CHAPTER 5

Enzymes

5

Chapter Outline

Key Concepts	Applications
Understand how enzymes work.	• Know why enzymes are so important to all organisms.
Understand what an enzyme is.	• Describe what happens when an enzyme and a substrate combine. • Relate the shape of an enzyme to its ability to help in a chemical reaction. • Explain the role of coenzymes and vitamins in enzyme action. • Describe why enzymes work in some situations and not in others. • Identify what you can do to make enzymes perform better.

5.1 Reactions, Catalysts, and Enzymes

All living things require energy and building materials in order to grow and reproduce. Energy may be in the form of visible light, or it may be in energy-containing covalent bonds found in nutrients. **Nutrients** are molecules required by organisms for growth, reproduction, or repair—they are a source of energy and molecular building materials. The formation, breakdown, and rearrangement of molecules to provide organisms with essential energy and building blocks are known as *biochemical reactions*. These reactions occur when atoms or molecules come together and form new, more stable relationships. This results in the formation of new molecules and a change in the energy distribution among the reactants and end products. Most chemical reactions require an input of energy to get them started. This is referred to as **activation energy.** This energy is used to make the reactants unstable and more likely to react (figure 5.1).

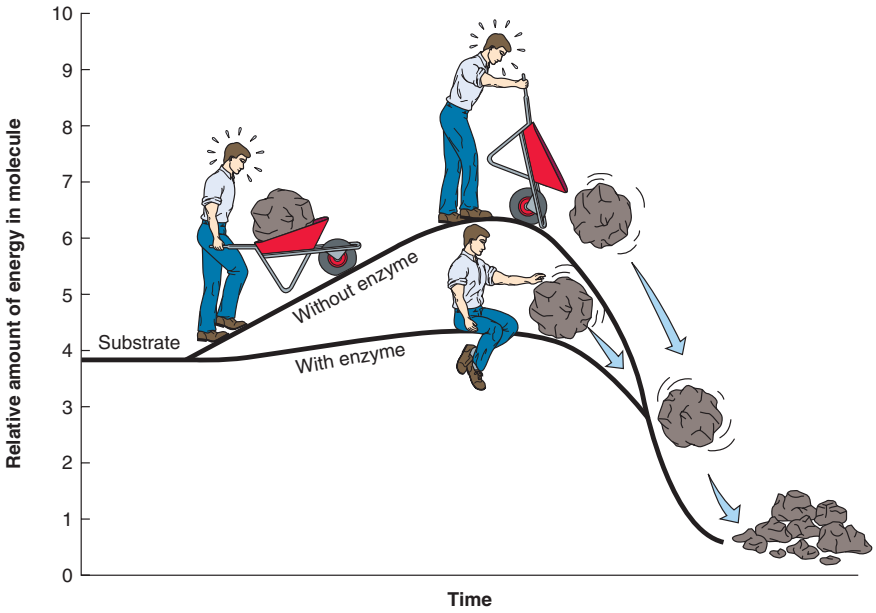


Figure 5.1

The Lowering of Activation Energy
Enzymes operate by lowering the amount of energy needed to get a reaction going—the activation energy. When this energy is lowered, the nature of the bonds is changed so they are more easily broken. Whereas the cartoon shows the breakdown of a single reactant into many end products (as in a hydrolysis reaction), the lowering of activation energy can also result in bonds being broken so that new bonds may be formed in the construction of a single, larger end product from several reactants (as in a synthesis reaction).

If organisms are to survive, they must obtain sizable amounts of energy and building materials in a very short time. Experience tells us that the sucrose in candy bars contains the potential energy needed to keep us active, as well as building materials to help us grow (sometimes to excess!). Yet, random chemical processes could take millions of years to break down a candy bar, releasing its energy and building materials. Of course, living things cannot wait that long. To sustain life, biochemical reactions must occur at extremely rapid rates. One way to increase the rate of any chemical reaction and make its energy and component parts available to a cell is to increase the temperature of the reactants. In general, the hotter the reactants, the faster they will react. However, this method of increasing reaction rates has a major drawback when it comes to living things: organisms die because cellular proteins are denatured before the temperature reaches the point required to sustain the biochemical reactions necessary for life. This is of practical concern to people who are experiencing a fever. Should the fever stay too high for too long, major disruptions of cellular biochemical processes could be fatal.

