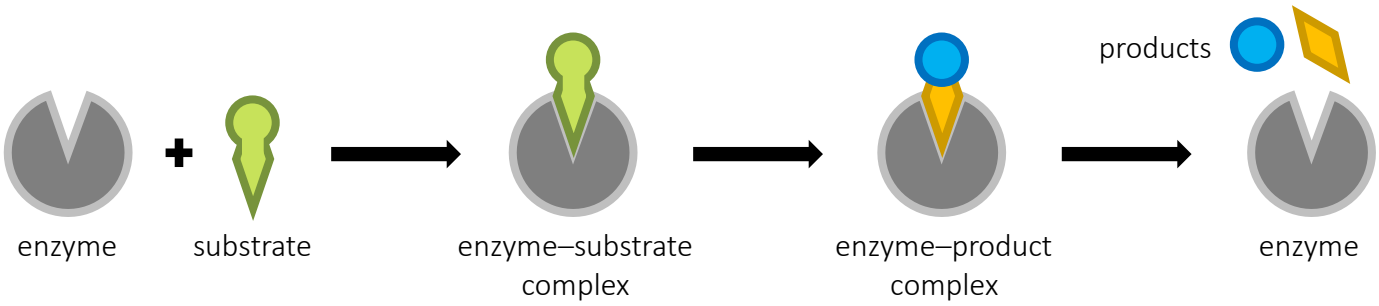
TOPIC: ENZYMES

Key Knowledge:

- The general role of enzymes and coenzymes in facilitating photosynthesis and cellular respiration
- The general factors that impact on enzyme function in relation to photosynthesis and cell respiration: changes in temperature, pH, concentration, competitive and non-competitive enzyme inhibitors

ENZYMES

Enzymes control the metabolism of a cell. An enzyme is a globular protein that acts as a **biological catalyst**. It speeds up the rate of a chemical reaction by lowering the activation energy threshold required for the reaction to proceed. Enzymes are not changed or consumed by the reactions they catalyse and thus can be reused. Enzymes are commonly named after the molecules they react with (called the **substrate**) and end with the suffix '-ase' (e.g. lipase is an enzyme that breaks down lipids, whereas proteases digest proteins).

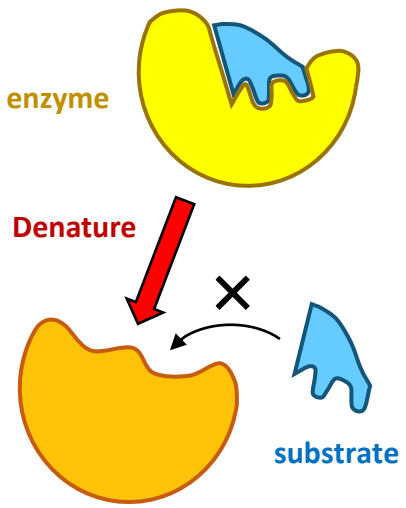


SPECIFICITY

All enzymes possess an indentation or cavity to which a substrate can bind – this is called the **active site**. The shape and chemical properties of the active site are complementary to a particular substrate. Thus, an enzyme demonstrates **specificity** for a given substrate. Some enzymes are *highly* specific and have an active site that precisely fits one distinct substrate (the 'lock and key' model), while other enzymes may be *broadly* specific and recognise a class of related molecules (e.g. proteases can digest a variety of proteins). In these instances, the active site undergoes a conformational change to improve bonding (the 'induce fit' model). This stresses the bonds in the substrate and increases reactivity (lowers activation energy hurdle).

DENATURATION

The shape and chemical properties of the active site are highly dependent on the **tertiary structure** of the enzyme. This structure can be modified by external factors such as temperature and pH. These factors may disrupt the chemical bonds needed to maintain the tertiary structure, potentially leading to a change in the shape of the active site. This will result in **denaturation** (loss of biological activity) as the enzyme will no longer be able to interact with the substrate. In most cases, denaturation results in an **irreversible** loss of biological activity. However, some enzymes may be able to return to a functional state if restored to their native conditions. In these instances, denaturation is considered to be **reversible**.



