Enzymes

One class of proteins is so important that it gets an entire section devoted to it. We're talking about enzymes here. What makes them so hot? It's because of what they do. They make reactions in a cell happen a whole lot faster than they otherwise would have. It's like this: molecules A and B are just sitting around in the cell and they could undergo **a reaction** to produce product C.

Just because reactants A and B could undergo a reaction, however, doesn't mean that they will anytime soon. Here lies the crux of an enzyme's job: **an enzyme speeds up the rate of a reaction.**

Does an enzyme make a reaction happen that otherwise would never ever have happened? No. Does it make the reaction churn out more products than otherwise possible? Nope. Does it alter the steps of the reaction itself in any way? No. What does an enzyme do again? An enzyme simply allows a reaction that could have happened anyway to happen faster by lowering the energy needed for it to start. (This energy is called the **activation energy**.)The enzyme itself is neither used up nor changed at all during the reaction. Once the reaction is completed, the enzyme molecule is free to "do it again"!

It's kind of like this: say you know that your friend in Kansas would really like your friend in Georgia and vice versa. Chances are, if left to fate, these two friends would never meet up with one another, though if they did, they'd really hit it off. So you intervene by getting them together. You invite them both over to your house. They both come to you, and in the process meet each other. It didn't cost you anything to get them together, and sure enough, when they meet each other they form this awesome friendship. After the friendship is made you are unaltered and you could even try to find two other friends to introduce.

WHY ENZYMES ARE CRITICALLY IMPORTANT TO A CELL

A cell can't afford to sit around forever waiting for a reaction to happen on its own sweet time. Instead the cell produces enzymes that get the reactants to react. This way the cell can carry on with all of its reaction, which keep it alive.

Let's look more closely at the hypothetical reaction that creates product C, which the cell simply must have in order to thrive.

$$\text{Reactants A + B} \rightarrow \text{Product C}$$

Say that the cell needs some product C and it needs it now. What does it do? It manufactures some enzyme Z. Why? So that Z can get the reactants A and B together to produces product C. Mission accomplished.

$$\text{Reactants A} + \text{B} + \text{Enzyme Z} \rightarrow \text{Product C} + \text{Enzyme Z}$$

Now let's say the cell has plenty of product C and really can't handle any more of it for a while. What does it do? It can cut down on production of enzyme Z. Without so much enzyme Z around to facilitate matters, the reaction rate slows down and less C's get made.

So enzymes are actually an ingenious tool used by the cell to fine tune activities and production lines. Sometimes enzymes are helped in performing their job. Their assistants are called **coenzymes**. **Vitamins** act as coenzymes. So, if you don't get the vitamins you need on a constant basis, the enzymes will not function well and your metabolism and needed body reactions will slow down.

Check Your Progress 1:

1. An enzyme reaction that is provided with sufficient enzymes and reactants most likely occurs
    a. Once in a blue moon
    b. Never

c. Rarely
d. Readily

2.

Enzymes speed up the _____ of a reaction.

3. Which of the following act as coenzymes?
   a. Lipids
   b. Peptides
   c. Minerals
   d. Vitamins

4. What is the fate of an enzyme upon completion of a catalysed reaction?
   a. it is degraded
   b. it becomes incorporated into the reaction product(s)
   c. it is unaffected and available to catalyse another like reaction
   d. it multiplies

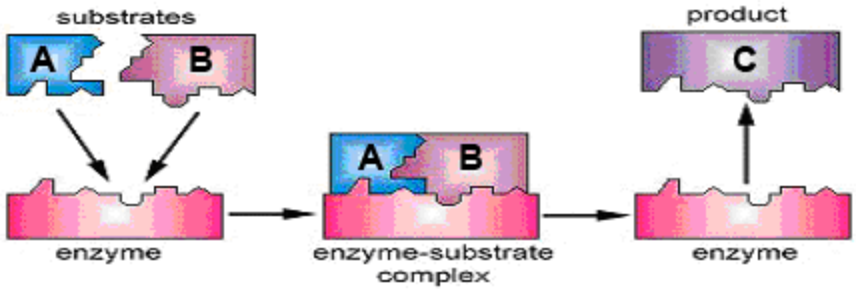
HOW DOES AN ENZYME WORK?

Since an enzyme is a protein, we know that it's made up of amino acids joined together by peptide bonds and that the polypeptide is then folded up into some three-dimensional shape.

