Proteins play many roles in the cell. Some proteins function as **enzymes.** Enzymes allow reactions to occur at rates of thousands of times per second. Without enzymes, necessary chemical reactions would not occur at the rate that is required for life.

Enzymes are protein catalysts.

Enzymes and Activation Energy

Enzymes function as **catalysts,** greatly speeding up the rate of a chemical reaction. Unlike a product of a reaction or the raw material for a reaction, the enzyme is not used up or changed as the reaction proceeds.

Catalysts are substances that speed up chemical reactions, without being changed or used up.

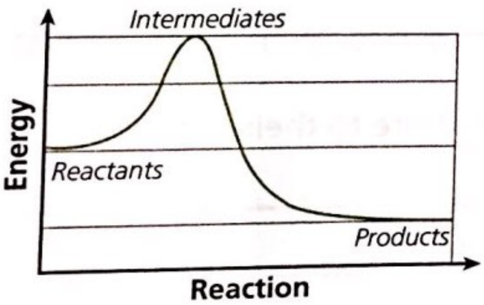
The graphs below compare the energy of the starting *reactants,* or raw materials, with that of the final *products.* As the reactants are changed to products, they take on an intermediate form. This form has a greater amount of energy than either the products or reactants. Unless this *activation energy* is added, the reaction cannot proceed.

In a reaction, *reactants* are chemically changed to *products.*

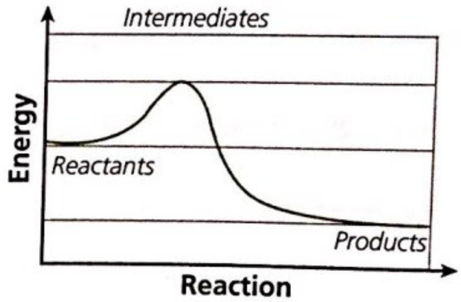
Enzymes work by lowering the activation energy of a chemical reaction. With a lower activation energy, the reactants can be changed to products at a much faster rate.

The energy required for chemical reaction to convert reactants to products is called the *activation energy.* Enzymes reduce the activation energy.

ACTIVATION ENERGY WITHOUT ENZYME



ACTIVATION ENERGY WITH ENZYME



How does the energy of a reaction change when it is catalyzed by an enzyme?

A The energy of the products increases.

B The energy of the products decreases.

C The energy of the intermediates increases.

D The energy of the intermediates decreases.

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Choices A and B are incorrect because the energy of the reactants and products does not change. An enzyme lowers the activation energy of a reaction, which is the energy required to form the intermediates. In a catalyzed reaction, the intermediates can form with less energy.

Enzyme Specificity

An organism can have thousands of enzymes, each one specific to a different reaction. An enzyme acts on the reactant, or starting material of a reaction. This substance is called a *substrate*. Enzymes are highly specific for the substrates they bind. For example, sucrose (table sugar) must be digested into monosaccharides so that our cells can absorb it. The enzyme sucrase speeds up this chemical reaction, but will not affect the breakdown of lactose (milk sugar).

sucrose → glucose + fructose

The shape of an enzyme is what makes it specific to one substrate and not any others. Enzymes are proteins, and proteins are folded into complex, three-dimensional structures. An enzyme's structure has a deep fold or pocket on its surface, to which a substrate molecule attaches. These folds are called *active sites*. Binding with the active site causes the substrate to be converted to products.

A substrate binding to the active site of an enzyme is analogous to a key fitting into a lock. The enzyme catalyzes the reaction only if the shape of the substrate fits the active site. A substrate can also *induce* the enzyme to fit. When the right substrate enters the active site, the enzyme's shape changes slightly as the substrate bonds with the active site.