FACTORS AFFECTING ENZYME ACTIVITY

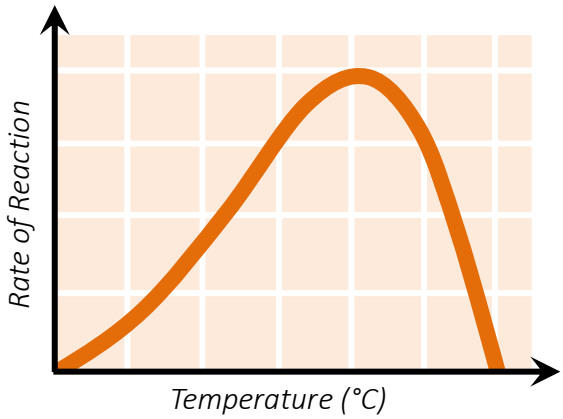
The efficiency of an enzyme-catalysed reaction will be influenced by two key factors:

- The frequency of successful enzyme-substrate collisions (due to more particles or more kinetic motion)
- The capacity for the enzyme and substrate to interact upon collision (will be impacted by denaturation)

Factors that affect enzyme activity include: temperature, pH, substrate concentration or enzyme levels

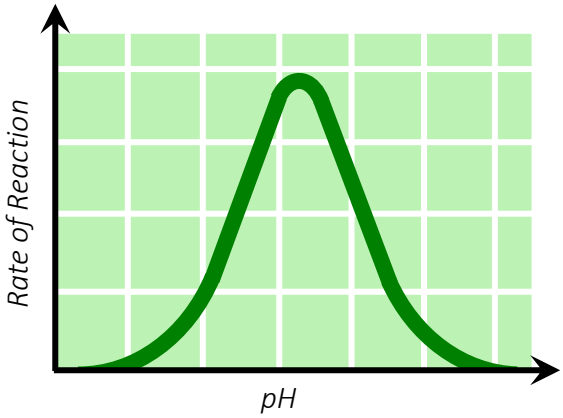
TEMPERATURE

Low temperatures result in insufficient thermal energy for the activation energy threshold to be reached. As temperature increases, particles gain **kinetic energy**, resulting in more frequent enzyme-substrate collisions. At an optimal temperature, enzyme activity will peak, because higher temperatures will disrupt the bonding within the enzyme, causing a loss of tertiary structure and a resulting loss of biological activity (denaturation).



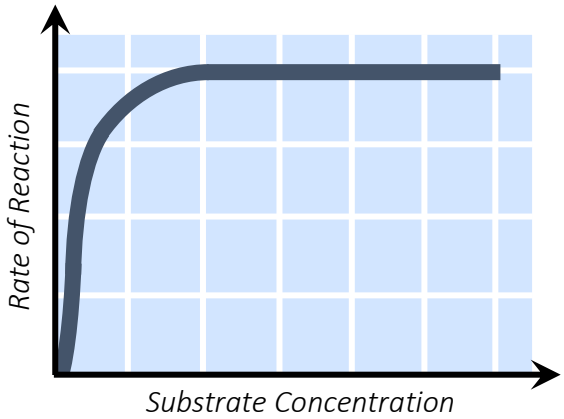
pH

All enzymes have an optimal pH, at which the activity of the enzyme is at its highest. Outside of this optimal range, enzyme activity will diminish. Amino acids are **zwitterions** (have both a positive and negative charge), and changing the pH alters the charge of the enzyme (which in turn alters both solubility and overall shape). Enzymes will denature outside of an optimal pH range, leading to a characteristic bell-shaped activity curve.



SUBSTRATE CONCENTRATION

Increasing substrate concentration will increase the activity of a corresponding enzyme. Higher substrate levels will result in increased frequency of collisions with the enzyme in a given period of time. Above a certain substrate concentration, the enzyme activity will **plateau**. This is because the environment is now saturated with substrate and all enzyme active sites are occupied (reaction is now at maximum catalysis).



