken with it and you are cooled ("evaporative cooling"). When water changes physical states, from solid to liquid or liquid to gas, energy is absorbed but the water temperature remains constant. The absorbed energy is used only to change the physical state of the water by breaking the hydrogen bonds that tether the water molecules together. In the reverse reactions, from gas to liquid or liquid to solid, the energy released reestablishes the hydrogen bonds. In Figure 2-3, the horizontal lines between the physical states of water indicate the absorption of energy without a rise in temperature. The energy associated with each of these transitions has a special name:

- **Heat of fusion** is the energy required to change water from a solid to a liquid.
- **Heat of vaporization** is the energy required to change water from a liquid to a gas.



Temperature of Water as a Function of Heat Absorbed

Figure 2-3

3. *Ice floats.* Unlike most substances that contract and become more dense when they freeze, water *expands* as it freezes, becomes less dense than its liquid form, and, as a result, floats in liquid water. Hydrogen bonds are typically weak, constantly breaking and reforming, allowing molecules to periodically approach one another. In the solid state of water, the weak hydrogen bonds between water molecules become rigid and form a crystal that keeps the molecules separated and less dense than its liquid form. If ice did not float, it would sink and remain frozen due to the insulating protection of the overlaying water. This would have a profound effect on the survival of organisms inhabiting the bottom of bodies of water.
4. *Water has strong* **cohesion** *and high* **surface tension.** Cohesion, or the attraction between *like* substances, occurs in water because of the hydrogen bonding between water molecules. The strong cohesion between water molecules produces a high surface tension, creating a water surface that is firm enough to allow many insects to walk upon it without sinking.
5. *Water has strong* **adhesion.** Adhesion is the attraction of *unlike* substances. This results from the attraction of the poles of water molecules to other polar substances. If you wet your finger, you can easily pick up a straight pin by touching it because the water on your finger adheres to both your skin and the pin. Similarly, some people wet their fingers to help them turn pages. When water adheres to the walls of narrow tubing or to absorbent solids like paper, it demonstrates **capillary action** by rising up the tubing or creeping through the paper.

Organic Molecules

Organic molecules are those that have carbon atoms. In living systems, large organic molecules, called **macromolecules,** may consist of hundreds or thousands of atoms. Most macromolecules are **polymers,** molecules that consist of a single group of atoms **(monomer)** repeated many times.

Four of carbon's six electrons are available to form bonds with other atoms. Thus, you will always see four lines connecting a carbon atom to other atoms, each line representing a pair of shared electrons (one electron from carbon and one from another atom). Complex molecules can be formed by stringing carbon atoms together in a straight line or by connecting carbons together to form rings. The presence of nitrogen, oxygen, and other atoms adds additional variety to these carbon molecules.

Many organic molecules share similar properties because they have similar clusters of atoms, called **functional groups.** Each functional group gives the molecule a particular property, such as acidity or polarity. The more common functional groups with their properties are listed in Figure 2-4.

Functional Group		Examples	Characteristics
—OH	hydroxyl	alcohols (e.g., ethanol), glycerol, sugars	polar, hydrophilic
—C(=O)—OH	carboxyl	acetic acid, amino acids, fatty acids, sugars	polar, hydrophilic, weak acid
—N(—H)—H	amino	amino acids	polar, hydrophilic, weak base
—P(=O)(—O⁻)—O⁻	phosphate	DNA, ATP, phospholipids	polar, hydrophilic, acid
—C(—H)(—H)—H	methyl	fatty acids, oils, waxes	nonpolar, hydrophobic

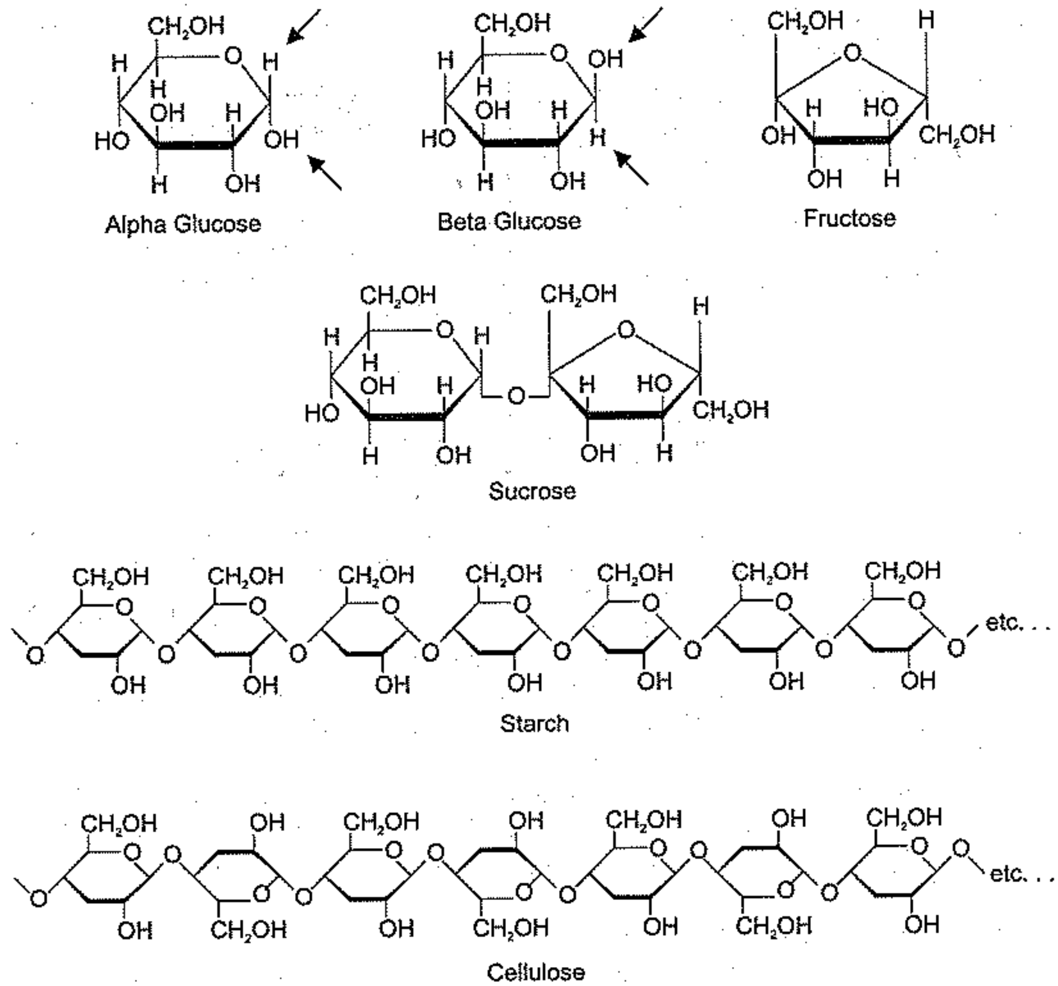
Functional Groups
Figure 2-4

Four important classes of organic molecules—carbohydrates, lipids, proteins, and nucleic acids—are discussed in the following sections. Although specific examples are provided, the AP exam does not require that you know their formulas. However, you should know the general characteristics that distinguish one group of molecules from another.

