CHEMICALS OF LIFE

These are building blocks of life. Organisms are made up of both inorganic and organic molecules.

Biological molecules

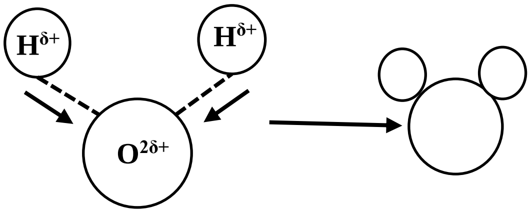
Living organisms are made of atoms that combine to form molecules which are the building blocks of life. The molecules vary from being simple to large molecules. Many simple molecules are soluble and can easily be transported within the cells. Large molecules are used for storage or structural purposes. These molecules are either organic (fats, starch, proteins) or inorganic (carbon dioxide, water, nitrogen).

Water

Water is a vital chemical constituent of living cells and it also provides an environment for those organisms that live in water.

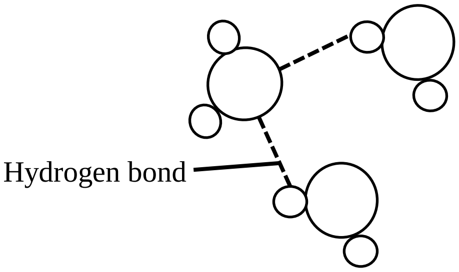
Water has unusual properties which are mainly due to its small size, polarity and the hydrogen bonding between its molecules. **Polarity** is the uneven distribution of charge within a molecule.

Arrangement of atoms in a water molecule



The oxygen atom has a tendency to draw electrons closer it. This gives the oxygen end of a water molecule a slightly negative charge and the hydrogen end a slightly positive charge.

In water one part is slightly positive while the other is slightly negative. This is known as a **dipole**. It occurs because the oxygen atom has a greater electron attracting power than the hydrogen atoms. As a result, the oxygen atom tends to attract the single electrons of the hydrogen atoms. This gives the oxygen atom a slightly negative charge relative to the hydrogen atom. Water molecules, therefore, have a weak attraction for each other, with opposite charges coming together and causing them to behave as if they were ‘sticky’, like magnets. These attractions are called **hydrogen bonds**. Although individually weak, their collective effect is responsible for many of the unusual physical properties of water.



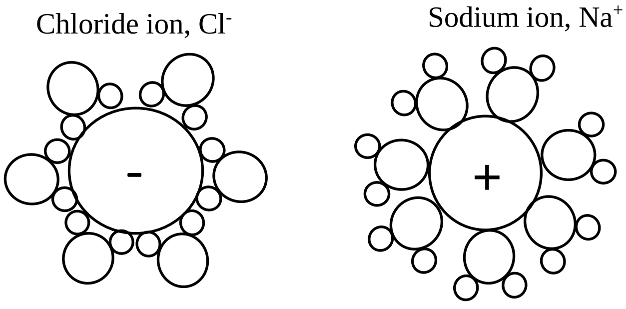
Water molecules have negative and positive ends so they tend to be pulled together by hydrogen bonding

Water is a universal solvent

The dipolar molecules make water an excellent solvent. It is referred to as a universal solvent because it dissolves many things. Polar and ionic substances have an electrostatic charge, so they are attracted to the charges on water molecules. They dissolve readily in water and are therefore called **hydrophilic** (water-loving). Non-polar substances, such as oil, have no charge on their molecules. They do not dissolve readily in water and are called **hydrophobic** (water-hating). When any salt or ionic compound dissolves in water, the ions separate and layers of water molecules form around the ions. These layers of water molecules stop ions or polar molecules from clumping together and keep the particles in solution.

Water is a good solvent because its molecules form around ions or molecules. In a solution of sodium chloride, the positive (hydrogen) ends of water molecules point towards the negative chloride ion, and the negative (oxygen) ends point towards the positive sodium ion.

Layers of water molecules form around many non-ionic organic substances such as sugars because they contain polar side groups.



The biological significance of water

Water is an excellent solvent for polar substances. These include ionic substances like salts, which contain charged particles(ions), and some non-ionic substances like sugars that contain polar groups (slightly charged) such as the slightly negatively hydroxyl group.

Properties of water

High heat capacity. Heat capacity of water is the amount of heat required to raise the temperature of 1 kg of water by 1 ^{0}C. Water has a high heat capacity. A large increase in heat energy results in a relatively small rise in temperature. This is because much of the energy is used in breaking the hydrogen bonds which restrict the movements of the molecules. Temperature changes within the water are minimized as a result of its high heat capacity. Biological processes, therefore, operate over a smaller temperature range, proceeding at more constant rates and are less likely to be inhibited by extremes of temperature.

