2. Enzymes and Biotechnology (see also rates notes at end of 2.)

Other aspects of the vitamin, food and drugs GCSE chemistry are on the "**Extra Organic Chemistry**" page

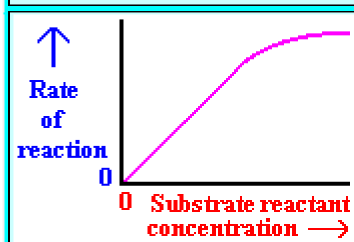
Living cells use chemical reactions to produce new materials. Living things produce catalysts called enzymes which allow chemical reactions to occur quite quickly at ordinary temperatures and pressures. Enzymes are powerful 'biochemical catalysts' and are widely used in the food industry and are being used more and more to manufacture many other chemicals. These biological catalysts promote most of the reactions in living tissue.

- **Cells contain protein molecules that act as biological or biochemical catalysts, they are known as ENZYMES.**
- **The chemical reactions brought about by living cells are quite fast in conditions that are warm rather than hot**. This is because the cells use these enzyme catalysts.
- **Enzymes are protein molecules** which are usually damaged by temperatures above about 45º C. Although not damaged by lower temperatures, the reactions may be too slow to be of any use. (see **rates notes** at the end of this section)
- **Different enzymes work best at different pH values.**
- **The enzymes in yeast cells (living organism's) convert sugar like into alcohol and carbon dioxide in brewing**.
  - eg **glucose ==> ethanol and carbon dioxide** in water and the absence of air.
  - $C_6H_{12}O_{6(aq)}$ **==>** $2C_2H_5OH_{(aq)}$ **+** $CO_{2(g)}$
  - This process occurs efficiently between 25 to 55°C and is called **fermentation** and is used to produce the alcohol in beer and wine. **The carbon dioxide dissolved in the final alcoholic drink produces the fizz!**
  - **Note on raising agents in cooking**: It is this reaction producing **bubbles of carbon dioxide which make dough mixtures rise in the kitchen or food industry when yeast is used in baking** bread or cake making etc.
    - An alternative to yeast is to use **sodium hydrogencarbonate** ('sodium bicarbonate' or 'baking soda') in baking. The rising action is also due to carbon dioxide gas formed from its reaction with an acid (eg tartaric acid), and nothing to do with enzymes:
      - self-raising baking powder = carbonate base + a solid organic acid, giving
      - sodium hydrogencarbonate + acid ==> sodium salt of acid + water + carbon dioxide
  - A simple laboratory test for carbon dioxide is that it forms a milky precipitate with limewater.
  - However other enzymes in living material can also catalyse oxidation with the oxygen in air. When alcoholic drinks turn sour it is due to the alcohol being oxidised to the weak organic acid ethanoic acid, commonly know as 'vinegar'!
- **Enzymes are involved in the following processes in the home**

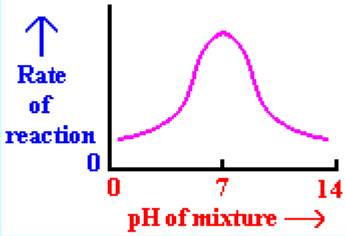
- bread dough raising (see above)
- biological detergents may contain protein-digesting protease enzymes and fat-digesting enzymes lipase enzymes.

- **In industry**, enzymes are used to bring about reactions at normal temperatures and pressures that would otherwise require more expensive and more energy demanding equipment eg
  - **Proteases** break down proteins and are used to 'pre-digest' the protein in some baby foods.
  - **Carbohydrases** are used to convert starch syrup into sugar syrup.
  - **Invertase** is used to make the sugar for for soft chocolates.
  - **Isomerase*** is used to convert glucose syrup into fructose syrup, which is much sweeter and therefore can be used in smaller quantities eg in slimming foods. (* The name comes from the word '**isomers**' which means molecules of the same molecular formula but different structures. Glucose and fructose both have the molecular formula $C_6H_{12}O_6$)
  - **Pectinase** breaks down insoluble pectin polysaccharides and so is used in clarify fruit juices.
  - **Amylases** break down carbohydrates and **Lipases** break down fats.
  - **Enzymes** are used in **genetic engineering** and **penicillin production**.
  - The **dairy industry uses enzymes** made by microorganisms (bacteria) **to produce yoghurt and cheese from milk**.
    - The **bacteria enzymes** convert the sugar in milk (lactose) to lactic acid.
  - **Enzymes in biological detergents** help break down staining food materials.
- **Successful industrial processes depending on enzymes usually:**
  - **stabilise the organism** to keep it functioning for a long period,
  - **immobilise the enzyme** by trapping it in an inert solid support or carrier such as alginate beads,
  - **allows a continuous process**, this means a continuous input of raw materials and output of product, so can run 24 hours a day for many weeks or months.
  - rather than batch process, which means loading the reactor vessel with reactants ==> extract product ==> clean out, re-load with reactants etc. etc. ie less efficient and time means money!