Carbohydrates

Carbohydrates are classified into three groups according to the number of sugar (or saccharide) molecules present:

1. A **monosaccharide** is the simplest kind of carbohydrate. It consists of a single sugar molecule, such as fructose or glucose (Figure 2-5). (Note that the symbol C for carbon may be omitted in ring structures; a carbon exists wherever four bond lines meet.) Sugar molecules have the formula $(CH_2O)_n$, where n is any number from 3 to 8. For **glucose,** n is 6, and its formula is $C_6H_{12}O_6$. The formula for **fructose** is also $C_6H_{12}O_6$, but as you can see in Figure 2-5, the placement of the carbon atoms is different. Two forms of glucose, **α-glucose** and **β-glucose,** differ simply by a reversal of the H and OH on the first carbon (clockwise, after the oxygen). As you will see below, even very small changes in the position of certain atoms may dramatically change the chemistry of a molecule.



Carbohydrates

Figure 2-5

2. A **disaccharide** consists of two sugar molecules joined by a **glycosidic linkage.** During the process of joining, a water molecule is lost. Thus, when glucose and fructose link to form sucrose, the formula is $C_{12}H_{22}O_{11}$ (not $C_{12}H_{24}O_{12}$) (Figure 2-5). This type of chemical reaction, where a small molecule is lost, is generally called a **condensation reaction** (or specifically, a **dehydration reaction,** if the lost molecule is water). The reverse reaction, where one molecule is *split* to form two molecules by the *addition* of water, is called **hydrolysis.** The formation of some common disaccharides with their dehydration reactions follows:
   - glucose + fructose = H_2O + **sucrose** (common table sugar)
   - glucose + galactose = H_2O + **lactose** (the sugar in milk)
   - glucose + glucose = H_2O + **maltose** (a product of the breakdown of starch)

3. A **polysaccharide** consists of a series of connected monosaccharides. Thus, a polysaccharide is a polymer because it consists of repeating units of a monosaccharide. The following examples of polysaccharides may contain thousands of glucose monomers (Figure 2-5):
   - **Starch** is a polymer of α-glucose molecules. It is the principal *energy storage* molecule in plant cells.
   - **Glycogen** is a polymer of α-glucose molecules. It differs from starch by its pattern of polymer branching. It is a major *energy storage* molecule in animal cells.

- **Cellulose** is a polymer of β-glucose molecules. It serves as a *structural* molecule in the walls of plant cells and is the major component of wood.
- **Chitin** is a polymer similar to cellulose, but each β-glucose molecule has a nitrogen-containing group attached to the ring. Chitin serves as a *structural* molecule in the walls of fungus cells and in the exoskeletons of insects, other arthropods, and mollusks.

The α-glucose in starch and the β-glucose in cellulose illustrate the dramatic chemical changes that can arise from subtle molecular changes: The bonds in starch (specifically, the α-glycosidic linkages) can easily be broken down (digested) by humans and other animals, but only specialized organisms, like the bacteria in the guts of termites, can break the bonds in cellulose (specifically, the β-glycosidic linkages).

Lipids

Lipids are a class of substances that are nearly insoluble in water (and other polar solvents) but are highly soluble in nonpolar substances (like ether or chloroform). There are three major groups of lipids:

1. **Triglycerides (triacylglycerols)** include fats and oils. They consist of three **fatty acids** attached to a **glycerol** molecule (Figure 2-6). Fatty acids are hydrocarbons (chains of covalently bonded carbons and hydrogens) with a carboxyl group (–COOH) at one end of the chain. Fatty acids vary in structure by the number of carbons and by the placement of single and double covalent bonds between the carbons. The double bond in a fatty acid creates a bend at the bond, slightly spreading the triglyceride apart. As a result, saturated fatty acids pack together more tightly, have higher melting temperatures, and are usually solid at room temperature (fats); in contrast, unsaturated fatty acids pack together more loosely, have lower melting temperatures, and are usually liquid at room temperature (oils).

   During the formation of a triglyceride, the carboxyl group of each fatty acid bonds to a hydroxyl group of the glycerol, releasing a water molecule. Thus, the formation of each bond is a dehydration reaction, and a total of three molecules is released when a triglyceride forms.

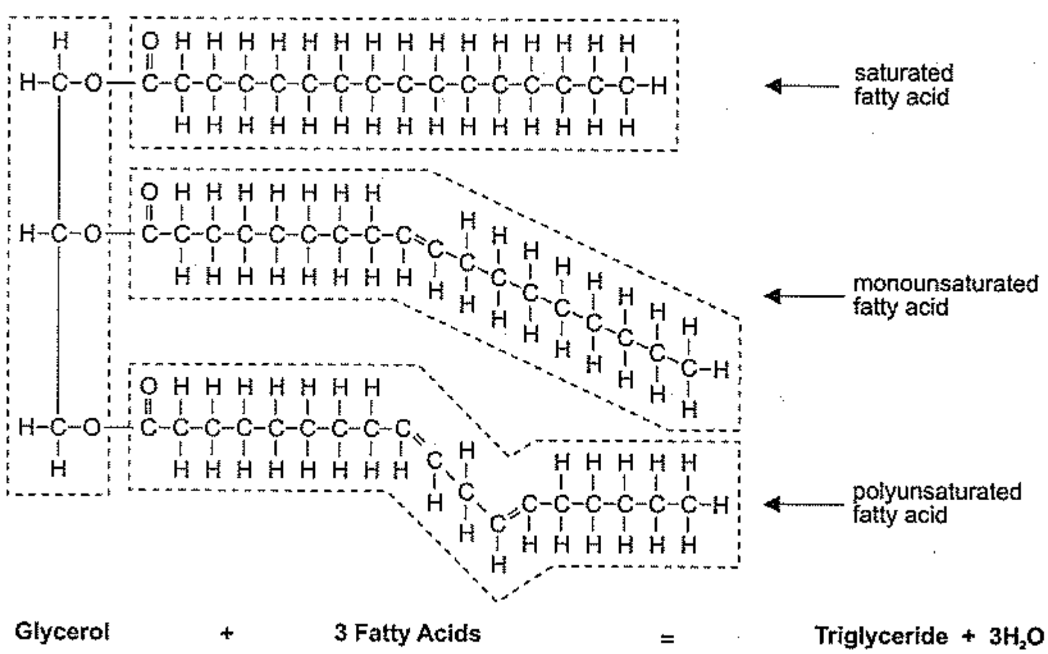


Figure 2-6

- A **saturated** fatty acid has a single covalent bond between each pair of carbon atoms, and each carbon has two hydrogens bonded to it (three hydrogens bonded to the last carbon). You can remember this by thinking that each carbon is "saturated" with hydrogen.