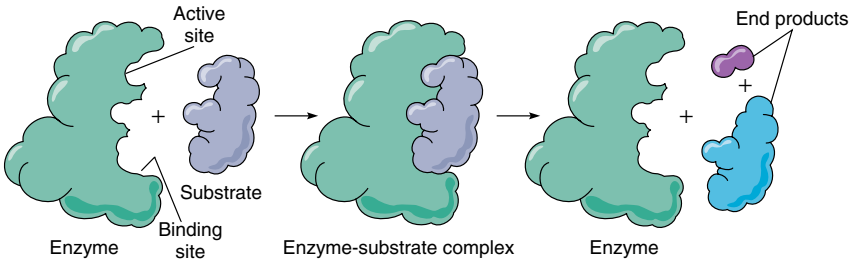
There is a way of increasing the rate of chemical reactions without increasing the temperature. This involves using substances called *catalysts*. A **catalyst** is a chemical that speeds the reaction but is not used up in the reaction. It can be recovered unchanged when the reaction is complete. Catalysts function by lowering the amount of activation energy needed to start the reaction. A cell manufactures specific proteins that act as catalysts. A protein molecule that acts as a catalyst to speed the rate of a reaction is called an **enzyme.** Enzymes can be used over and over again until they are worn out or broken. The production of these protein catalysts is under the direct control of an organism's genetic material (DNA). The instructions for the manufacture of all enzymes are found in the genes of the cell. Organisms make their own enzymes. How the genetic information is used to direct the synthesis of these specific protein molecules is discussed in chapter 7.

5.2 How Enzymes Speed Chemical Reaction Rates

As the instructions for the production of an enzyme are read from the genetic material, a specific sequence of amino acids is linked together at the ribosomes. Once bonded, the chain of amino acids folds and twists to form a globular molecule. It is the nature of its three-dimensional shape that allows this enzyme to combine with a reactant and lower the activation energy. Each enzyme has a specific three-dimensional shape that, in turn, is specific to the kind of reactant with which it

Figure 5.2

Enzyme-Substrate Complex Formation During an enzyme-controlled reaction, the enzyme and substrate come together to form a new molecule–the enzyme-substrate complex molecule. This molecule exists for only a very short time. During that time, activation energy is lowered and bonds are changed. The result is the formation of a new molecule or molecules called the end products of the reaction. Notice that the enzyme comes out of the reaction intact and ready to be used again.



can combine. The enzyme physically fits with the reactant. The molecule to which the enzyme attaches itself (the reactant) is known as the **substrate.** When the enzyme attaches itself to the substrate molecule, a new, temporary molecule—the **enzyme-substrate complex**—is formed (figure 5.2). When the substrate is combined with the enzyme, its bonds are less stable and more likely to be altered and form new bonds. The enzyme is specific because it has a particular shape that can combine only with specific parts of certain substrate molecules (Outlooks 5.1).

You might think of an enzyme as a tool that makes a job easier and faster. For example, the use of an open-end crescent wrench can make the job of removing or attaching a nut and bolt go much faster than doing that same job by hand. In order to accomplish this job, the proper wrench must be used. Just any old tool (screwdriver or hammer) won't work! The enzyme must also physically attach itself to the substrate; therefore, there is a specific **binding site** or **attachment site** on the enzyme surface. Figure 5.3 illustrates the specificity of both wrench and enzyme. Note that the wrench and enzyme are recovered unchanged after they have been used. This means that the enzyme and wrench can be used again. Eventually, like wrenches, enzymes wear out and have to be replaced by synthesizing new ones using the instructions provided by the cell's genes. Generally, only very small quantities of enzymes are necessary because they work so fast and can be reused.

Both enzymes and wrenches are specific in that they have a particular surface geometry or shape that matches the geometry of their respective substrates. Note that both the enzyme and wrench are flexible. The enzyme can bend or fold to fit the substrate just as the wrench can be adjusted to fit the nut. This is called the *induced fit hypothesis*. The fit is induced because the presence of the substrate causes the enzyme to "mold" or "adjust" itself to the substrate as the two come together.

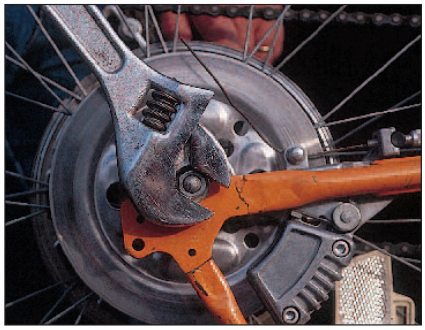
The place on the enzyme that causes a specific part of the substrate to change is called the **active site** of the enzyme, or the place on the enzyme surface where chemical bonds are formed or broken. (Note in the case illustrated in figure 5.3 that the "active site" is the same as the "binding site." This is typical of many enzymes.) This site is the place where the activation energy is lowered and the electrons are shifted to change the bonds. The active site may enable a positively charged surface to combine with the negative portion of a reactant. Although the active site does mold itself to a substrate, enzymes do not have the ability to fit all substrates. Enzymes are specific to a certain substrate or group of very similar substrate molecules. One enzyme cannot speed the rate of all types of biochemical reactions. Rather, a special enzyme is required to control the rate of each type of chemical reaction occurring in an organism.

