2·17 Enzymes are proteins that speed up chemical reactions.

Protein shape is particularly critical in **enzymes,** molecules that help initiate and accelerate the chemical reactions in our bodies. Enzymes emerge unchanged—in their original form—when the reaction is complete and thus can be used again and again. Here's how they work.

Think of an enzyme as a big piece of popcorn. Its tertiary or quaternary structure gives it a complex shape with lots of nooks and crannies. Within one of those nooks is a small area called the **active site** (**FIGURE 2-42**). Based on the chemical properties of the atoms lining this pocket, the active site provides a place for the participants in a chemical reaction, the reactants or **substrate** molecules, to nestle briefly.

Enzymes are very choosy: they bind only with their appropriate substrate molecules, much like a lock that can be opened with only one key (see Figure 2-42). The exposed atoms in the active site have electrical charges that attract rather than repel the substrate molecules, and only the substrate molecules can fit into the active-site groove. Once the substrate is bound to the active site, a reaction can take place—and usually does so very quickly.

The chemical reactions that occur in organisms can either release energy or consume energy. But in either case, there is a certain minimum energy—a little "push"—needed to initiate the reaction, called **activation energy.** And although enzymes don't alter the amount of energy released by a reaction, they act as catalysts by lowering the activation energy, which causes the reaction to occur more quickly.

An enzyme can reduce the activation energy and initiate a chemical reaction in a variety of ways. These include:

1. Stressing critical chemical bonds in the substrate molecule, thus increasing the likelihood of their breaking.
2. Directly participating in the reaction, increasing the substrate's ability to make or break other bonds.
3. Creating a "micro-habitat" that favors the reaction. For instance, the active site might be a nonpolar environment, or it might have a different pH than the surrounding fluid. These slight alterations might increase the likelihood that a particular reaction occurs.
4. Simply orienting or holding substrate molecules in place so that they can be modified.

By virtue of their catalytic capacities, enzymes are at the heart of the chemistry of living organisms. Taken together, all of the chemical reactions in a living organism are its *metabolism.*

These reactions are generally arranged in sequential "metabolic pathways" by which increasingly complex molecules are synthesized or degraded. Each step of these metabolic pathways is catalyzed by an enzyme produced in the body. Proteins are the building blocks with which living organisms are built, but since nearly all enzymes are proteins, proteins can also be thought of as the *builders* of bodies, too.

ENZYMES FACILITATE CHEMICAL REACTIONS

Enzymes can help to bring about chemical reactions in a variety of ways. The enzyme lactase, for example, breaks down the milk sugar lactose into two simple sugars that can be used for energy.

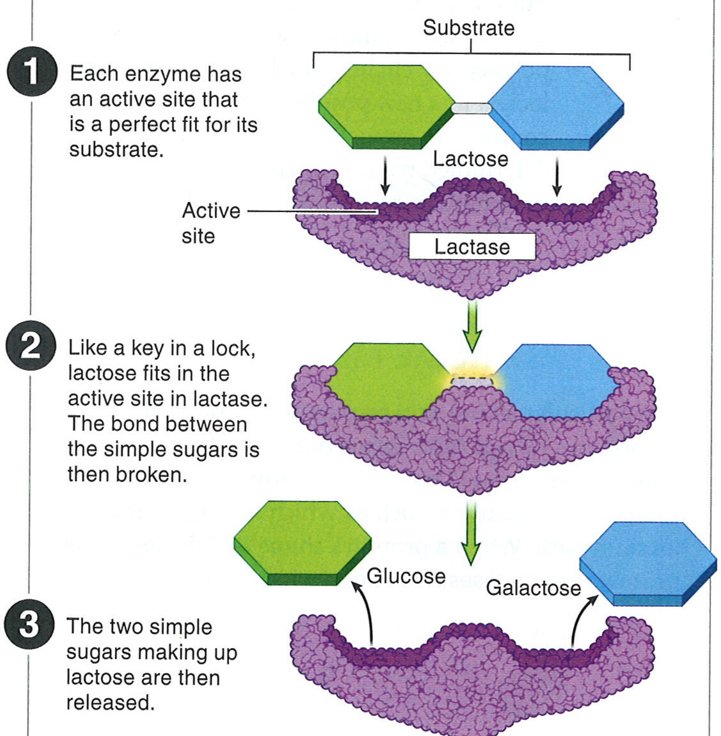


FIGURE 2-42 Lock and key. Enzymes are *very* specific about which molecules and reactions they will catalyze.

TAKE-HOME MESSAGE 2·17

Enzymes are proteins that help initiate and speed up chemical reactions. They aren't permanently altered in the process, but rather can be used again and again.