Now here's what's special about an enzyme's shape: it has what is called an **active site**. The active site is like a dock where reactants (also called **substrates**) can temporarily anchor themselves. There's a special binding site for two or more substances on the enzyme's active site. Now let's think about this for a minute. If, say, there are two boats out on sea somewhere, it's pretty unlikely that by chance they will even get within sight of one another. After all, the sea's a pretty big place and two boats are comparatively small.

But if the boats happen to pull up at the same dock to moor, well, now they're positioned right next to one another, in adjacent boat slips.

Enzymes act as the dock, and the binding sites on their active sites act as the boat slips. The substrates act as the boats and the entire intracellular space can be thought of as the sea. The substrates would have a hard time finding one another in the open sea that is the intracellular space. So an enzyme acts as a temporary docking site (matchmaker!), bringing the substrates in close to one another. The close proximity of the substrates initiates the reaction.



What happens to all of the players once the reaction is over?

1. The reactants don't exist anymore. (Substrate A and Substrate B are now history)
2. Product C appears.
3. The enzyme is left exactly the same as it was before the reaction took place.

FYI: Before the reaction we have Substrate A, Substrate B, and the enzyme.
After the reaction we have product C and the enzyme

UNCHANGED AND READY FOR ACTION

As you read before, enzymes are not changed when facilitating a reaction and can be used repeatedly as long as more substrate is present. This ability of an enzyme to speed up the rate of reaction without itself being changed has earned it the name of **organic catalyst**. You already know what organic means (it contains carbon). A **catalyst** is something that effects a change in something, but is not itself changed (or used up) in the process. Enzymes can catalyze both forward **and** reverse reactions (think: dehydration synthesis and hydrolysis reactions, for example).

Check Your Progress 2:

Answer yes or no to the following questions.

1. _____Can an enzyme be used more than once for a reaction?
2. _____Does an enzyme undergo change during a reaction?
3. _____Is an enzyme an organic catalyst?
4. _____Does an enzyme slow the rate of a reaction?
5. _____Are reactants A and B present after a reaction has occurred?
6. _____Is a substrate also a reactant?
7. _____Does an enzyme allow the cell a measure of control over which reactions will take place when?
8. _____Does an enzyme work by bringing the products of a reaction close to one another.

ENZYME SPECIFICITY

If you can realize that a perfect square and a moon shape can't fit together, then you understand the idea of enzyme specificity. The shape of the enzyme allows it its function by determining what substrate (shape) will bind to it. For instance a triangular-shaped substrate won't fit into a round active site. A square substrate won't fit into a crescent-shaped active site.

Let's say you have a normal shaped car that looks something like this:

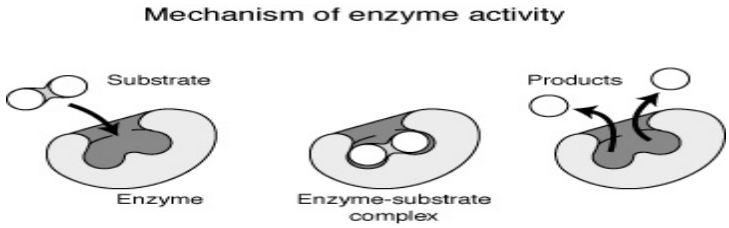
and your garage space that looks like this:

Your architect was going through a "triangular phase" at the time. A lot of good your triangular garage does for you: your car can't fit into that space, so it stays outside under all those bird nests, getting wet, rusting, and covered with you-know-what. The car isn't the proper fit for the garage site, so the garage can't really work for that car.

If, during her triangular phase, the architect had also designed a car for you, there would be a happier ending to the story. This particular car would fit the garage site and the garage could do its job for the car.

THE LOCK-AND-KEY THEORY OF ENZYMES

Enzymes operate in the same way that our garage does. If a specific substrate does not fit the **active site**, then the substrate won't bind there and the enzyme won't catalyze that particular reaction. This concept is called the **lock-and-key theory**, which makes sense if you think about it. Only one key will fit a given lock. All those dips and grooves have to fit precisely in order to engage and allow the door to open. The grooves and dips in the enzyme's active site must match those in the substrate, or nothing happens. Recently they have modified this theory. We now believe that when the substrate and enzyme make contact the enzyme has some ability to change its shape to allow the substrate to fit. This idea is called the **induced fit theory**. Substrate and enzyme must still fit like a lock and key, but just like the locks in my life, often it takes a little wiggle and holding it just right to make it work.