Because the enzyme is specific to both the substrate to which it can attach and the reaction that it can encourage, a

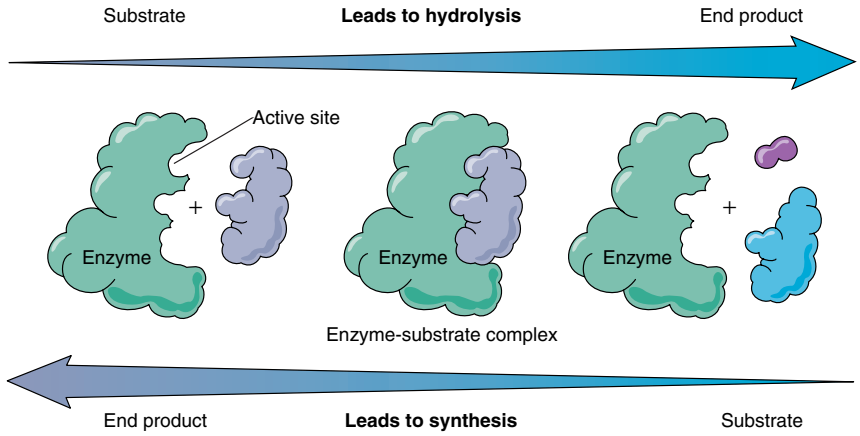
OUTLOOKS 5.1

Enzymes and Stonewashed "Genes"

The popularity of stonewashed jeans grew dramatically in the late 1960s. To get the stonewashed effect, the denim was actually washed in machines along with stones. The stones rubbed against the denim, wearing the blue dye off the surface of the material. But the stones also damaged the cotton fibers. The fiber damage shortened the life of the fabric, a feature that many consumers found unacceptable. Now, to create the stonewashed look and still maintain strong cotton fibers, enzymes are used that "digest" or hydrolyze the blue dye on the surface of the fabric. Because the enzyme is substrate or dye specific, the cotton fibers are not harmed.



(a)



(b)

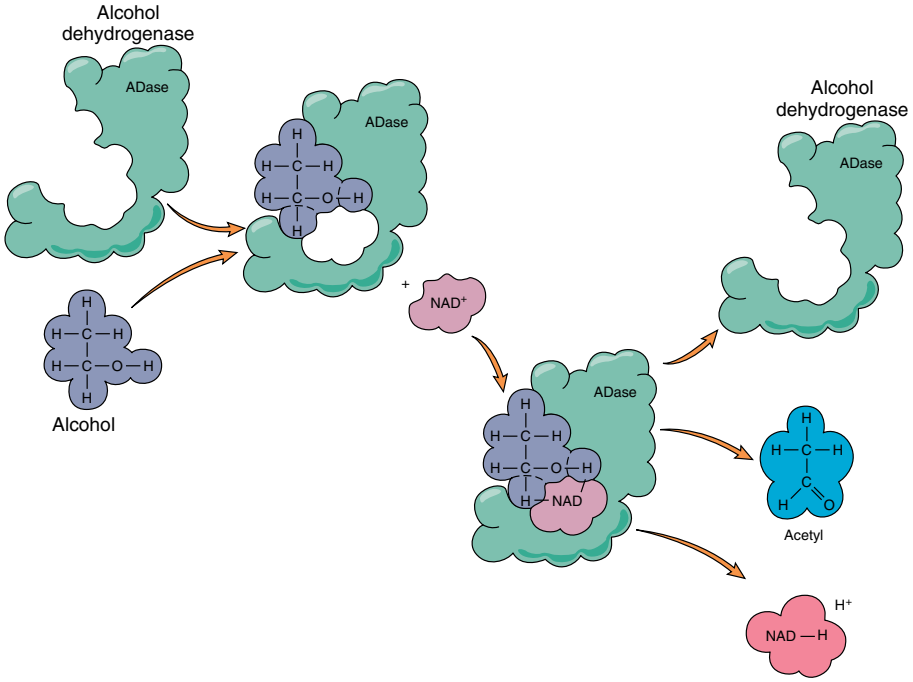
Figure 5.3

It Fits, It's Fast, and It Works
(*a*) Although it could be done by hand, an open-end crescent wrench can be used to remove the wheel from this bicycle more efficiently. The wrench is adjusted and attached, temporarily forming a nut-bolt-wrench complex. Turning the wrench loosens the bonds holding the nut to the bolt and the two are separated. The use of the wrench makes the task much easier. Keep in mind that the same wrench that is used to disassemble the bicycle can be used to reassemble it. Enzymes function in the same way. (*b*) An enzyme will "adjust itself" as it attaches to its substrate, forming a temporary enzyme-substrate complex. The presence and position of the enzyme in relation to the substrate lowers the activation energy required to alter the bonds. Depending on the circumstances (what job needs to be done), the enzyme might be involved in synthesis (constructive, i.e., anabolic) or hydrolysis (destructive, i.e., catabolic) reactions.

unique name can be given to each enzyme. The first part of an enzyme's name is the name of the molecule to which it can become attached. The second part of the name indicates the type of reaction it facilitates. The third part of the name is "-ase," the ending that tells you it is an enzyme. For example, *DNA polymerase* is the name of the enzyme that attaches to the molecule DNA and is responsible for increasing its length through a polymerization reaction. A few enzymes (e.g., pepsin and trypsin) are still referred to by their original names. The enzyme responsible for the dehydration synthesis reactions among several glucose molecules to form glycogen is known as *glycogen synthetase*. The enzyme responsible for breaking the bond that attaches the amino group to the amino acid arginine is known as *arginine aminase*. When an enzyme is very common, we often shorten its formal name. The salivary enzyme involved in the digestion of starch is *amylose* (starch) *hydrolase;* it is generally known as *amylase*. Other enzymes associated with the human digestive system are noted in table 18.2.