ENZYME CONCENTRATION

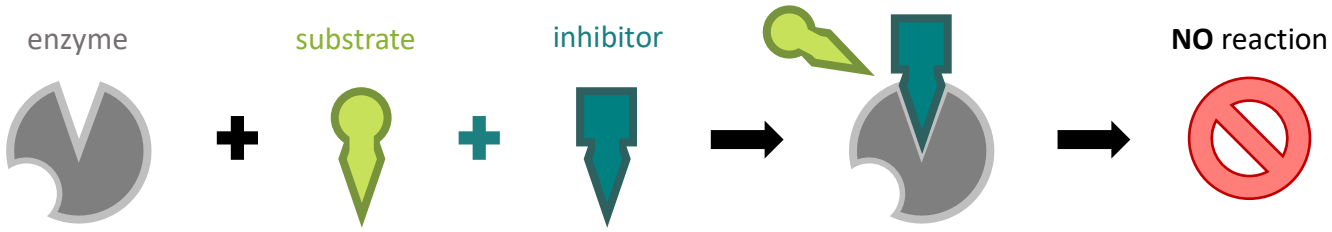
Increasing enzyme concentration will result in a **linear** increase in activity. This is because the rate of reaction will be proportional to the amount of enzyme available for reaction (more enzymes will result in more frequent enzyme-substrate collisions, leading to a higher rate of activity). Enzymes will typically exist in low concentrations within living organisms. This is because enzymes are not consumed by the reactions that they catalyse and can continually be reused. Enzymes are generally only used in higher amounts in industrialised settings (e.g. in certain household products or in the generation of chemicals or biofuels).

ENZYME INHIBITION

An inhibitor is a molecule that disrupts the normal reaction pathway between an enzyme and a substrate. Inhibition can be either reversible or irreversible depending on whether the binding and subsequent action between an inhibitor and enzyme is permanent *(irreversible inhibition)* or temporary *(reversible inhibition)*. Enzyme inhibitors can be either competitive or non-competitive depending on their mechanism of action.

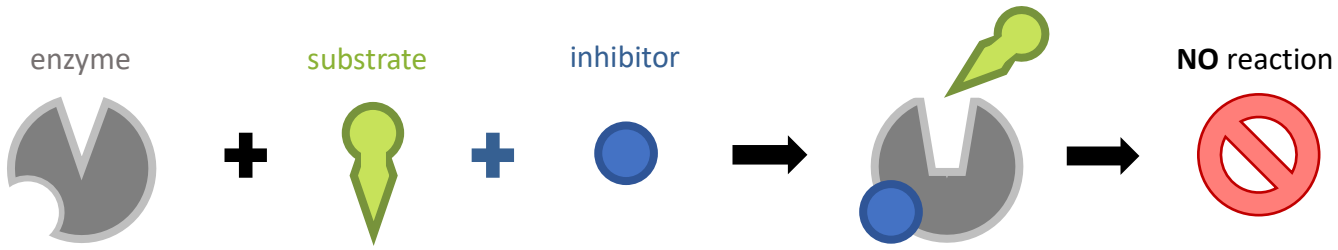
COMPETITIVE INHIBITION

A competitive inhibitor is a molecule that binds to an enzyme's **active site** (other than the substrate). The inhibitor is structurally and chemically similar to the substrate and hence is able to **occlude** the active site. If the active site is blocked by a competitive inhibitor, the enzyme cannot catalyse conversion of substrate into product. As the inhibitor is in direct competition with the substrate for the enzyme's active site, the effects of competitive inhibition can be reduced by increasing substrate concentration.