- A **monounsaturated** fatty acid has *one double* covalent bond, and each of the two carbons in this bond has only one hydrogen atom bonded to it.
- A **polyunsaturated** fatty acid is like a monounsaturated fatty acid except that there are *two or more double* covalent bonds.

2. A **phospholipid** looks just like a triglyceride except that one of the fatty acid chains is replaced by a phosphate group ($-PO_3^{2-}$) (Figure 2-7). An additional and variable group of atoms (indicated by R, for radical, in Figure 2-7) is covalently attached to the phosphate group. The two fatty-acid "tails" of the phospholipid are nonpolar and hydrophobic, and the phosphate "head" is polar and hydrophilic. Phospholipids are often found oriented in sandwich-like formations, with the hydrophobic tails grouped together on the inside of the sandwich and the hydrophilic heads oriented toward the outside and facing an aqueous environment. Such formations of phospholipids provide the structural foundation of cell membranes.

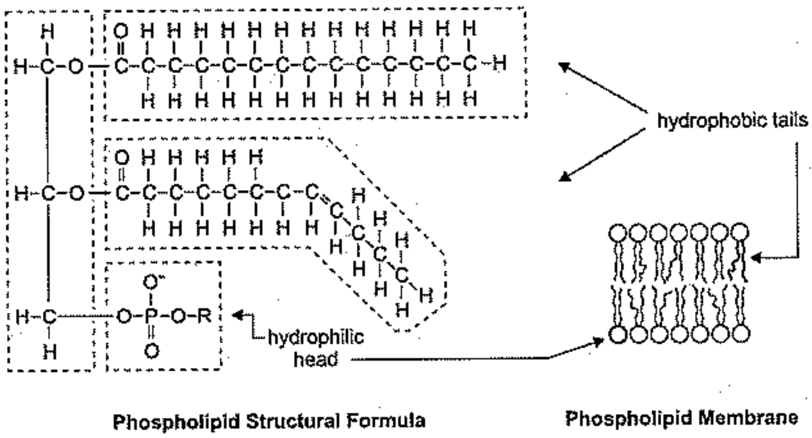


Figure 2-7

3. **Steroids** are characterized by a backbone of four linked carbon rings (Figure 2-8). Examples of steroids include cholesterol (a component of cell membranes) and certain hormones, including testosterone and estrogen.

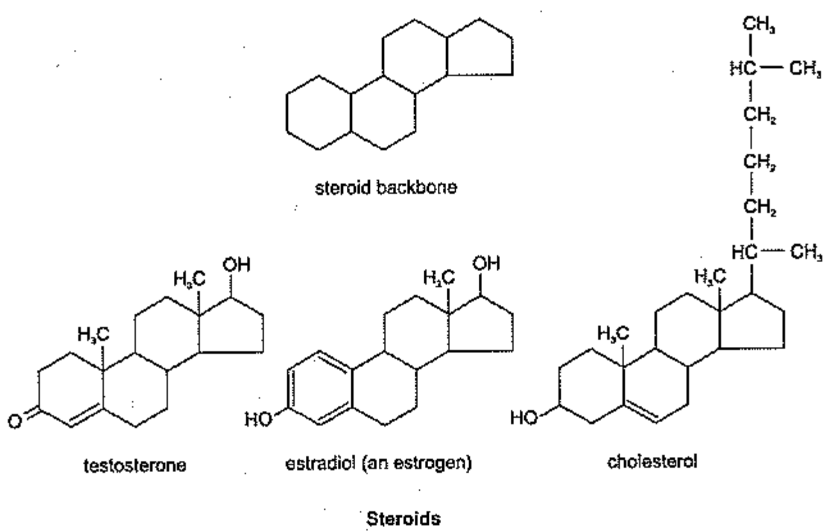


Figure 2-8

Proteins

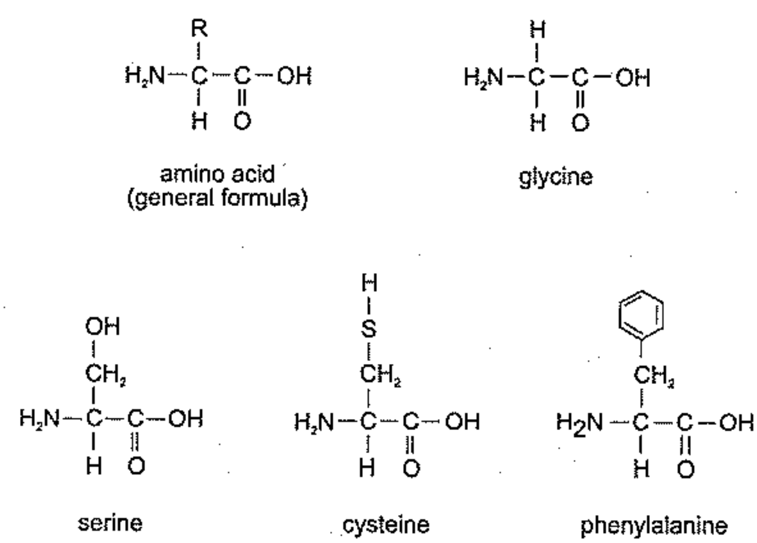
Proteins can be grouped according to their functions. Some major categories follow:

1. **Structural proteins,** such as keratin in the hair and horns of animals, collagen in connective tissues, and silk in spider webs
2. **Storage proteins,** such as casein in milk, ovalbumin in egg whites, and zein in corn seeds
3. **Transport proteins,** such as those in the membranes of cells that transport materials into and out of cells and as oxygen-carrying hemoglobin in red blood cells
4. **Defensive proteins,** such as the antibodies that provide protection against foreign substances that enter the bodies of animals
5. **Enzymes** that regulate the rate of chemical reactions

Although the functions of proteins are diverse, their structures are similar. All proteins are polymers of **amino acids;** that is, they consist of a chain of amino acids covalently bonded. The bonds between the amino acids are called **peptide bonds,** and the chain is a **polypeptide,** or peptide. Similar to the formation of carbohydrate polymers, the peptide bonds of proteins form by dehydration synthesis; that is, one H_2O molecule is released during the formation of each peptide bond.

