Enzymes and Cellular Regulation

What are the factors that regulate the rate at which enzymes catalyze reactions?

Why?

Digestive enzymes are protein-based biological catalysts that play important roles in our lives. They help remove stains from our shirts, turn milk into cheese, and are responsible for turning our dinner into usable fuel for our bodies. Enzymes however do not work well universally. Some are meant to work at high temperatures, others at low temperatures. They may work best in acidic conditions or neutral conditions. In this activity we will look at the optimal conditions for two different enzymes. The digestive enzyme lipase is made in the pancreas and breaks down lipids in the small intestine, while pepsin breaks down proteins in the stomach.

Model 1 – Two Digestive Enzymes

<table>
<thead>
<tr>
<th>lipase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triglycerides → glycerol + fatty acids</td>
</tr>
<tr>
<td>pepsin</td>
</tr>
<tr>
<td>Large polypeptides → smaller polypeptides + amino acids</td>
</tr>
</tbody>
</table>

Effect of pH on Enzyme Activity

1. Name the two enzymes illustrated in Model 1.

   Pepsin, lipase

2. Consider the information provided in the Why? box and in Model 1 about these proteins.
   a. In which body organ is pepsin active?

      Stomach

   b. In which body organ is pancreatic lipase active?

      Small intestine
3. For each enzyme in Model 1, circle the pH that best represents the environment in which the enzyme is most active.

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>pH</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pepsin</td>
<td>8</td>
<td>10.4</td>
</tr>
<tr>
<td>Lipase</td>
<td>1.5</td>
<td>8</td>
</tr>
</tbody>
</table>

4. Compare the rate of the pepsin-catalyzed reaction at pH 1.5 with the rate of the lipase-catalyzed reaction at pH 1.5.

@ 1.5 pH - Pepsin makes rate of reaction, lipase non-functional

5. Compare the rate of the pepsin-catalyzed reaction at pH 8 with the rate of the lipase-catalyzed reaction at pH 8.

Reverse / alone.

6. Using your knowledge of protein structure, explain in detail the effect of exposing an enzyme to a pH outside of its optimal range. Include the effect on both enzyme structure and function.

extreme pH denatures the protein (unfolding), thus rendering it useless as a catalyst

7. At what pH values is lipase likely to be denatured? Justify your answer.

Above 12.9 below 4

8. At what pH values is pepsin likely to be denatured? Justify your answer.

Above 5

9. In addition to being produced in the pancreas, lipase is also produced in the stomach. Is the structure of pancreatic lipase the same as gastric (produced in the stomach) lipase? Justify your reasoning.

No, stomach pH is 1.5, thus this enzyme needs to be tolerant to those conditions.

10. Add a line to the graph in Model 1 that shows a prediction for gastric lipase activity.

11. Antacids work by neutralizing acids, bringing the pH of the stomach to a range of 6–7. What is the effect of taking an antacid on a person’s ability to digest proteins?

Think of an antacid as an inhibitor, temporarily denaturer enzyme.

Address Nick’s question!
Model 2 – Amylase Rate of Reaction

12. Amylase is an enzyme that catalyzes the digestion of carbohydrates. The graphs in Model 2 provide data on several factors that affect the function of amylase in the body.

   a. The relationship of which two variables is illustrated in graph A of Model 2?
      \[ \text{Rate vs. Time} \]

   b. The relationship of which two variables is illustrated in graph B or Model 2?
      \[ \text{Rate vs. Enzyme Conc.} \]

   c. The relationship of which two variables is illustrated in graph C or Model 2?
      \[ \text{Rate vs. Substrate Conc.} \]

13. Refer to Model 2.

   a. What is the optimum temperature for amylase?
      \[ \sim 35 \degree C \text{ or } 37 \degree C \]

   b. What is the biological significance of the temperature at which the amylase-catalyzed reaction is fastest?
      \[ \text{It's at the temp of the human body!} \]
14. Predict what causes a decrease in enzyme activity at temperatures above 37 °C.

Denaturation of the enzyme.

15. A young child runs a fever of 40 °C for 24 hours. Explain what effect this may have on his digestion.

Slows digestion as amylase (among other enzymes) denatures.

16. Consider the data in graph B of Model 2.

a. Describe the relationship between enzyme concentration and reaction rate.

More enzyme = \( \uparrow \) reaction rate

b. Propose an explanation for this relationship.

More enzyme = more available active sites

17. Consider the data in graph C of Model 2.

a. What is the relationship between substrate concentration and the reaction rate?

More substrate = \( \uparrow \) reaction rate (until amount of substrate exceeds amount of enzyme)

b. Propose an explanation for why a maximum reaction rate is reached in graph C.

When all active sites are full, the reaction rate levels

18. As a group, develop an analogy for the function of an enzyme that will explain the concentration graphs in Model 2 (graphs B and C).

Enzyme are like construction workers.

When the amount of housing projects exceeds the amount of construction crews, the rate of new home development levels.

19. Would the reaction rate on graph B of Model 2 ever reach a maximum level? Justify your answer.

Only when the enzyme concentration = substrate concentration

POGIL™ Activities for AP* Biology
Extension Questions

20. Thermophilic bacteria, such as *Thermus aquaticus*, live in hot springs where the temperature is greater than 70 °C. Draw a graph similar to graph A in Model 2 representing the optimal temperature of *T. aquaticus*.

![Graph](image)

21. DNA polymerase from *T. aquaticus (Taq)* is used in PCR (polymerase chain reaction). PCR is a technique where millions of copies of DNA can be made from one original copy. In this method, the target DNA molecule is subjected to temperatures over 95 °C to make the double-stranded DNA separate. The temperature is then lowered slightly to allow primers to anneal before the *Taq* polymerase catalyzes the reactions to incorporate new nucleotides into the complementary strands. The cycle is then repeated over and over until there are millions of copies of the target DNA.

   a. Predict why this bacterial polymerase is used instead of a human polymerase.

   ![Human polymerase denatures at 95°C, Taq doesn't](image)

   b. What would happen if you used a human polymerase in a series of PCR reactions?

   ![The human polymerase would denature at the high temp so PCR wouldn't occur. OR Depending on timing, a new human polymerase would be used each time.](image)

Read This!

The rate of an enzyme-catalyzed reaction can also be affected by the presence of other molecules that can bind to the enzyme, changing its shape. In some reactions a coenzyme is necessary. This molecule binds to the protein strands of the enzyme, changing its shape so that is ready to receive the substrate molecule. Without the coenzyme, the enzyme would not be able to attach to the substrate. Other molecules can reduce the rate of reaction for enzymes by binding to the protein and either blocking the spot where the substrate will bind or by making the enzyme’s shape incompatible with the substrate. These molecules are called inhibitors.

22. Sketch a graph that shows the relationship between the rate of an enzyme reaction and the concentration of coenzyme necessary for the enzyme to function properly.

![Graph](image)

23. Add a line to graph C of Model 2 that shows the rate of an enzyme reaction in the presence of inhibitor molecules.

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