Certain enzymes need an additional molecule, a *cofactor,* to enable them to function. Cofactors may be certain elements or complex organic molecules. Cofactors temporarily attach to the enzyme and work with the protein catalyst to speed up a reaction. If the cofactor is not protein but another kind of organic molecule, it is called a *coenzyme*. A **coenzyme** aids a reaction by removing one of the end products or by bringing in part of the substrate. Many coenzymes cannot be manufactured by organisms and must be obtained from their foods. In addition, coenzymes are frequently constructed from minerals (zinc, magnesium, or iron), vitamins, and nucleotides. You know that a constant small supply of vitamins in your diet is necessary for good health. The reason your cells require vitamins is to serve in the manufacture of certain coenzymes. A coenzyme can work with a variety of enzymes; therefore, you need extremely small quantities of vitamins. An example of enzyme–coenzyme cooperation is shown in figure 5.4. The metabolism of alcohol consists of a series of reactions resulting in its breakdown to carbon dioxide (CO_2), water (H_2O), and energy. During one of the reactions in this sequence, the enzyme alcohol dehydrogenase picks up hydrogen from alcohol and attaches it to NAD. In this reaction, NAD (*n*icotinamide *a*denine *d*inucleotide, manufactured from the vitamin niacin) acts as a coenzyme because NAD carries the hydrogen away from the reaction as the alcohol is broken down. The presence of the coenzyme NAD is necessary for the enzyme to function properly.

Figure 5.4



The Role of Coenzymes
NAD is a coenzyme that works with the enzyme alcohol dehydrogenase (ADase) during the decomposition of alcohol. The coenzyme carries the hydrogen from the alcohol molecule after it is removed by the enzyme. Notice that the hydrogen on the alcohol is picked up by the NAD. The use of the coenzyme NAD makes the enzyme function more efficiently because one of the end products of this reaction (hydrogen) is removed from the reaction site. Because the hydrogen is no longer close to the reacting molecules, the overall direction of the reaction is toward the formation of acetyl. This encourages more alcohol to be broken down.

5.3 Environmental Effects on Enzyme Action

An enzyme forms a complex with one substrate molecule, encourages a reaction to occur, detaches itself, and then forms a complex with another molecule of the same substrate. The number of molecules of substrate that a single enzyme molecule can react with in a given time (e.g., reactions per minute) is called the **turnover number.**

Sometimes the number of jobs an enzyme can perform during a particular time period is incredibly large—ranging between a thousand (10^3) and 10 thousand trillion (10^{16}) times faster per minute than uncatalyzed reactions! Without the enzyme, perhaps only 50 or 100 substrate molecules might be altered in the same time. With this in mind, let's identify the ideal conditions for an enzyme and consider how these conditions influence the turnover number.

An important environmental condition affecting enzyme-controlled reactions is temperature (figure 5.5), which has two effects on enzymes: (1) It can change the rate of molecular motion, and (2) it can cause changes in the shape of an enzyme. As the temperature of an enzyme-substrate system increases, you would expect an increase in the amount of product molecules formed. This is true up to a point. The temperature at which the rate of formation of enzyme-substrate complex is fastest is termed the *optimum temperature*. *Optimum* means the best or most productive quantity or condition. In this case, the optimum temperature is the temperature at which the product is formed most rapidly.

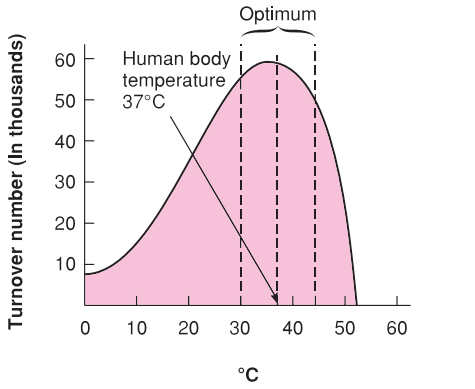


Figure 5.5

The Effect of Temperature on the Turnover Number
As the temperature increases, the rate of an enzymatic reaction increases. The increasing temperature increases molecular motion and may increase the number of times an enzyme contacts and combines with a substrate molecule. Temperature may also influence the shape of the enzyme molecule, making it fit better with the substrate. At high temperatures, the enzyme molecule is irreversibly changed so that it can no longer function as an enzyme. At that point, it has been denatured. Notice that the enzyme represented in this graph has an optimum (best) temperature range of between 30°C and 45°C.

As one lowers the temperature below the optimum, molecular motion slows, and the rate at which the enzyme-substrate complexes form decreases. Even though the enzyme is still able to operate, it does so very slowly. That is why foods can be preserved for long periods by storing them in freezers or refrigerators.