One protein differs from another by the number and arrangement of the 20 different amino acids. Each amino acid consists of a central carbon bonded to an amino group ($-NH_2$), a carboxyl group ($-COOH$), and a hydrogen atom (Figure 2-9). The fourth bond of the central carbon is shown with the letter R, which indicates an atom or group of atoms that varies from one kind of amino acid to another. For the simplest amino acid, glycine, the R is a hydrogen atom. For serine, R is CH_2OH. For other amino acids, R may contain sulfur (as in cysteine) or a carbon ring (as in phenylalanine). The R group is also called the side chain.

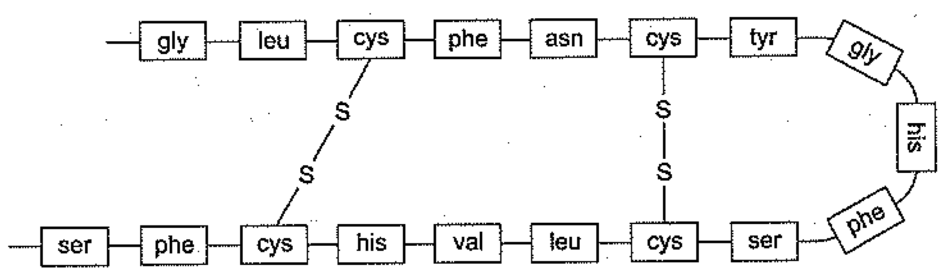
The protein, then, is a polymer of different amino acids with $-NH_2$ at one end and $-COOH$ at the other end. Each amino acid carries an R group with specific properties. For example, the R group may make the amino acid hydrophobic or hydrophilic, polar or nonpolar, or acidic or basic. As a result, proteins can differ widely in structure (size and shape) and chemistry, which, in turn, makes for dramatic differences in protein function.



Amino Acids
Figure 2-9

Four levels describe the structure of a protein:

1. The **primary structure** of a protein describes the order of amino acids. Using three letters to represent each amino acid, the primary structure for the protein antidiuretic hormone (ADH) can be written as Cys-Tyr-Phe-Gln-Asn-Cys-Pro-Arg-Gly. Using the one letter abbreviations, ADH is written as C-Y-F-Q-N-C-P-R-G. You do not need to know the abbreviations for each amino acid for the exam; rather, just be aware that they represent amino acids.
2. The **secondary structure** of a protein is a three-dimensional shape that results from hydrogen bonding between the amino and carboxyl groups of nearby amino acids. The bonding produces a spiral **(alpha helix)** or a folded plane that looks much like the pleats on a skirt **(beta pleated sheet).** Proteins whose shapes are dominated by these two patterns often form **fibrous proteins.**
3. The **tertiary structure** of a protein includes additional three-dimensional shaping and often dominates the structure of **globular proteins.** The following factors contribute to the tertiary structure.
   - **Hydrogen bonding** between R groups of amino acids.
   - **Ionic bonding** between R groups of amino acids.
   - The **hydrophobic effect** that occurs when hydrophobic R groups move toward the center of the protein (away from the water in which the protein is usually immersed).
   - The formation of **disulfide bonds** that occurs when the sulfur atom in the amino acid cysteine bonds to the sulfur atom in another cysteine (forming cystine, a kind of "double" amino acid). This disulfide bridge helps maintain the folds of the amino acid chain (Figure 2-10).



Disulfide Bridges in a Polypeptide

Figure 2-10

4. The **quaternary structure** describes a protein that is assembled from two or more separate peptide chains. The globular protein hemoglobin, for example, consists of four peptide chains that are held together by hydrogen bonding and interactions among R groups.

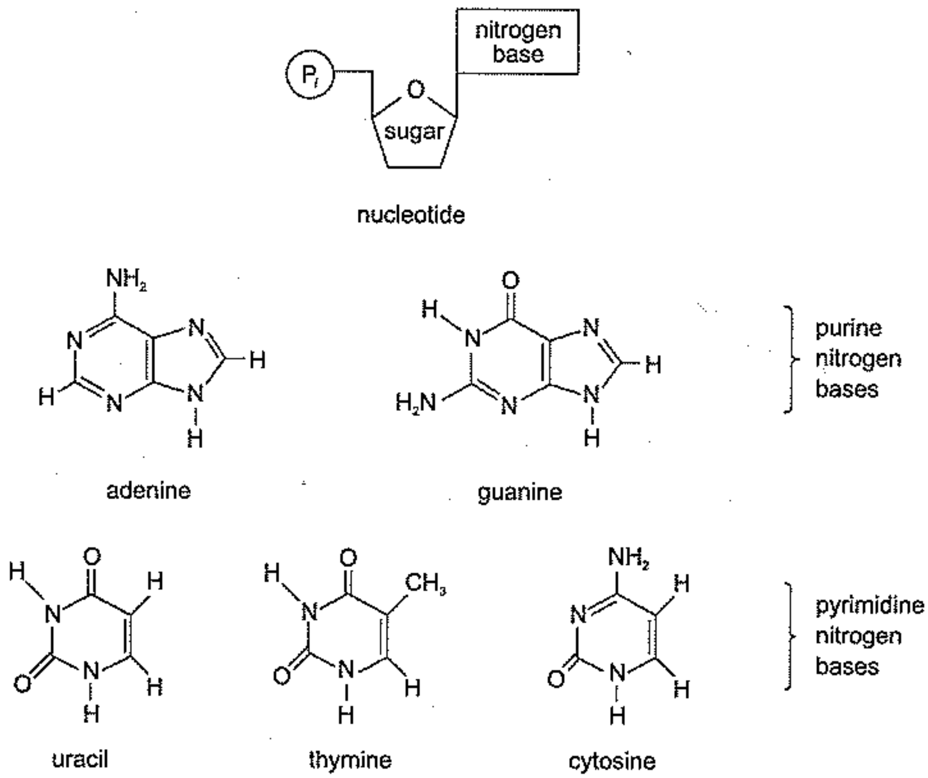
Nucleic Acids

The genetic information of a cell is stored in molecules of deoxyribonucleic acid (DNA). The DNA, in turn, passes its genetic instructions to ribonucleic acid (RNA) for directing various metabolic activities of the cell.