If the substrate does match the active site in shape, then we get what is called the **enzyme-substrate complex**. What is it? It's a single structure created by temporary association of substrate (reactants) with enzyme. As soon as the reactants do their thing, however, the enzyme-substrate complex disbands and we're left with enzyme and product(s) – two separate structures.

Check your progress 3:
Fill in the blank with true or false.

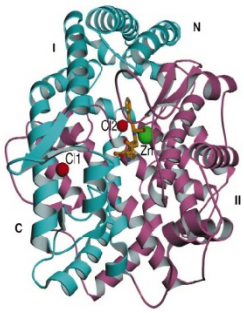
1. _____A single enzyme is capable of catalyzing many different types of reactions.
2. _____A single enzyme is capable of catalyzing a specific reaction many times.
3. _____The enzyme-substrate complex is a transient structure that precedes formation of a product in an enzymatic reaction.
4. _____The lock-and-key theory of enzymes attempts to explain an enzyme's specificity for a substrate.

FACTORS THAT AFFECT ENZYMES

So enzymes seem to be pretty amazing in the way in which they can catalyze a reaction over and over again without seeming to suffer any consequences. This might lead you to wonder if enzymes are indestructible. The answer is no. Eventually an enzyme wears out. What's more, certain conditions **stop an enzyme in its tracks**:

1. **High temperatures and low temperatures**
2. **pH that is too low or too high**
3. **Salinity that is too high**

Here's where you ought to think of an enzyme not as an abstract thought, but as a real **three-dimensional structure (protein conformation)**. Imagine that you are holding an enzyme between your palms (it's lightweight but awkwardly shaped) or walking around one and admiring it from all angles, as if it were a piece of artwork sitting on a table.



KEEPING IN SHAPE IS SERIOUS BUSINESS TO AN ENZYME

An enzyme's ability to function depends in a big way on its three-dimensional shape. The bonds that form between atoms give the enzyme its shape. (Keep in mind here that the most important part of the enzyme is the active site, where the substrates actually bind). It turns out that extremes in **pH, temperature**, or **salinity** disrupts bonds ("denatures" the enzyme). This alters the enzyme's **shape**, and therefore the enzyme's ability to **function**. After all, if the active site no longer has the right shape for its substrates to fit into, then the substrates can't bind. If the substrates can't bind, then they won't be brought close to one another, and the reaction won't happen.

Naming

The names of most enzymes are linked to the names of the substrates acted upon; the normal ending of a substrate name is replaced with "-ase". So, enzymes acting on lipids are lipases;, on proteins would be proteases; on cellulose--cellulase; on amylose (starch)--amylase. Exceptions include some of the first enzymes discovered: trypsin and pepsin (they catalyze polypeptide digestion in the small intestine).

FYI:

Low temperature: Molecules move slower at low temperatures, so enzymes work slowly in this environment. However, the bonds are not disrupted, so if normal temperature is restored, the enzymes will resume normal activity.

High temperature: Molecules move faster as they are heated and work faster, but at some point (temp) unique to each enzyme, the heat actually breaks bond (this process is called **denaturation**; the enzyme has lost its natural shape). When the bonds break, the active site is disrupted and the enzyme protein is usually out of commission permanently.

Low or High pH: Acts like high temperature in disrupting bonds permanently; each enzyme has an optimal pH where the bonds are intact and the active site "fits" with the substrate.

SATURATION KINETICS

Now that you've considered an enzyme in terms of shape, let's think of it in its capacity as a worker. We said that each time it catalyzes one reaction, it

1. binds to substrate A and substrate B (assuming it is a synthesis type of reaction)
2. forms an **enzyme-substrate complex** as an intermediate step
3. disbands, leaving the product(s) and the enzyme in its original state.

So if we think about it, each time an enzyme is engaged with its substrate, it is unavailable to bind with more substrate. As soon as it disengages, of course, it is available and ready to catalyze another reaction by binding more substrate. What we're talking about here is supply and demand.

WHEN THERE'S MORE ENZYME THAN SUBSTRATE

If you have 50 enzyme molecules and 20 substrate molecules for a given reaction, then even when all of the substrates are engaged, there are lots of enzyme molecules that are not working. If the cell then produces more substrate molecules – say, 30 more- then all of the enzyme molecules are now busy working, all of the substrate molecules are engaged, and the number of times the reaction takes place goes up.

What happens if the cell adds even more substrate at this point?

WHEN THERE'S MORE SUBSTRATE THAN ENZYME

Now we have over 50 substrate molecules, but only 50 enzyme molecules. The enzyme is in demand (it's wanted by other substrates) but it is already busy with its current substrate. The enzyme is now **saturated**.