When the temperature is raised above the optimum, some of the molecules of enzyme are changed in such a way that they can no longer form the enzyme-substrate complex; thus, the reaction is not encouraged. If the temperature continues to increase, more and more of the enzyme molecules will become inactive. When heat is applied to an enzyme, it causes permanent changes in the three-dimensional shape of the molecule. The surface geometry of the enzyme molecule will not be recovered, even when the temperature is reduced. We can again use the wrench analogy. When a wrench is heated above a certain temperature, the metal begins to change shape. The shape of the wrench is changed permanently so that even if the temperature is reduced, the surface geometry of the end of the wrench is permanently lost. When this happens to an enzyme, we say that it has been *denatured*. A **denatured** enzyme is one whose protein structure has been permanently changed so that it has lost its original biochemical properties. Because enzymes are molecules and are not alive, they are not "killed," but denatured. Although egg white is not an enzyme, it is a protein and provides a common example of what happens when denaturation occurs as a result of heating. As heat is applied to the egg white, it is permanently changed (denatured).

Another environmental condition that influences enzyme action is pH. The three-dimensional structure of a protein leaves certain side chains exposed. These side chains may attract ions from the environment. Under the right conditions, a group of positively charged hydrogen ions may accumulate on certain parts of an enzyme. In an environment that lacks these hydrogen ions, this would not happen. Thus, variation in the most effective shape of the enzyme could be caused by a change in the number of hydrogen ions present in the solution. Because the environmental pH is so important in determining the shapes of protein molecules, there is an optimum pH for each specific enzyme. The enzyme will fit with the substrate only when it is at the proper pH. Many enzymes function best at a pH close to neutral (7.0). However, a number of enzymes perform best at pHs quite different from 7. Pepsin, an enzyme found in the stomach, works well at an acid pH of 1.5 to 2.2, whereas arginase, an enzyme in the liver, works well at a basic pH of 9.5 to 9.9 (figure 5.6).

In addition to temperature and pH, the concentration of enzymes, substrates, and products influences the rates of enzymatic reactions. Although the enzyme and the substrate are in contact with one another for only a short period of time, when there are huge numbers of substrate molecules it may happen that all the enzymes present are always occupied by substrate molecules. When this occurs, the rate of product formation cannot be increased unless the number of enzymes is increased. Cells can actually do this by synthesizing more enzymes. However, just because there are more enzyme molecules does not mean that any one enzyme molecule will be working any faster. The turnover number for each enzyme stays the same. As the enzyme concentration increases, the amount of product formed increases in a specified time. A greater number of enzymes are turning over substrates; they are not turning over substrates faster. Similarly, if enzyme numbers are decreased, the amount of product formed declines.

We can also look at this from the point of view of the substrate. If substrate is in short supply, enzymes may have to wait for a substrate molecule to become available. Under these conditions, as the amount of substrate increases, the amount of product formed increases. The increase in product is the result of more substrates available to be changed. If there is a very large amount of substrate, even a small amount of enzyme can eventually change all the substrate to product; it will just take longer. Decreasing the amount of substrate results in reduced product formation because some enzymes

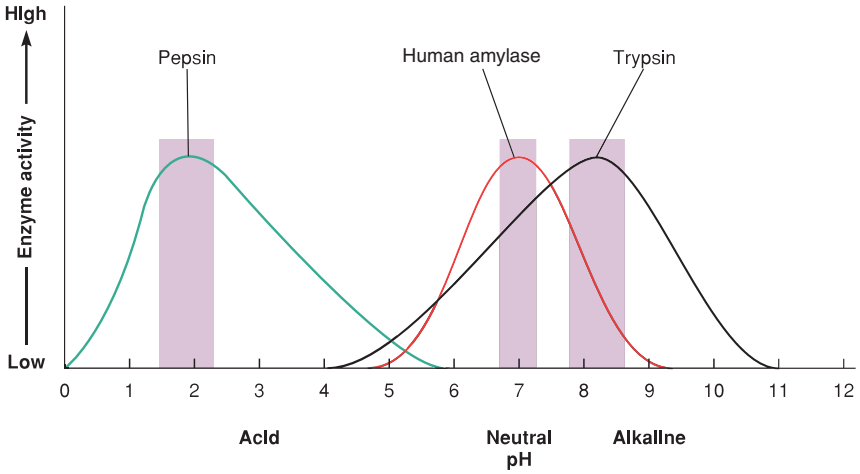


Figure 5.6

The Effect of pH on the Turnover Number
As the pH changes, the rate of the enzymatic reaction changes. The ions in solution alter the environment of the enzyme's active site and the overall shape of the enzyme. The enzymes illustrated here are human amylase, pepsin, and trypsin. Amylase is found in saliva and is responsible for hydrolyzing starch to glucose. Pepsin is found in the stomach and hydrolyzes protein. Trypsin is produced in the pancreas and enters the small intestine where it also hydrolyzes protein. Notice that each enzyme has its own pH range of activity, the optimum (shown in the color bars) being different for each.

will go for long periods without coming in contact with a substrate molecule.

