5.1: Catalytic Efficiency of Enzymes

Introduction

An enzyme's active sites are usually composed of amino acid residues; depending on which amino acid residues are present, the specificity of the substrate can vary greatly. Depending on the pH level, the physical properties (mainly the electric charge) of an enzyme can change. A change in the electric charge can alter the interaction between the active site amino acid residues and the incoming substrate. With that said, the substrate can bind to the active site via hydrogen bonding or van der Waals forces. Once the substrate binds to the active site it forms an enzyme-substrate complex that is then involved in further chemical reactions.

In order for an enzyme to be active and be energetically favorable to allow a chemical reaction to proceed forward, a substrate must bind to an enzyme's "active site". An active site can be thought of as a lock and the substrate as a key; this is known as the **lock and key model**. A key (substrate) must be inserted and turned (chemical reaction), then the lock (enzyme) opens (production of products). Note that an enzyme might have more than one active site. Another theory on the active site-substrate relationship is the **induced fit theory**, which is quite opposite of the lock and key theory (where the active site is seemingly inflexible). In the induced fit theory, the active site of the enzyme is very flexible, and only changes its conformation when the substrate binds to it.

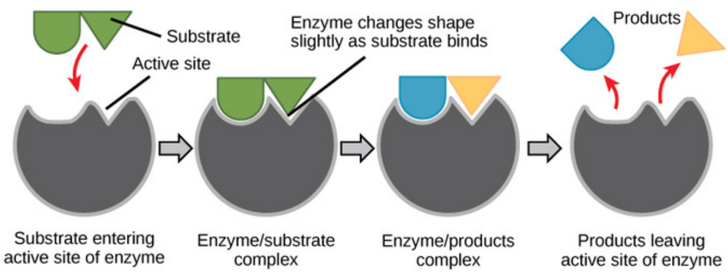

Figure 5.1.1: According to the induced fit model, both enzyme and substrate undergo dynamic conformational changes upon binding. The enzyme contorts the substrate into its transition state, thereby increasing the rate of the reaction.

Enzymes work as a catalyst by lowering the Gibbs free energy of activation of the enzyme-substrate complex. Below are two figures showing a basic enzymatic reaction with and without a catalyst.

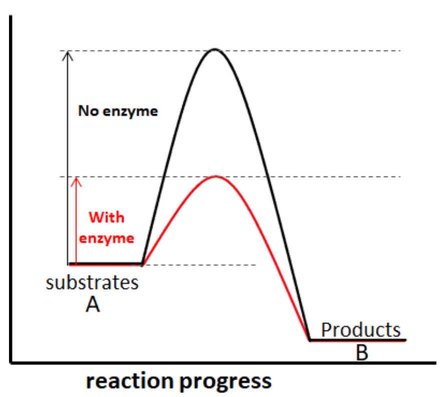

Figure 5.1.2: The energies of the stages of a chemical reaction. Without enzyme (Black line), substrates need a lot of activation energy to reach a transition state, which then decays into lower-energy products. When enzyme catalyzed (Red line), the enzyme binds the substrates (ES), then stabilizes the transition state ($ES^{\ddagger}$) to reduce the activation energy required to produce products (EP) which are finally released.

Notice the difference of the Gibbs energy with the presence of a catalyst; it is higher in value when a catalyst is absent. The Gibbs energy can tell us whether or not a reaction is spontaneous judging from its value. In this case $\Delta G^{\ddagger}$, the Gibbs free energy, can be conceptualized as the probability of a reaction occurring in nature without any interference. With a lower (more negative) Gibbs energy value, the probability of reaction is higher, and vice versa. Enzymes are here to increase the probability of the chemical reaction via many mechanisms, with one of the more prominent explanations being that it adopts a more favorable conformation.

Enzyme Active Site and Substrate Specificity

Enzymes bind with chemical reactants called substrates. There may be one or more substrates for each type of enzyme, depending on the particular chemical reaction. In some reactions, a single-reactant substrate is broken down into multiple products. In others, two substrates may come together to create one larger molecule. Two reactants might also enter a reaction, both become modified, and leave the reaction as two products.

The enzyme’s active site binds to the substrate. Since enzymes are proteins, this site is composed of a unique combination of amino acid residues (side chains or R groups). Each amino acid residue can be large or small; weakly acidic or basic; hydrophilic or hydrophobic; and positively-charged, negatively-charged, or neutral. The positions, sequences, structures, and properties of these residues create a very specific chemical environment within the active site. A specific chemical substrate matches this site like a jigsaw puzzle piece and makes the enzyme specific to its substrate.

Active Sites and Environmental Conditions

Environmental conditions can affect an enzyme’s active site and, therefore, the rate at which a chemical reaction can proceed. Increasing the environmental temperature generally increases reaction rates because the molecules are moving more quickly and are more likely to come into contact with each other.

However, increasing or decreasing the temperature outside of an optimal range can affect chemical bonds within the enzyme and change its shape. If the enzyme changes shape, the active site may no longer bind to the appropriate substrate and the rate of reaction will decrease. Dramatic changes to the temperature and pH will eventually cause enzymes to denature.

Enzyme-Substrate Complex

When an enzyme binds its substrate, it forms an enzyme-substrate complex. This complex lowers the activation energy of the reaction and promotes its rapid progression by providing certain ions or chemical groups that actually form covalent bonds with molecules as a necessary step of the reaction process. Enzymes also promote chemical reactions by bringing substrates together in an optimal orientation, lining up the atoms and bonds of one molecule with the atoms and bonds of the other molecule. This can contort the substrate molecules and facilitate bond-breaking. The active site of an enzyme also creates an ideal environment, such as a slightly acidic or non-polar environment, for the reaction to occur. The enzyme will always return to its original state at the completion of the reaction. One of the important properties of enzymes is that they remain ultimately unchanged by the reactions they catalyze. After an enzyme is done catalyzing a reaction, it releases its products (substrates).