DNA is a polymer of **nucleotides.** A DNA nucleotide consists of three parts—a **nitrogen base,** a five-carbon sugar called **deoxyribose,** and a **phosphate group.** There are four DNA nucleotides, each with one of the four nitrogen bases, as follows (see Figure 2-11):

1. Adenine—a double-ring base (purine)
2. Thymine—a single-ring base (pyrimidine)
3. Cytosine—a single-ring base (pyrimidine)
4. Guanine—a double-ring base (purine)

Pyrimidines are single-ring nitrogen bases, and purines are double-ring bases. You can remember which of these bases are purines by the words "pure silver," where pure suggests purine and Ag (*a*denine and *g*uanine) is the chemical symbol for silver. The first letter of each of these four bases is often used to symbolize the respective nucleotide (A for the adenine nucleotide, for example).



Nitrogen Bases

Figure 2-11

DNA nucleotides form a single-stranded DNA molecule when the phosphate group of one nucleotide joins to the sugar of the adjacent nucleotide (Figure 2-12). Two of these single strands of DNA, paired by weak hydrogen bonds between the bases, form a double-stranded DNA. When bonded in this way, DNA forms a two-stranded spiral, or double helix. *Note that adenine always bonds with thymine and guanine always bonds with cytosine (always a purine with a pyrimidine)* (Figure 2-12).

The two strands of a DNA helix are antiparallel, that is, oriented in opposite directions. One strand is arranged in the 5′ → 3′ direction; that is, it begins with a phosphate group attached to the *fifth* carbon of the deoxyribose (5′ end) and ends where the phosphate of the next nucleotide would attach, at the *third* deoxyribose carbon (3′). The adjacent strand is oriented in the opposite, or 3′ → 5′, direction.

RNA differs from DNA in the following ways:

1. The sugar in the nucleotides that make an RNA molecule is ribose, not deoxyribose as it is in DNA.
2. The thymine nucleotide does not occur in RNA. It is replaced by uracil. When pairing of bases occurs in RNA, uracil (instead of thymine) pairs with adenine.
3. RNA is usually single-stranded and does not form a double helix as it does in DNA.

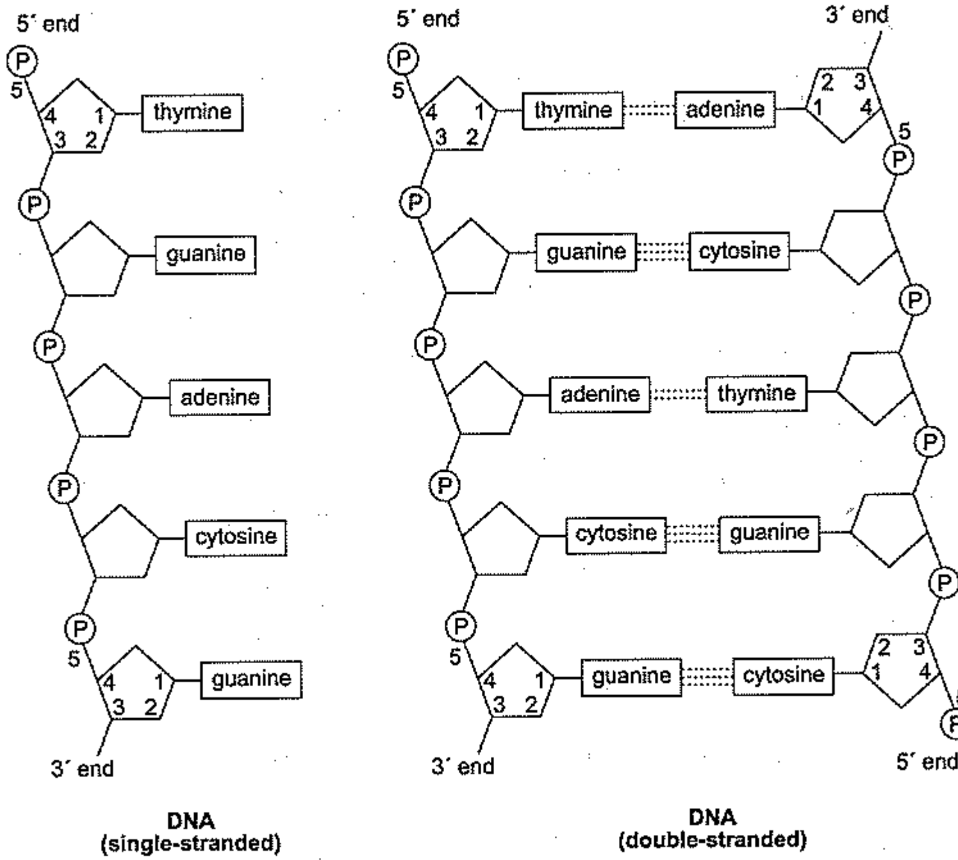


Figure 2-12

For clarification purposes, the structural formulas of the nucleotide bases are given in Figure 2-11. But the AP exam requires only that you know the general structure of a nucleotide (nitrogen base + five-carbon sugar + phosphate), the names of the nucleotides, which are double-ring purines and which are single-ring pyrimidines, and the differences between DNA and RNA.

Chemical Reactions in Metabolic Processes

In order for a chemical reaction to take place, the reacting molecules (or atoms) must first collide and then have sufficient energy (**activation energy**) to trigger the formation of new bonds. Although many reactions can occur spontaneously, the presence of a **catalyst** accelerates the rate of the reaction because it lowers the activation energy required for the reaction to take place. A catalyst is any substance that accelerates a reaction but does not undergo a chemical change itself. Since the catalyst is not changed by the reaction, it can be used over and over again.