2·18 Enzymes regulate reactions in several ways (but malformed enzymes can cause problems).

If not for enzymes, it is possible that nothing would ever get done. At least not in living organisms. Enzymes don't alter the outcome of reactions, but without the chemical "nudge" they supply—often increasing reaction rates to millions of times their uncatalyzed rate—the processes necessary to sustain life could not occur.

The rate at which an enzyme catalyzes a reaction is influenced by several chemical and physical factors (**FIGURE 2-43**). These include:

1. **Enzyme and substrate concentration.** For a given amount of substrate, an increase in the amount of enzyme increases the rate at which the reaction occurs. Similarly, for a given amount of enzyme, an increase in the substrate concentration increases the reaction rate. In both cases, the increases occur only up to the point at which all of the enzyme molecules are bound to substrate, or vice versa, at which point additional enzyme or substrate no longer increases the reaction rate.

2. **Temperature.** Because increasing the temperature increases the movement of molecules, reaction rates generally increase at higher temperatures. This occurs only up to the optimum temperature for an enzyme. At temperatures above the optimum, reaction rates decrease as enzymes lose their shape or even denature. Enzymes from different species can have widely differing optimum temperatures.

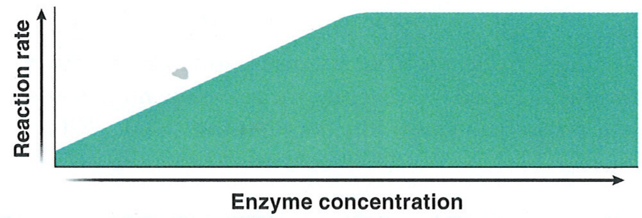
3. **pH.** As with temperature, enzymes have an optimum pH. Above or below this pH, interactions between excess hydrogen or hydroxide ions and amino acid side chains in the active site disrupt enzyme function (and sometimes structure) and decrease reaction rates.

4. **Presence of inhibitors or activators.** One of the most common ways that cells regulate their metabolic pathways is through the binding of other chemicals to enzymes. This can alter enzyme shape in a way that increases or decreases the enzyme's activity. **Inhibitors** reduce enzyme activity and come in two types: **competitive inhibitors** bind to the active site, blocking substrate molecules from the site and thus from taking part in the reaction. **Noncompetitive inhibitors** do not compete for the active site but rather bind to another

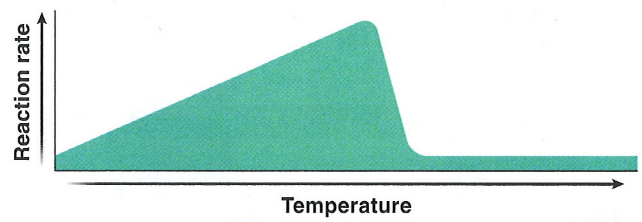
ENZYME ACTIVITY

The rate at which an enzyme catalyzes a reaction is influenced by several chemical and physical factors.

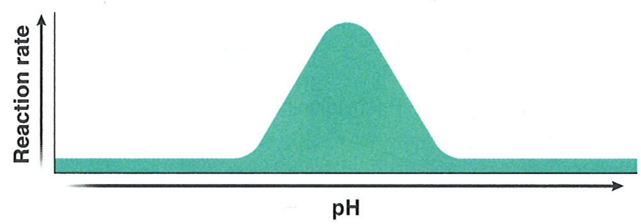
ENZYME AND SUBSTRATE CONCENTRATION
Reaction rates increase with increased amounts of enzyme (or substrate), but only up to the point at which all of the enzyme molecules are bound to substrate. At that point, additional enzyme (or substrate) no longer increases the reaction rate.



TEMPERATURE
Reaction rates generally increase at higher temperatures, but only up to the optimum temperature for an enzyme. At temperatures above the optimum, reaction rates decrease as enzymes lose their shape or even denature.



pH
Reaction rates generally increase as pH nears the optimum level for an enzyme. Above or below this pH, enzyme function can be disrupted and reaction rates decrease.



PRESENCE OF INHIBITORS OR ACTIVATORS
Reaction rates increase in the presence of activators and decrease in the presence of inhibitors.

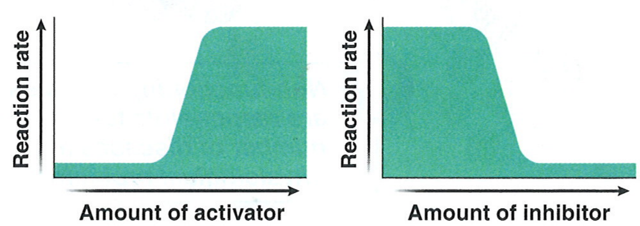


FIGURE 2-43 Enzyme activity is influenced by physical factors such as temperature and pH, and by chemical factors such as enzyme and substrate concentrations.

part of the enzyme, altering its shape in a way that changes the structure of the active site, reducing or blocking its ability to bind with substrate. Often, it is the very product of a metabolic pathway that acts as an inhibitor of enzymes early in the pathway, effectively shutting off the pathway when enough of its end product has been produced.

