What we call “life” is essentially a unique series of biochemical reactions.

The immense number, variety, and complexity of reactions that must occur together in a biological system to keep it “alive” places restrictions on the conditions under which those reactions must occur.

Hence different organisms each have an optimal range of conditions in which they can survive. (Yr11- Tolerance)

Hence different organisms must be able to respond to their environment in different ways in order to ensure these they can regulate these internal processes (Yr11- Homeostasis)
Chemical Reactions

Reactants ➔ Products

Sometimes these reactions can occur spontaneously such as when two unstable products are mixed.

Other reactions require energy for the reaction to start. This **activation energy** is the amount of energy required to start a reaction.

Example:
Methane requires the input of heat (sparks) before it will react with oxygen in a combustion reaction.

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{energy}
\]

Once this **exothermic** reaction has begun, enough energy is released (as heat) to trigger the combustion of more reactants.
Activation Energy

Essentially this activation energy is needed to break the bonds of chemical reactants so that new bonds can form to make products.

**Exothermic** reactions release heat

**Endothermic** reactions absorb heat

In Biology we are mainly interested in the reactions that require activation energy.
An increase in temperature increases the amount of available energy in a system.

As a result the reactant molecules move with greater velocity and collide with a greater force; it becomes easier for the reactants to overcome the activation energy and cause a reaction.

Increase temperature     Increase reaction rate
Decrease temperature     Decrease reaction rate
Concentration: The availability of reactants will also influence the number of collisions.

- Increase concentration: Increase reaction rate
- Decrease concentration: Decrease reaction rate

**Web Animation**

![Graph showing reaction rate vs. substrate concentration](image)

- $V_{\text{max}}$
- $\frac{1}{2}V_{\text{max}}$
- $K_m$

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Rates of Reaction: Surface Area

Greater surface area leads to a greater likelihood of contact and collision.

Web Animation

Increase surface area → Increase reaction rate
Decrease surface area → Decrease reaction rate
Catalysts are substances that lower the activation energy needed to start a reaction. Catalysts are not changed in the reaction itself.

Web Animation

Hydrogen peroxide breaks down slowly, forming water and oxygen gas.
**Metabolism** describes sum total of all biochemical pathways that occur in a living system

Biological systems must regulate

1. the availability of reactants
2. when a reaction starts
3. how quickly a reaction occurs
4. when a reaction should stop
I. The Availability of Reactants

We already know that living systems can control the availability of reactants in a variety of ways.

Exploiting a high $SA:V$ ratio

* the small size of a prokaryote
* the use of organelles in eukaryotes

Using membrane-bound compartments to localise the concentration of reactants

* the cell membrane; boundary between intracellular and extracellular environments
* membrane-bound organelles; compartmentalising the eukaryotic cell

Uptake of essential components by meeting nutritional needs and cravings

* the survival behaviour of a whole organism in its environment
2. Starting a Reaction

Biological systems use **ATP** to provide activation energy

* Adenosine Triphosphate (ATP) is composed of adenine, ribose, and 3 phosphate groups
* The phosphate groups are linked by high energy bonds

**Web animation:** ATP migrates to the site of a reaction

* When the bond linking the terminal phosphate group is broken energy is released

* ATP then becomes Adenosine Diphosphate (ADP)
Living organisms would be unable to meet their metabolic needs or respond quickly to their environment without the aid of catalysts to speed up reactions.

Biological catalysts are called enzymes—nearly all are proteins.

Enzymes reduce the amount of activation energy required to start a reaction; so less ATP is expended and the reaction proceeds more quickly.

Enzymes provide an active site in which the reaction occurs. Reactants that enter this active site are known as substrates.

Enzymes are usually named as <substrate>-ase.

_Eg: Lactase, Maltase etc._
3.1 The Active Site

An enzyme will only accept substrates with a shape complementary to the conformation of the active site. Like a 3D jigsaw, tertiary and/or quaternary structure is paramount.

Substrates are drawn into the active site in the proper orientation by molecular interactions between functional groups and R groups on the amino acids. These interactions weaken the bonds within the substrate thereby lowering the activation energy needed to start the reaction.

There are 2 models of enzyme action

- **Lock and Key**
- **Induced Fit**
The **Induced Fit** model has only one difference—molecular interactions between the substrate and active site cause the enzyme to change shape.

This change of shape activates its catalyst function the reaction proceeds.

**Web Animation**

*Enzymes: Induced Fit Model (Web Animation)*
4. Stopping a Reaction

When a biochemical pathway needs to be stopped two mechanisms may be employed.

**A competitive inhibitor** mimics the substrate and competes for the active site.

**A non-competitive inhibitor** binds to a regulatory region of the enzyme and changes the active site's shape so that it can no longer bind.
Feedback inhibition is the switching off of a metabolic pathway by its end product.

Feedback inhibition is similar to the negative feedback mechanism you studied in Yr11. It may be competitive or non-competitive.
4.2 Reversible and Irreversible Inhibition

**Reversible Inhibition**
Typically the action of an inhibitor is reversible
- Binding to the active site or regulatory region is non-covalent.
- Disassociation of the inhibitor switches the enzyme back on.

**Irreversible Inhibition**
Sometimes an inhibitor permanently deactivates an enzyme
- Binding to the active site or regulatory region is covalent
- Such molecules are toxic to cells and include heavy metals, nerve gases and some toxins.
**Environmental Effects: Temperature**

**Temperature**
Proteins and enzymes react within an organism’s *tolerance range*. Within this range;

* increases in temperature will increase reaction rates
* decreases in temperature will decrease reaction rates

Excessive increases in temperature can *denature* proteins and thus destroy the function of enzymes.

Due to the need to maintain stability and homeostasis, biological systems generally do not make effective use of temperature to regulate chemical reactions.

There are exceptions, however, such as:

* ectothermic metabolism
* hibernation behaviour
* fever responses

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**Tolerance Ranges for Different Enzymes**

- **Blue-** enzyme from a psychrophile
- **Red-** enzyme from human intestine
- **Green-** enzyme from a thermophile

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*environmental Effects: Temperature*

**Environmental Effects: Temperature**

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Enzymes have particular tolerance ranges for pH levels as well. 

**Denaturation** can also occur where the pH environment is outside the tolerance range of the protein.

All three of these enzymes function in different sites of the human body and thus exhibit different tolerance ranges.
In biochemical reactions continually increasing concentration will not usually result in a continual increase in reaction rate.

Remember that an active site must facilitate each reaction. Increasing substrate concentration places a greater demand on available active sites- as a result the enzyme, not the reactants, becomes a limiting factor.

For example: A crowd of thousands will enter a building just as quickly as a crowd of millions. The only way to increase the rate of entry is to open more doors.

Describe the relationship between substrate, enzyme, and rate of reaction at points (a), (b), and (c).
Biochemical reactions share different characteristics

**Anabolic** reactions build molecules

**Endergonic** reactions absorb energy

**Catabolic** reactions break down molecules

**Exergonic** reactions release energy

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**The ATP Cycle**

After it “unloads” energy and the terminal phosphate group an ADP molecule can undergo a second reaction that adds a new phosphate group and “reloads” it as ATP.

These two reactions have different energy demands.
Another major metabolic distinction; you should recognise these two from Yr11.

**Aerobic** reactions require oxygen

**Anaerobic** reactions do not require oxygen

We’ll be looking at these reactions in great detail later.