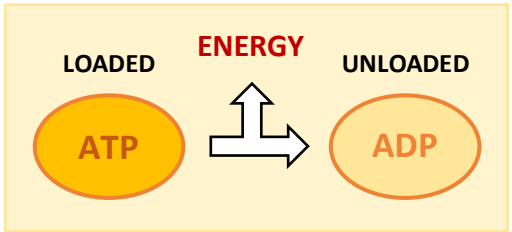
NON-COMPETITIVE INHIBITION

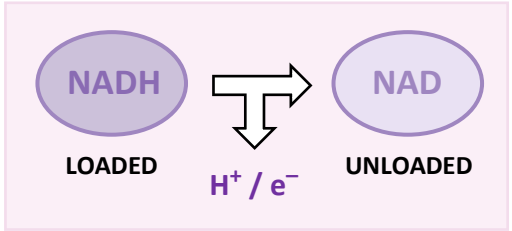
Non-competitive inhibitors bind to sites on the enzyme other than the active site (i.e. an **allosteric site**). Binding of the inhibitor to the allosteric site causes a **conformational change** to the enzyme's active site. As a result of this change, the active site and substrate no longer share specificity, meaning the substrate cannot bind to the enzyme. As the inhibitor is not in direct competition with the substrate for the active site, the effects of non-competitive inhibition cannot be reduced by increasing substrate concentration.



COENZYMES

A coenzyme is a complex organic molecule that is required for an enzyme's metabolic activity. Coenzymes cycle between two states: a loaded form capable of assisting enzyme activity and an unloaded form (similar to a charged and expended battery). **Adenosine triphosphate** (ATP) is a coenzyme that is used to provide *chemical energy* to all metabolic reactions. It functions as the energy currency of the cell (and is unloaded to form ADP). **Hydrogen carriers** (including NADH and NADPH) are coenzymes that transfer *protons (H^+)* and *electrons (e^-)* between reactions. They function as intermediate energy sources, and are used to generate ATP stocks or to synthesise organic macromolecules.



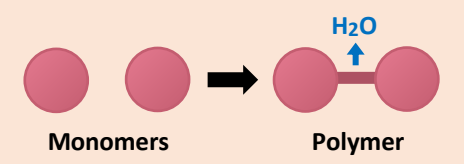


METABOLISM

Metabolism describes the totality of chemical processes that occur within a cell in order to maintain life. These metabolic processes provide a source of energy for biological processes and enable the synthesis and assimilation of cellular materials for use within the cell. Metabolic reactions are typically organised into pathways consisting of chains or cycles of enzyme-catalysed reactions (to allow for a greater level of regulatory control). Metabolic reactions can broadly be described as being either anabolic or catabolic:

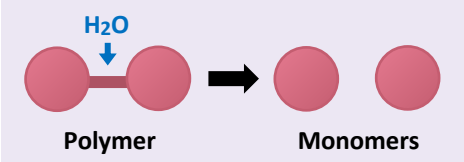
Anabolism:

- Smaller compounds are **combined** to form larger compounds
- In the case of organic compounds, this involves **condensation**
- Water is **released** as a by-product of condensation reactions



Catabolism:

- Large compounds are **broken down** into smaller compounds
- In the case of organic compounds, this involves **hydrolysis**
- Water is **required** as an input for hydrolysis reactions



PHOTOSYNTHESIS

Photosynthesis is an example on an anabolic reaction. It is an endergonic process that uses light energy (from the sun) to load coenzymes (ATP and NADPH). These loaded coenzymes are then used as a source of chemical energy to synthesise organic molecules (glucose) from inorganic reactants (CO_2 and H_2O), with oxygen gas (O_2) produced as a by-product. These reactions typically occur within the chloroplast of plants.

CELLULAR RESPIRATION

Cellular respiration is an example of a catabolic reaction. It is an exergonic process that releases energy (as ATP) from the breakdown of carbon compounds (glucose). This process can involve the partial breakdown of glucose in the absence of oxygen (anaerobic) for a small yield of ATP, or involve a complete breakdown of glucose in the presence of oxygen (aerobic) for a much larger yield of ATP. Aerobic respiration requires a specialised organelle (mitochondrion), whereas anaerobic respiration will occur within the cytosol of a cell.

CELL RESPIRATION VERSUS PHOTOSYNTHESIS

Aerobic cell respiration and photosynthesis function as **complementary** processes. Photosynthesis builds glucose molecules via anabolic processes, whereas aerobic respiration breaks down glucose via catabolic processes. The outputs of photosynthesis (glucose and oxygen) are the inputs aerobic respiration, while the outputs of aerobic respiration (carbon dioxide and water) are the inputs of photosynthesis. Plants may achieve a **compensation point** where the rates of both processes become equal (no net inputs or outputs).