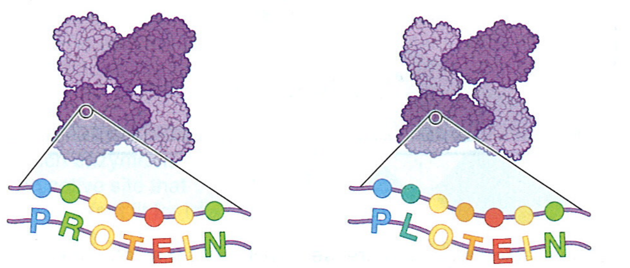
Just as a molecule can bind to an enzyme and inhibit the enzyme's activity, some cellular chemicals act as **activators.** Instead of their binding to an enzyme "turning it off," their binding to the enzyme "turns it on," altering the enzyme's shape or structure so that it can now catalyze a reaction.

Sometimes a cell produces a protein "word" that is misspelled—that is, the sequence of amino acids is incorrect. If an enzyme is altered even slightly, the active site may change and the enzyme no longer functions (**FIGURE 2-44**). Slightly

NON-FUNCTIONING ENZYMES

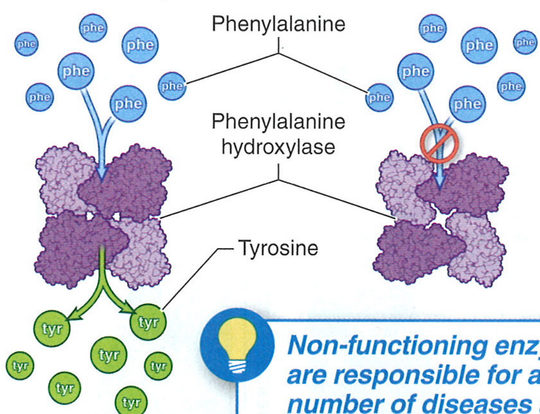
Sometimes a protein "word" is misspelled—that is, the sequence of amino acids is incorrect. If an enzyme is altered even slightly, the active site may change, which can cause the enzyme to no longer function.

FUNCTIONING ENZYME | **NON-FUNCTIONING ENZYME**



When functioning normally, the enzyme phenylalanine hydroxylase converts the amino acid phenylalanine into another amino acid, tyrosine.

If the shape of phenylalanine hydroxylase is altered, it may not be able to convert phenylalanine into tyrosine.



Non-functioning enzymes are responsible for a large number of diseases and physiological problems.

FIGURE 2-44 **When a protein is "misspelled."**

modified, non-functioning enzy… large number of diseases and physiological problems (see Section 5-9). An example is the body's inability to break down the amino acid phenylalanine (in a condition known as phenylketonuria).

One health issue influenced by enzyme function is the condition called lactose intolerance. Normally, during digestion, the lactose in milk is broken down into its component parts, glucose and galactose (see Figure 2-42). These simple sugars are then used for energy. But some people, when they become adults, are unable to break the bond linking the two simple sugars because they no longer produce the enzyme lactase that assists in this process. Consequently, any lactose in their diet passes through their stomach and small intestine undigested. Then, when it reaches the large intestine, bacteria living there consume the lactose. The problem is that, as the bacteria break down the lactose, they produce some carbon dioxide and other gases. These gases are trapped in the intestine and lead to severe discomfort. Interestingly, in regions of the world with long traditions of pastoralism (raising and consuming livestock), lactose intolerance is much rarer than in other parts of the world. Only about 10% of people from Denmark or Sweden have lactose intolerance, but among people from China, which has historically been largely non-pastoral, about 99% are lactose intolerant.

Q Why do some adults get sick when they drink milk?

The unpleasant symptoms of lactose intolerance can be avoided by not consuming milk, cheese, yogurt, ice cream, or any other dairy products, but they can also be avoided by taking a pill containing the enzyme lactase. It doesn't matter how the enzyme gets into your digestive system; as long as it's there, the lactose in the milk can be broken down.

TAKE-HOME MESSAGE 2·18

Enzyme activity is influenced by physical factors such as temperature and pH, as well as chemical factors, including enzyme and substrate concentrations. Inhibitors and activators are chemicals that bind to enzymes and by blocking the active site or altering the shape or structure of the enzyme can change the rate at which the enzyme catalyzes reactions.