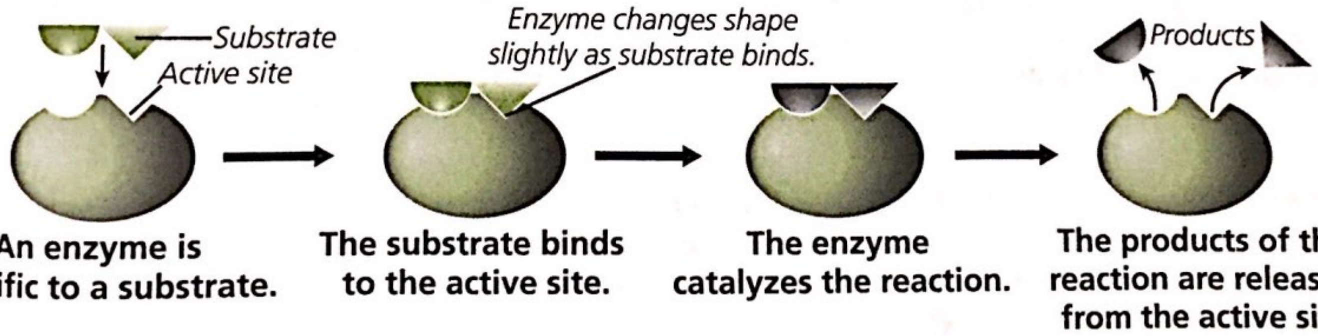
The *substrate* is the substance that the enzyme helps to react. Enzymes are *substrate-specific*.

Enzyme names often end in the suffix *-ase*.

Sucrose and lactose are both disaccharides made up of two monosaccharides.

The *active site* is the region on an enzyme to which the substrate binds. Binding catalyzes the change from substrate to product. Active site bonds are very temporary.

The older lock-and-key model and the newer induced-fit model are two ways of describing how a substrate binds to an enzyme.



Some enzymes have evolved from enzymes with different substrates and functions. Which amino acids in the enzyme most likely changed during the course of this evolution?

Because the active site plays such an important role in substrate specificity and enzyme function, amino acids making up this part of the protein are most likely to have changed.

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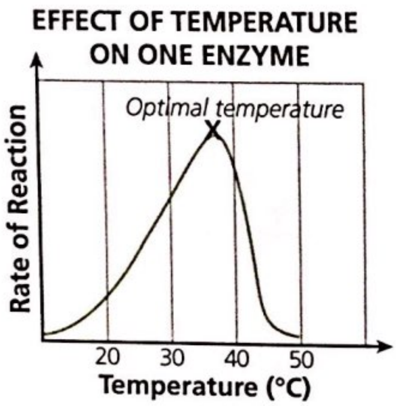
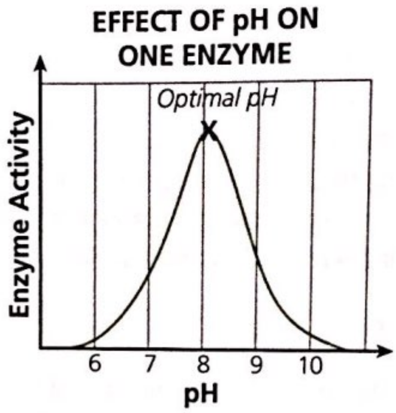
Enzymes and Optimal Conditions

An enzyme functions best at an optimal temperature and pH level. Its reaction rate slows if it is placed in less-than-optimal conditions. This is because enzymes are proteins, macromolecules with complex, highly folded, three-dimensional structures. An enzyme's ability to catalyze a reaction depends on its structure. When conditions disrupt an enzyme's structure, the enzyme's activity is affected.

The reaction rate refers to how fast or slow the reaction occurs.





On the pH scale, 0 to 6 is acidic, 7 is neutral, and 8 to 14 is basic.

Different enzymes function best in different conditions. The optimum temperature for enzymes in the human body, for example, is about 37°C (98.6°F). Similar enzymes in a cold-water fish function best at lower temperatures.

Temperatures or pH levels that are too high or low can cause an enzyme to *denature*. A denatured enzyme no longer functions. Denaturation may be permanent or may be reversible if conditions change.

Denaturation is the process of an enzyme becoming inactive due to factors that alter the enzyme's structure.

A denatured enzyme does not catalyze a reaction.

Thermophilic bacteria live in hot springs with temperatures of 70°C (158° F). Water this hot would instantly scald your skin. A scientist collects these bacteria to be cultured in a laboratory. Explain what the scientist would need to do to ensure a healthy culture.

Because the bacteria are adapted to hot temperatures, their enzymes function optimally in these conditions. To culture the bacteria in a laboratory, the scientist would need to grow them in a solution at 70°C.

Enzyme and Substrate Concentrations

It seems obvious that adding more substrate to an enzyme will result in more product (that is, enzyme activity increases). Is this always the case? The graph on the next page shows that increasing the concentration of substrate does increase enzyme activity—up to a point. Then, the activity levels off.