5.4 Cellular-Controlling Processes and Enzymes

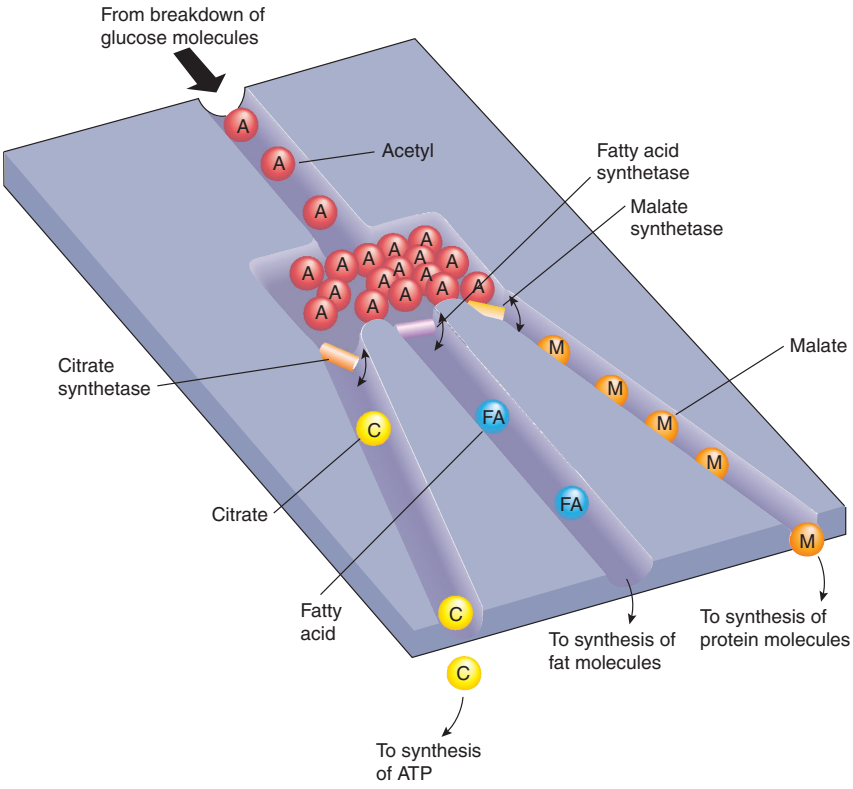
In any cell there are thousands of kinds of enzymes. Each controls specific chemical reactions and is sensitive to changing environmental conditions such as pH and temperature. In order for a cell to stay alive in an ever-changing environment, its innumerable biochemical reactions must be controlled. **Control processes** are mechanisms that ensure that an organism will carry out all metabolic activities in the proper sequence (coordination) and at the proper rate (regulation). *Coordination* of enzymatic activities in a cell results when specific reactions occur in a given sequence; for example, $A \rightarrow B \rightarrow C \rightarrow D \rightarrow E$. This ensures that a particular nutrient will be converted to a particular end product necessary to the survival of the cell. Should a cell not be able to coordinate its reactions, essential products might be produced at the wrong time or never be produced at all, and the cell would die. *Regulation* of biochemical reactions refers to how a cell controls the amount of chemical product produced. The old expression "having too much of a good thing" applies to this situation. For example, if a cell manufactures too much lipid, the presence of those molecules could interfere with other life-sustaining reactions, resulting in the death of the cell. On the other hand, if a cell does not produce enough of an essential molecule, such as a digestive enzyme, it might also die. The cellular control process involves both enzymes and genes.

Keep in mind that any one substrate may be acted upon by several different enzymes. Although all these different enzymes may combine with the same substrate, they do not have the same chemical effect on the substrate because each converts the substrate to different end products. For example, acetyl is a substrate that can be acted upon by three different enzymes: citrate synthetase, fatty acid synthetase, and malate synthetase (figure 5.7). Which enzyme has the greatest success depends on the number of each type of enzyme available and the suitability of the environment for the enzyme's operation. The enzyme that is present in the greatest number or is best suited to the job in the environment of the cell wins, and the amount of its end product becomes greatest.

Whenever there are several different enzymes available to combine with a given substrate, **enzymatic competition** results. For example, the use a cell makes of the substrate molecule acetyl is directly controlled by the amount and kinds of enzymes it produces. The number and kind of enzymes produced are regulated by the cell's genes. It is the

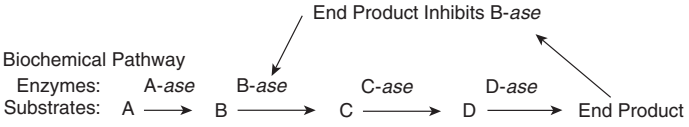
Figure 5.7

Enzymatic Competition
Acetyl can serve as a substrate for a number of different reactions. Whether it becomes a fatty acid, malate, or citrate is determined by the enzymes present. Each of the three enzymes may be thought of as being in competition for the same substrate–the acetyl molecule. The cell can partially control which end product will be produced in the greatest quantity by producing greater numbers of one kind of enzyme and fewer of the other kinds. If citrate synthetase is present in the highest quantity, more of the acetyl substrate will be acted upon by that enzyme and converted to citrate rather than to the other two end products, malate and fatty acids. The illustration represents the action of each enzyme as an "enzyme gate."