Chemical reactions that occur in biological systems are referred to as **metabolism**. Metabolism includes the breakdown of substances (**catabolism**), the formation of new products (**synthesis** or **anabolism**), or the transferring of energy from one substance to another. Metabolic processes have the following characteristics in common:

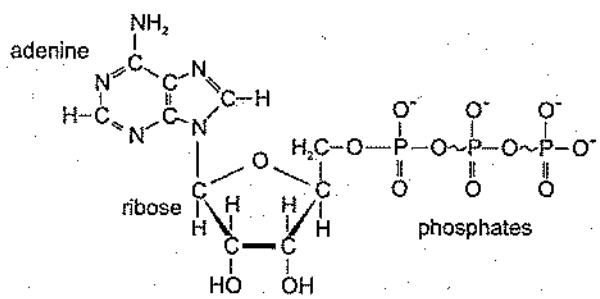
1. The net direction of metabolic reactions, that is, whether the overall reaction proceeds in the forward direction or in the reverse direction, is determined by the concentrations of the reactants and the end products. Chemical **equilibrium** describes the condition where the rate of reaction in the forward direction equals the rate in the reverse direction, and, as a result, there is no net production of reactants or products. When the reaction shown below is in chemical equilibrium, the rate at which molecules of C and D are formed (in the forward direction) is the same as the rate at which molecules of A and B are formed (in the reverse direction).

$$A + B \rightleftarrows C + D$$

2. **Enzymes** are globular proteins that act as catalysts (activators or accelerators) for metabolic reactions. Note the following characteristics of enzymes:
   - *The* **substrate** *is the substance or substances upon which the enzyme acts.* For example, the enzyme amylase catalyzes the breakdown of the substrate amylose (starch).
   - *Enzymes are substrate specific.* The enzyme amylase, for example, catalyzes the reaction that breaks the α-glycosidic linkage in starch but cannot break the β-glycosidic linkage in cellulose.
   - *An enzyme is unchanged as a result of a reaction.* It can perform its enzymatic function repeatedly.
   - *An enzyme catalyzes a reaction in both forward and reverse directions.* The direction of *net* activity is determined by substrate concentrations and other factors. The net direction of an enzyme reaction can be driven in the forward direction by keeping the product concentration low (by its removal, or conversion to another product).
   - *The efficiency of an enzyme is affected by temperature and pH.* The human body, for example, is maintained at a temperature of 98.6°F, near the optimal temperature for most human enzymes. Above 104°F, these enzymes begin to lose their ability to catalyze reactions as they become **denatured**, that is, they lose their three-dimensional shape as hydrogen bonds and peptide bonds begin to break down. Most enzymes have an optimal pH of around 7.0; however, the enzyme pepsin, which digests proteins in the stomach, becomes active only at a low pH (very acidic).
   - *The standard suffix for enzymes is "-ase,"* so it is easy to identify enzymes that use this ending, although some do not.
   - *The* **induced-fit model** *describes how enzymes work.* Within the protein (the enzyme), there is an active site with which the reactants readily interact because of the shape, polarity, or other characteristics of the active site. The interaction of the reactants (substrate) and the enzyme causes the enzyme to change shape. The new position places the substrate molecules into a position favorable to their reaction. Once the reaction takes place, the product is released.
3. **Cofactors** are nonprotein molecules that assist enzymes.
   - **Coenzymes** are *organic* cofactors that usually function to donate or accept some component of a reaction, often electrons. Some vitamins are coenzymes or components of coenzymes.
   - **Inorganic cofactors** are often metal ions, like Fe^{2+} and Mg^{2+}.
4. **ATP** (adenosine triphosphate) is a common source of activation energy for metabolic reactions (Figure 2-13). ATP is essentially an RNA adenine nucleotide with two additional phosphate groups. When ATP releases its energy, a **hydrolysis reaction** breaks the last phosphate bond of the ATP molecule to form ADP (adenosine *di*phosphate) and an inorganic phosphate group (P_i), like this:

$$ATP + H_2O \rightarrow ADP + P_i + \text{energy}$$

In the reverse dehydration reaction, new ATP molecules are assembled by **phosphorylation** when ADP combines with a phosphate group using energy obtained from some energy-rich molecule (like glucose).



Adenosine Triphosphate (ATP)

Figure 2-13

How do living systems regulate chemical reactions? How do they know when to start a reaction and when to shut it off? One way of regulating a reaction is by regulating its enzyme. Here are five common ways in which this is done:

1. **Enzymes** have two kinds of binding sites—one an active site for the substrate and one or more possible allosteric sites for an **allosteric effector.** There are two kinds of allosteric effectors:
   - An **allosteric activator** binds to the enzyme and induces the enzyme's *active* form.
   - An **allosteric inhibitor** binds to the enzyme and induces the enzyme's *inactive* form.

   Some inhibitors bind irreversibly, permanently changing the structure of the enzyme by modifying an amino acid. Other inhibitors are weakly bonded to the enzyme by ionic or hydrogen bonds, and their effects are reversible.
2. In **feedback inhibition,** an end product of a series of reactions acts as an allosteric inhibitor, shutting down one of the enzymes catalyzing the reaction series.
3. In **competitive inhibition,** a substance that mimics the substrate inhibits an enzyme by occupying the active site. The mimic displaces the substrate and prevents the enzyme from catalyzing the substrate.
4. In **noncompetitive inhibition,** a substance inhibits the action of an enzyme by binding to the enzyme at a location other than the active site (i.e., allosteric site). The inhibitor changes the shape of the enzyme, which disables its enzymatic activity. Many toxins and antibiotics are noncompetitive inhibitors.
5. In **cooperativity,** an enzyme becomes more receptive to additional substrate molecules after one substrate molecule attaches to an active site. This occurs, for example, in enzymes that consist of two or more subunits (quaternary structure), each with its own active site. A common example of this process (though not an enzyme) is hemoglobin, whose binding capacity to additional oxygen molecules increases after the first oxygen binds to an active site.

Review Questions

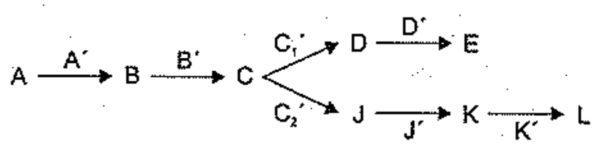
Multiple-Choice Questions

The questions that follow provide a review of the material presented in this chapter. Use them to evaluate how well you understand the terms, concepts, and processes presented. Actual AP multiple-choice questions are often more general, covering a broad range of concepts, and often more lengthy. For multiple-choice questions typical of the exam, take the two practice exams in this book.

Directions: Each of the following questions or statements is followed by four possible answers or sentence completions. Choose the one best answer or sentence completion.

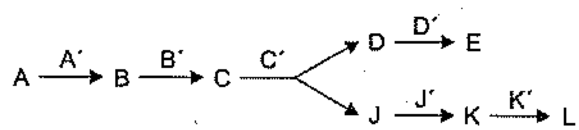
1. Which of the following molecules orient themselves into sandwich-like membranes because of hydrophobic components within the molecule?

A. glycogen molecules
B. cellulose molecules
C. phospholipid molecules
D. protein molecules



2. In the series of metabolic reactions shown above, C_1' catalyzes the conversion of C to D, and C_2' catalyzes the conversion of C to J. Assume that product E is an allosteric effector that inhibits enzyme D′. Normally, products E and L are consumed by other reactions. Which of the following would likely happen if product E were not consumed by other reactions?