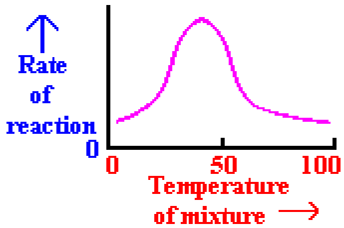
Rates of Reaction and Enzymes (full rates of reaction notes)



If either the substrate reactant eg sugar, or the yeast cell (enzyme) concentration is increased, the rate of reaction increases in a simple proportional way. However, if the concentration of enzyme is low but the substrate concentration is high, the rate of reaction rises to a maximum and then stays constant. The reason for this, is, the maximum number of catalyst sites for the 'key and lock' mechanism are in use and the rate of reaction depends on the rate of diffusion of substrate in and product out.

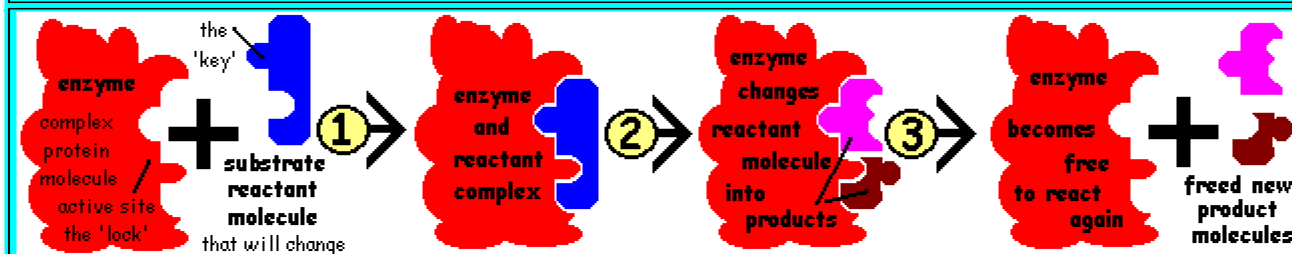


The structure of the protein enzyme depends upon how acid or alkaline the reaction medium is, that is, it is pH dependent. If it is too acid or too alkaline, the structure of the protein is changed. If the enzymes does not have the correct 'lock' structure, it cannot function efficiently. Most enzymes have an optimum pH of between 4 and 9, and quite frequently near the neutral point of 7. The **'key and lock' mechanism** is explained later on.



The structure of the protein enzyme can depend the temperature. If the enzymes does not have the correct 'lock' structure, it cannot function efficiently. The shape of the graph is due to two factors. (1) The initial rise in rate of reaction is what you normally expect for any chemical reaction. The increase in temperature increases the kinetic energy of the molecules to increase the chance of the product forming from more 'fruitful collisions. (2) However as the temperature rises further, the increasing thermal vibration of the enzyme molecule causes its structure to break down (denature) and so the 'lock' is damaged so the enzyme is less efficient (see key-lock below). The optimum temperature for the fastest rate of reaction is often around 30-40°C (note our body temperature is a bout 37°C, no coincidence!). At high temperatures the enzyme ceases to function.

Explaining enzyme biochemical catalysis



- The **enzyme is a complex protein molecule**, but there is a particular site where the reactant molecule 'docks in' by random collision. The enzyme is sometimes referred to as the '**lock**' and the initial reactant substrate molecule as the '**key**', hence this is called the 'key and lock' mechanism. This is also explains why **enzymes are very specific** - you need the right molecular key for a particular molecular lock.
- Once the '**reactant-enzyme complex**' is formed the enzyme function changes the reactant molecule into the new product molecule.
- The '**enzyme-new molecule complex**' breaks down to free the **new product molecule** and the enzyme who's reactive **site can now be re-used** by another reactant molecule.
  - **Note 1.** Compared to the un-catalysed reaction**, the enzyme provides a 'chemical change route' with a much lower activation energy,** and so this greatly increases the rate of reaction as more molecules have enough kinetic energy to react at the same temperatuire.
  - **Note 2. The products are shown as two molecules, because there are quite often two products for each step of the breakdown of a bigger molecule into smaller molecules eg protein to 'smaller protein' + amino acid,** or **starch to 'smaller starch' plus a glucose molecule** etc. But there **can be just one product molecule eg when isomerase changes glucose into fructose**. There can also be two substrate reactant molecules being combined to form a bigger molecule. In other words there are lots of possibilities!
  - **Note 3. Many drugs work by blocking the sites normally used by enzymes**. The molecular key (the drug) goes onto the reactive enzyme site, but stays there, so inhibiting

enzyme activity which promotes harmful chemical-organism effects in the body. The harmful effect might be the production of toxic chemicals from a bacteria or the reproduction of a harmful organism etc.

- **Note 4. "Rates of Reaction Notes"** fully explains all the factors, experimental methods and reaction profiles, activation energy.
- **Note 5. Different reactions need different enzymes**, and also if enzymes, which bring about the same chemical change, are quite likely to have different optimum rate pH's or temperatures.