job of chemical messengers to inform the genes as to whether specific enzyme-producing genes should be turned on or off or whether they should have their protein-producing activities increased or decreased. Such chemical messengers are called **gene-regulator proteins.** Gene-regulator proteins that decrease protein production are called *gene-repressor proteins,* whereas those that increase protein production are *gene-activator proteins.* Returning to our example, if the cell is in need of protein, the acetyl could be metabolized to provide one of the building blocks for the construction of protein by turning up the production of the enzyme malate synthetase. If the cell requires energy to move or grow, more acetyl can be metabolized to release this energy by producing more citrate synthetase. When the enzyme fatty acid synthetase outcompetes the other two, the acetyl is used in fat production and storage.

Another method of controlling the synthesis of many molecules within a cell is called **negative-feedback inhibition.** This control process occurs within an enzyme-controlled reaction sequence. As the number of end products increases, some product molecules *feed back* to one of the previous reactions and have a *negative effect* on the enzyme controlling that reaction; that is, they *inhibit* or prevent that enzyme from performing at its best.



Because the end product can no longer be produced at the same rapid rate, its concentration falls. When there are too few end product molecules to feed back they no longer cause inhibition. The enzyme resumes its previous optimum rate of operation, and the end product concentration begins to increase. This also helps regulate the number of end products formed but does not involve the genes.

In addition, the operation of enzymes can be influenced by the presence of other molecules. An **inhibitor** is a molecule that attaches itself to an enzyme and interferes with its ability to form an enzyme-substrate complex (figure 5.8). One of the early kinds of pesticides used to spray fruit trees contained arsenic. The arsenic attached itself to insect enzymes and inhibited the normal growth and reproduction of insects. Organophosphates are pesticides that inhibit several enzymes necessary for the operation of the nervous system. When they are incorporated into nerve cells, they disrupt normal nerve transmission and cause the death of the

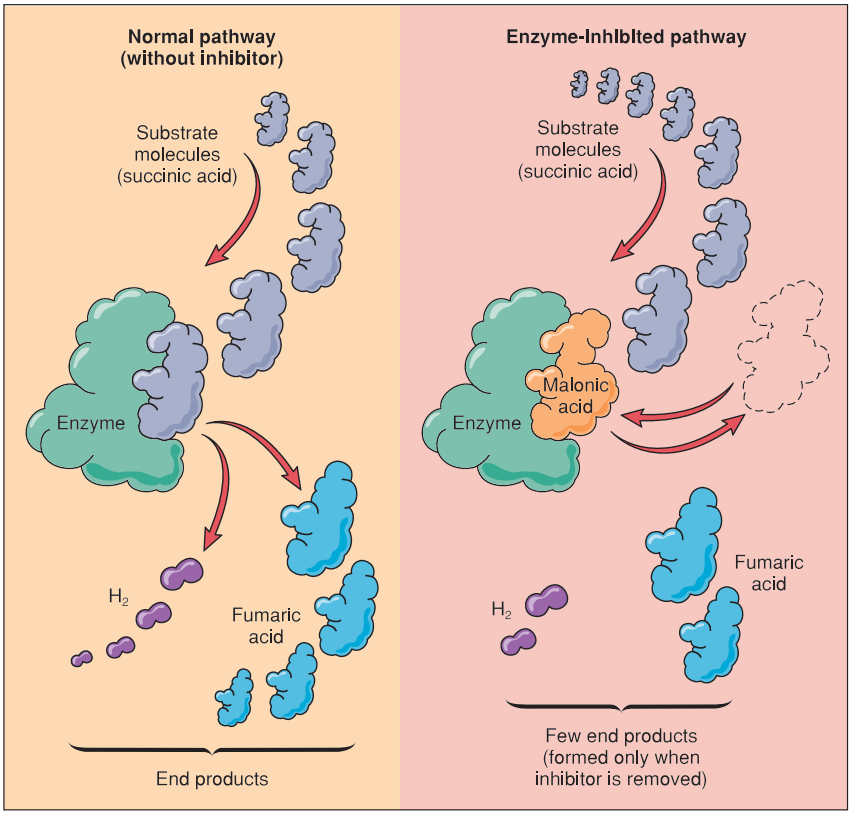


Figure 5.8

Enzymatic Inhibition
The left-hand side of the illustration shows the normal functioning of the enzyme. On the right-hand side, the enzyme is unable to function. This is because an inhibitor, malonic acid, is attached to the enzyme and prevents the enzyme from forming the normal complex with succinic acid. As long as malonic acid is present, the enzyme will be unable to function. If the malonic acid is removed, the enzyme will begin to function normally again. Its attachment to the inhibitor in this case is not permanent but has the effect of reducing the number of product molecules formed per unit of time.

affected organisms. In humans, death that is due to pesticides is usually caused by uncontrolled muscle contractions, resulting in breathing failure.