A. The net rate of production of product B would decrease.
B. The net rate of production of product C would decrease.
C. The net rate of production of product D would decrease.
D. The net rate of production of product J would decrease.

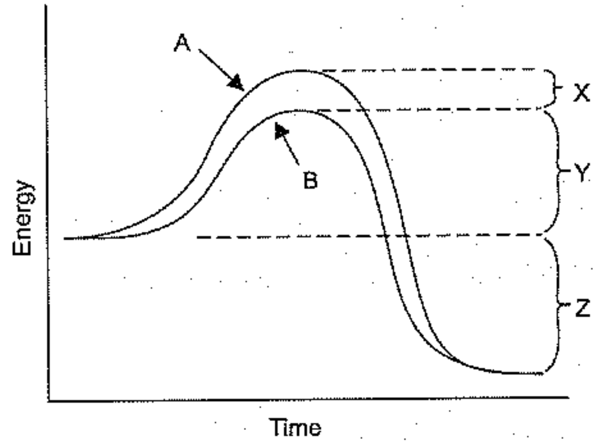


3. In the series of metabolic reactions shown above, C′ catalyzes the splitting of C into D and J. Assume that product E is an allosteric effector that inhibits enzyme C′. If product E were not consumed in a subsequent reaction, which of the following would likely happen?

A. The rate of production of product D would increase.
B. The rate of production of product E would increase.
C. The rate of production of product J would increase.
D. The rate of production of all products—D, E, J, K, and L—would decrease.

4. Each of the following molecules is a polymer EXCEPT:

A. protein
B. glucose
C. cellulose
D. starch

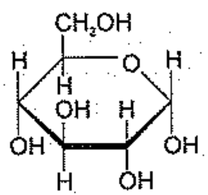


5. For the graph given above, the two curves describe the potential energy of substances during the progress of a chemical reaction. All of the following items could apply to this graph EXCEPT:

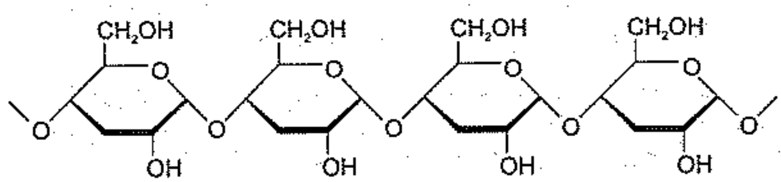
- **A.** Curve B could be showing the influence of an enzyme.
- **B.** The sum of energy in the products of the reaction is less than the sum of energy in the reactants.
- **C.** The activation energy of this reaction could be given by X + Y + Z.
- **D.** This reaction graph could describe the reaction ATP $\rightarrow$ ADP + P_i.

Questions 6–9 refer to the molecules below. For each question, indicate the molecule that is being described.

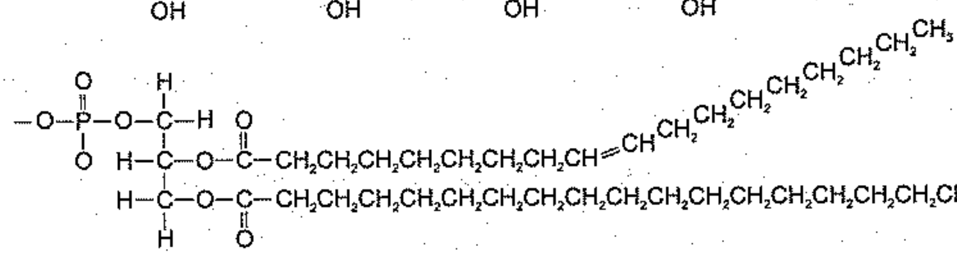
A.



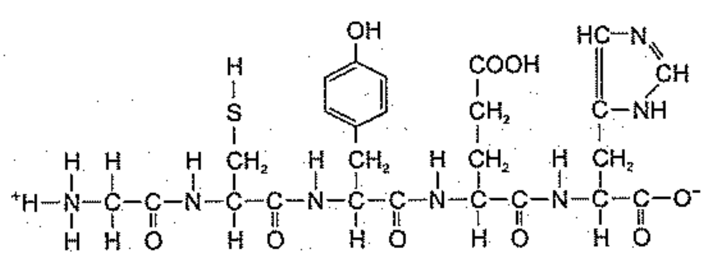
B.



C.



D.



6. a monosaccharide

7. a polysaccharide

8. a polypeptide

9. a major component of cell membranes

10. Hydrophilic properties are characteristic of all of the following EXCEPT:

A. polar molecules
B. molecules soluble in water
C. molecules that readily ionize in water
D. the long hydrocarbon chain components of some molecules

11. All of the following are carbohydrates EXCEPT:

A. polypeptide
B. glycogen
C. glucose
D. polysaccharide

Free-Response Questions

The AP exam has long and short free-response questions. The long questions have considerable descriptive information that may include tables, graphs, or figures. The short questions are brief but may also include figures. Both kinds of questions have four parts and generally require that you bring together concepts from multiple areas of biology.

The questions that follow are designed to further your understanding of the concepts presented in this chapter. Unlike the free-response questions on the exam, they are narrowly focused on the material in this chapter. For free-response questions typical of the exam, take the two practice exams in this book.

Directions: The best way to prepare for the AP exam is to write out your answers as if you were taking the exam. Use complete sentences and do *not* use outline form or bullets. You may use diagrams to supplement your answers, but be sure to describe the importance or relevance of your diagrams.

1. The protein albumin that surrounds the yolk of an egg is a clear liquid when raw and a white solid when cooked. Explain why cooking causes this change.

2. Cells are made up mostly of water. Explain why the specific heat of water is important to a cell.

3. A nucleic acid molecule has a distinct 3′ end and a distinct 5′ end. Explain the significance of these ends during the assembly of a double-helix DNA molecule.

4. The rate of a reaction with and without the presence of an enzyme is provided in the table below. Explain the significance of temperature and the presence of an enzyme on the rate of a reaction.

Reaction Rates with and without an Enzyme at Different Temperatures				
Temperature (°C)	15°C	25°C	35°C	45°C
Reaction Rate – Enzyme Absent (mmol/m^3/sec)	0.0001	0.0002	0.0003	0.0004
Reaction Rate – Enzyme Present (mmol/m^3/sec)	1.0000	2.5000	4.0000	0.0004

5. Describe each of the following:

a. the structure of an enzyme
b. how enzymes function
c. how enzymes are regulated

Answers and Explanations

Multiple-Choice Questions

1. C. Phospholipids are composed of glycerol molecules bonded to two fatty acids and one phosphate group. The phosphate group is a hydrophilic "head," and the long hydrocarbon chains of fatty acids are hydrophobic "tails." In cell membranes, phospholipids orient themselves into two layers, with the hydrophobic tails pointing to the inside of the "sandwich."