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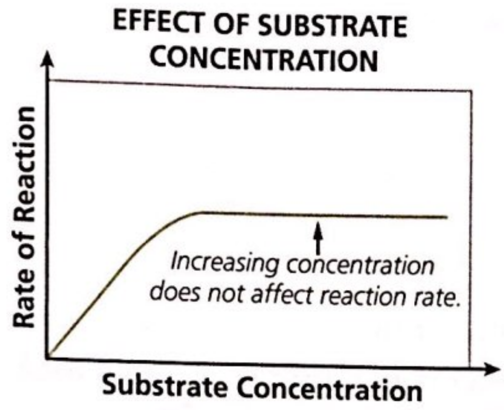
Suppose enough substrate is added to fill all the active sites of all the enzyme molecules. Any additional substrate will not be catalyzed because there are no available active sites. At this point, increasing substrate concentration will have no effect on the rate of enzyme activity. It is limited by enzyme concentration.

Past a certain substrate concentration, adding more substrate does not affect the reaction rate.



Similarly, if the concentration of enzyme that is added to the substrate increases, the reaction rate will also increase. This then levels off above a certain enzyme concentration. At this point, all the substrate molecules are bound to enzyme. Increasing enzyme concentration will have no effect on activity—there is no substrate available for them to catalyze.

Past a certain enzyme concentration, adding more enzyme does not affect the reaction rate.

In an experiment, test tubes are filled with equal enzyme concentrations and different substrate concentrations. As substrate concentration increases, the reaction occurs at a faster rate. However, after a certain concentration, the reaction rate remains the same. Can you change the quantities in the test tube to obtain more product?

Yes. The rate of reaction is limited by the availability of enzyme. There is more substrate than enzyme. Adding additional enzyme to the test tube will catalyze the extra substrate and increase the reaction rate.

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IT'S YOUR TURN

Please read each question carefully. For a multiple-choice question, circle the letter of the correct response. For a constructed-response question, write your answers on the lines.

1 Which is **not** a structural feature of an enzyme?

A protein

B substrate

C active site

D amino acid

2 Organisms produce hydrogen peroxide (H_2O_2), a by-product of metabolism that is toxic to cells. The catalase protein catalyzes the reaction shown below.

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

Which statement describes the reaction?

A Water is the substrate.

B Hydrogen peroxide is the enzyme.

C Catalase is consumed by the reaction.

D Oxygen gas is a product of the reaction.

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3 The enzyme lactase catalyzes the breakdown of lactose (milk sugar) to glucose and galactose. Students set up a beaker with milk and lactase enzyme. Which describes how the concentrations of these substances will change?

A The concentration of lactase will decrease, and the concentration of galactose will increase.

B The concentration of galactose will decrease, and the concentration of glucose will increase.

C The concentration of galactose will increase, and the concentration of lactase will remain the same.

D The concentration of lactose will increase, and the concentration of glucose will remain the same.

4 A reaction tube is set up at 37°C with twice as much substrate as enzyme. The pH level of the solution is 5. The reaction rate is measured. Which of the following changes will **not** affect the rate of the reaction?

A increasing the pH level

B increasing the temperature

C increasing the enzyme concentration

D increasing the substrate concentration

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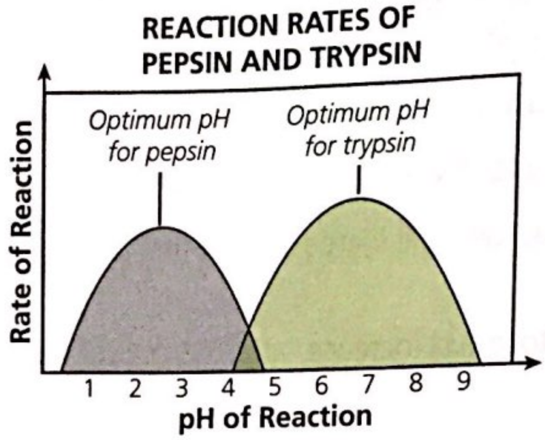
Use the graph below to answer question 5.



5 The graph shows the rate of enzyme activity in relation to pH for two enzymes—pepsin and pancreatic trypsin. Both enzymes break down proteins in food. Pepsin works within the stomach. Trypsin works in the small intestine.

A What does the graph indicate about the pH of the stomach and small intestine?

B The contents of the stomach are released into the small intestine. How does this affect the function of the pepsin that is included with the stomach contents?

C What is the advantage to having two different protein-digesting enzymes, rather than just one?

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