Some inhibitors have a shape that closely resembles the normal substrate of the enzyme. The enzyme is unable to distinguish the inhibitor from the normal substrate and so it combines with either or both. As long as the inhibitor is combined with an enzyme, the enzyme is ineffective in its normal role. Some of these enzyme-inhibitor complexes are permanent. An inhibitor removes a specific enzyme as a functioning part of the cell: the reaction that enzyme catalyzes no longer occurs, and none of the product is formed. This is termed **competitive inhibition** because the inhibitor molecule competes with the normal substrate for the active site of the enzyme.

We use enzyme inhibition to control disease. The sulfa drugs are used to control a variety of bacteria, such as the bacterium *Streptococcus pyogenes,* the cause of strep throat and scarlet fever. The drug resembles one of the bacterium's necessary substrates and so prevents some of the cell's enzymes from producing an essential cell component. As a result, the bacterial cell dies because its normal metabolism is not maintained. Those that survive become the grandparents of a new population of drug-resistant bacteria. Antibiotics act as agents of natural selection favoring those cells that have the genetic ability to withstand the effects of the drug. Since one essential life characteristic is evolution, the prevention of drug resistance is impossible. The development of resistance can only be slowed, not stopped. Microbes may become resistant to antibiotics in four ways: (1) they can stop producing the molecule that is the target of the drug; (2) they can modify the target; (3) they can become impermeable to the drug; or (4) they can release enzymes that inactivate the antibiotic.

SUMMARY

Enzymes are protein catalysts that speed up the rate of chemical reactions without any significant increase in the temperature. They do this by lowering activation energy. Enzymes have a very specific structure that matches the structure of particular substrate molecules. Actually, the substrate molecule comes in contact with only a specific part of the enzyme molecule—the attachment site. The active site of the enzyme is the place where the substrate molecule is changed. The enzyme-substrate complex reacts to form the end product. The protein nature of enzymes makes them sensitive to environmental conditions, such as temperature and pH, that change the structure of proteins. The number and kinds of enzymes are ultimately controlled by the genetic information of the cell. Other kinds of molecules, such as coenzymes, inhibitors, or competing enzymes, can influence specific enzymes. Changing conditions within the cell shift the enzymatic priorities of the cell by influencing the turnover number.

THINKING CRITICALLY

The data below were obtained by a number of Nobel-prize-winning scientists from Lower Slobovia. As a member of the group, interpret the data with respect to the following:

1. Enzyme activities
2. Movement of substrates into and out of the cell
3. Competition among different enzymes for the same substrate
4. Cell structure

Data:

a. A lowering of the atmospheric temperature from 22°C to 18°C causes organisms to form a thick protective coat.
b. Below 18°C, no additional coat material is produced.
c. If the cell is heated to 35°C and then cooled to 18°C, no coat is produced.
d. The coat consists of a complex carbohydrate.
e. The coat will form even if there is a low concentration of simple sugars in the surroundings.
f. If the cell needs energy for growth, no cell coats are produced at any temperature.

CONCEPT MAP TERMINOLOGY

Construct a concept map to show relationships among the following concepts:

coenzyme
enzyme
enzyme-substrate complex
inhibitor
substrate
temperature
turnover number

KEY TERMS

activation energy
active site
attachment site
binding site
catalyst
coenzyme
competitive inhibition
control processes
denature
enzymatic competition
enzyme
enzyme-substrate complex
gene-regulator proteins
inhibitor
negative-feedback inhibition
nutrients
substrate
turnover number

e—LEARNING CONNECTIONS *www.mhhe.com/enger10*

Topics	Questions	Media Resources
5.1 Reactions, Catalysts, and Enzymes	1. What is the difference between a catalyst and an enzyme? 2. Describe the sequence of events in an enzyme-controlled reaction. 3. Would you expect a fat and a sugar molecule to be acted on by the same enzyme? Why or why not? 4. Where in a cell would you look for enzymes?	**Quick Overview** • Why are enzymes important? **Key Points** • Reactions, catalysts, and enzymes **Animations and Review** • Thermodynamics • Enzymes **Experience This!** • Enzymes for your laundry?
5.2 How Enzymes Speed Chemical Reaction Rates	5. What is turnover number? Why is it important?	**Quick Overview** • Active sites and substrates **Key Points** • How enzymes speed chemical reaction rates
5.3 Environmental Effects on Enzyme Action	6. How does changing temperature affect the rate of an enzyme-controlled reaction? 7. What factors in the cell can speed up or slow down enzyme reactions? 8. What is the relationship between vitamins and coenzymes? 9. What effect might a change in pH have on enzyme activity?	**Quick Overview** • Factors that alter turnover **Key Points** • Environmental effects on enzyme action **Human Explorations** • Cell chemistry: Thermodynamics **Interactive Concept Maps** • Inhibitors
5.4 Cellular-Controlling Processes and Enzymes	10. What is enzyme competition, and why is it important to all cells?	**Quick Overview** • Importance of regulating enzymes **Key Points** • Cellular-controlling processes and enzymes **Interactive Concept Maps** • Text concept map **Review Questions** • Enzymes