About Saturation

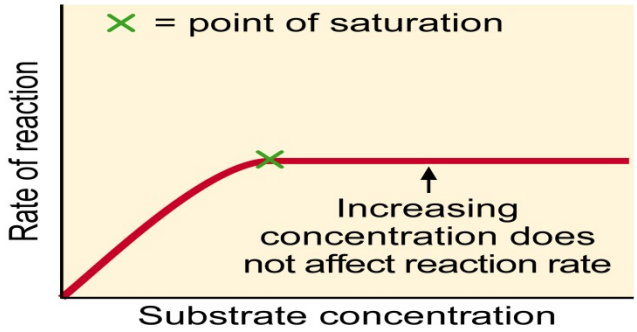
When the sheer number of enzyme molecules available to catalyze a reaction falls below the number of substrate molecules that are waiting to bind, the enzyme molecules are **saturated**. No matter how many extra substrate molecules get added at this point, the enzyme reaction rate (how fast the reaction takes place) remains the same, because the enzyme molecules are already operating at maximum speed.

With saturation, there are more substrate molecules around than there are enzyme molecules to deal with them. That means that the substrate molecules basically wait their turn to be engaged with the next available enzyme molecule (much like waiting in line at the grocery store when it is busy). We all know what waiting for our turn is like. (And you never thought you could empathize with a substrate molecule).

HERE'S OUR CHANCE TO PRACTICE READING A GRAPH

One skill you'll want to develop as you study biology is how to read graphs and charts. They come up pretty frequently in biology, and are handy in real life. It helps to know what you're looking at when you encounter one.

In this case we're going to look at a graph of how **substrate concentration** affects **enzyme activity** (reaction rate) for a particular reaction. Here's the layout: on the horizontal axis (x-axis) we track the amount of substrate present; it increases as we move to the right. On the vertical axis (y-axis) we track enzymatic activity; it increases as we move up.



Now that we have a better handle on what it is we are measuring (enzymatic activity) against what is known (substrate concentration), we can take a look at the information the graph provides.

According to this graph, as substrate molecules are added, enzymatic activity goes up. (See for yourself – pick a spot about ½ inch along the x-axis and then run your eye up to the spot where the line is. Take a look at where that lands you on the y-axis and mark it. Now, do the same thing about 1 inch along the x-axis. Notice that as you move upwards (to the right) along the x-axis, you also move upwards on the y-axis. (**Direct relationship**: one goes up the other goes up, one goes down the other goes down). That means that as substrate concentration increases, so does enzyme activity (reaction rate).

What happens, though, when you do the same thing further along the x-axis (to the right of the X)? When you match up two different points to the right of the X (say, at 1.5 and 2.5 inches along the x-axis) with the corresponding points on the y-axis, you'll find that the enzyme activity stays the same (an increase in substrate concentration does **not** result in an increase in enzyme activity). We say that the **enzyme is saturated**, at these substrate concentrations

The maximum substrate concentration at which an increase in enzyme activity is observed defines the **saturation point** of the enzyme. Beyond an enzyme's saturation point, additional substrate does not result in an increase in enzyme activity.

Check your progress 4:

1. List three conditions that denature (destroy) an enzyme.
    a. _____
    b. _____
    c. _____

2. How do low and high temperature affect an enzyme's activity?

    a. Low temperature _____
    b. High temperature _____

3. Draw a graph that plots enzyme activity (y-axis) vs. temperature (x-axis).

4. Say you are performing a lab experiment in your basement and you notice that if you add more substrate to your enzyme reaction, you get more enzyme activity. What can you conclude about the reaction?
    a. There is probably more substrate present than there is enzyme.
    b. There is probably more enzyme available than there is substrate.
    c. There is probably more product present than there is either substrate or enzyme.
    d. Extreme heat was probably applied to the enzyme before the reaction.

5. What if you add still more substrate to the mix and you find that it has no effect on the rate of enzyme activity? What would you now conclude is happening?
    e. The concentration of available enzyme has exceeded the concentration of substrate.
    f. The concentration of available enzyme has exceeded the concentration of product.
    g. The concentration of available enzyme has exceeded the concentration of the enzyme-substrate complexes.
    h. The concentration of substrate present has exceeded the concentration of available enzyme.

6. What term defines the situation described in question 5?
    i. Saturation
    j. Denaturation
    k. Competition
    l. Inhibition