2. C. When product E is no longer consumed by other reactions, it is available to inactivate enzyme D′. As quantities of product E accumulate, more and more of D′ would be inactivated. As a result, the rate of production of E would decrease and quantities of product D would accumulate. As product D accumulates, its rate of production decreases. At the same time, the rate of the reverse reaction, of D to C, increases. Now, more of C would be available for conversion to J (and then to K and L), and as C increases, the rate of production of J increases. Eventually, the rate of production of D would equal the rate of the reverse reaction (of D to C), and chemical equilibrium between C and D would be reached (the net rate of production of D would be zero).

3. D. The effect of the allosteric effector E is to inhibit enzyme C′. As quantities of product E accumulate, increasing amounts of C′ would become inactivated. As a result, fewer and fewer quantities of C would be converted to products D and J. Thus, the rate of production of D and J, as well as E, K, and L, would decrease. As quantities of C increase, the rate of the reverse reaction of C to B (and then to A) would increase. In the end, A, B, and C would be in chemical equilibrium, and the rate of production of products D, E, J, K, and L would be zero.

4. B. Glucose is a monomer consisting of a single glucose molecule. Starch and cellulose are polymers consisting of repeating units of glucose. Protein is a polymer of amino acids.

5. C. The activation energy is given by X + Y for curve A or Y for curve B. Curve B shows how the activation energy would be lowered if an enzyme were present. Since the products (right side of the curve) have less energy than the reactants, energy is released. This kind of reaction, where energy is released, is called an exergonic reaction. In contrast, if the products had more energy than the reactants, it would be an endergonic reaction. The reaction $ATP \rightarrow ADP + P_i$ is an exergonic reaction where the energy released is used as activation energy for other metabolic reactions.

6. A. This is the ring structure of glucose.

7. B. This is amylose, a starch found in plants.

8. D. This polypeptide contains five amino acids.

9. C. This is a phospholipid. Note that this phospholipid contains one saturated and one monounsaturated fatty acid.

10. D. Long hydrocarbon chains are nonpolar and, therefore, hydrophobic. Any polar molecule is hydrophilic. When a substance ionizes in water, it dissolves; thus, it is hydrophilic.

11. A. A polypeptide is a protein. Glucose is a monosaccharide carbohydrate, while glycogen is a polysaccharide carbohydrate.

Free-Response Questions

1. When a protein is heated above a critical temperature, it begins to lose its three-dimensional structure. When the secondary, tertiary, and quaternary structures of a protein break down, as they will when excessively heated, the structure of the protein is permanently destroyed.

2. Because water has a high specific heat capacity, its temperature changes very slowly in response to energy changes. As a result, metabolic activities occurring in the cell that release or absorb energy do not significantly change the temperature of the cell, allowing the internal temperature of the cell to remain fairly constant.

3. A double-helix DNA molecule consists of two single-strands of DNA. The base pairing between nucleotides requires that the two strands are arranged in opposite directions, or antiparallel.

4. Both temperature and the presence of an enzyme increase the rate of a reaction. Because molecules are moving faster at higher temperatures, there are more collisions and, therefore, more reactions. As a catalyst, an enzyme speeds up reactions by facilitating the coming together of the reactants (thus, lowering activation energy). At 45°C, the influence of the enzyme is eliminated because the high temperature denaturizes it, and the reaction rate falls back to the rate that occurs in the absence of an enzyme.

5. a. Enzymes are globular proteins. Proteins, in turn, are polymers of amino acids—chains of amino acids, bonded to each other by peptide bonds. The general formula for an amino acid is a central carbon atom bonded to an amino group ($-NH_2$), a carboxyl group ($-COOH$), and a hydrogen atom. A fourth bond is made with a group of atoms that varies with each of the 20 amino acids. This variable group can be a single hydrogen atom or a group of many atoms sometimes including sulfur, nitrogen, or carbon rings. The individual amino acids in a protein interact with one another, giving the protein special spatial and functional characteristics. These characteristics impart to an enzyme unique attributes that allow it to catalyze specific reactions of specific substrates. The characteristics of proteins (and, therefore, enzymes) are derived from four features of the protein's structure. The first, described by the primary structure, is the kind and arrangement of amino acids in the protein. A secondary structure originates from hydrogen bonding between amino and carboxyl groups of amino acids. This secondary structure is the three-dimensional shape of a helix or a pleated sheet. Further interactions between amino acids give proteins a tertiary structure. These interactions include hydrogen bonding and ionic bonding between R groups, the "hiding" of hydrophobic R groups into the interior of the protein, and a disulfide bridge between two cysteine amino acids. The summation of all of the interactions gives enzymes a globular shape.

   b. The function of an enzyme is to speed up the rate of, or catalyze, a reaction. The induced-fit model describes how enzymes work. In this model, there are specific active sites within the enzyme to which substrate molecules weakly bond. When substrate molecules bond to the active sites, the enzyme changes shape in such a way as to reduce the activation energy required for a bond to form between the substrate molecules. With less energy required, bonding proceeds at a faster rate.

   Many enzymes require a cofactor to catalyze a reaction. Cofactors include coenzymes (nonprotein, organic molecules) and metal ions (like Fe^{2+} or Mg^{2+}).

   c. There are several ways that enzymes are regulated. Allosteric enzymes are controlled by allosteric effectors, substances that bind to the enzyme and inhibit (or activate) the enzyme. Sometimes an allosteric inhibitor is a product of a series of reactions partly catalyzed by the allosteric enzyme. This is an example of feedback inhibition. Allosteric effectors bind to special sites in the enzyme. In competitive inhibition, however, an inhibitor binds to the active site, competing with substrate molecules. As a result, the activity of the enzyme is inhibited. Some toxins and drugs (including penicillin, an antibiotic) are examples. Environmental factors also contribute to the activity of enzymes. Enzymes operate best at specific temperatures and pH. Enzymes in the stomach, for example, are active only when the pH is low.

This answer provides quite a bit of detail on the structure of proteins. Although the material is relevant, you may be able to condense your answer to allow time to answer other questions if you were actually taking the AP exam. On the other hand, if time were available, you could give examples of some specific enzymes or coenzymes (both of which you'll learn about in subsequent chapters).