The high heat of vaporization. The latent heat of vaporization is the amount of energy required to vaporize a liquid, i.e. to overcome the attractive forces between its molecules so that they can escape as a gas. A relatively large high amount of energy is needed to vaporize water. The energy transferred to water molecules to allow them to vaporize results in a loss of energy from their surroundings causing cooling. This is made use of in the sweating and panting of mammals. A large amount of heat can be lost with minimal loss of water from the body.

The high heat of fusion. The latent heat of fusion is the amount of heat energy required to melt a solid, in this case, ice. With its high heat capacity, water requires relatively large amounts of heat energy to melt it. At the same time, liquid water must lose a relatively large amount of heat energy to freeze. Contents of cells and their environments are therefore less likely to freeze. Ice crystals are particularly damaging if they develop inside cells.

High surface tension and cohesion. Cohesion is the force that makes water molecules stick together. At the surface of a liquid, a force called surface tension exists between the molecules as a result of cohesive forces between water molecules. This forms a firm ground for some organisms which can rest on the water surface. Such organisms can exploit different niches.

The cohesion of water molecules is also important in cells and in translocation of water through the xylem in plants.

Density and freezing properties. The density of water decreases below 4 ^{0}C. This makes ice to float. It first forms at the surface and the bottom last. Ice insulates the water below it, thus increasing the chances of survival of organisms in the water. This is important in cold climates and cold seasons and must have been particularly so in the past.

In liquid water hydrogen bonds are constantly forming and reforming. When water freezes, each molecule forms hydrogen bonds with four other molecules. This makes a rigid lattice, which holds water molecules further apart than in water. This is why water expands when it freezes. Although individual hydrogen bonds are weak, combined in their thousands they make ice as solid rock.

Other properties of water

- ✓ **It is difficult to compress water**. This enables water to form an important structural agent, forming hydrostatic skeleton in worms and turgor in plants.
- ✓ **It has a relatively high density compared with air**. Water supports organisms as large as whales; it also supports and disperses reproductive structures such as larvae and large fruits such as coconuts.
- ✓ **Water is colourless and transparent**. Transmission of sunlight enables aquatic plants to photosynthesize.
- ✓ **It conducts electricity**. However, pure water has a low conductivity but dissolved ions make it a good conductor. This enables the transmission of impulses in organism.
- ✓ **Water is a liquid at room temperature**. This provides a liquid environment inside cells and aquatic environments for organisms to live in.
- ✓ **Water is the universal solvent**. It dissolves more substances than any other solvent. This enables chemical reactions inside cells to take place in aqueous solution; water also forms the main transport medium in organisms.
- ✓ **Water has a low viscosity**. It flows freely, its molecules can easily slide over each other. This makes water to freely flow through narrow vessels. Watery solutions also form lubricants for example mucus which allows food to move easily down the oesophagus.
- ✓ **Water has a high tensile strength** caused by combined hydrogen bonds between its molecules. It therefore continuously flows in columns through the xylem vessels up to the top of a tree during transpiration.

Importance of water

- Structure: high water content of cells (70-95%).
- Solvent and medium for diffusion.
- Reagent in hydrolysis.
- Support for aquatic organisms.
- Fertilisation by swimming gametes.
- Dispersal of seeds, gametes and larval stages of aquatic organisms, and seeds of some terrestrial species e.g. coconut.
- Osmosis and turgidity (important in many ways, such as growth (cell enlargement), support, guard cell mechanism).
- Reagent in photosynthesis.
- Transpiration.

- Translocation of inorganic ions and organic compounds.
- Germination of seeds; water causes the swelling and breaking open of the testa and further development.
- Transport in the blood vascular system, lymphatic system, excretory system.
- Osmoregulation.
- Cooling by evaporation, such as sweating, panting Lubrication, as in joints.
- Support. A hydrostatic skeleton of e.g. annelid worms Protection, for example, lachrymal fluid (tears), mucus Migration in ocean currents.

Acids, Bases and Salts

Acid is a substance that ionizes in aqueous solution to release hydrogen ions as the positively charged ions. It is a proton donor. The strength of an acid is determined by the easy it can release hydrogen ions; strong acids ionize completely while weak acids partially ionize in aqueous solutions.

$$H_2SO_4(aq) \longrightarrow 2H^+(aq) + SO_4^{2-}(aq)$$

A base is a substance that accepts protons from the acid.

Sodium carbonate dissociates and releases hydrogen carbonate ions. These ions accept protons from the acid. In this way, it acts as a buffer by resisting change in pH.

$$Na_2CO_3(aq) \longrightarrow H^+(aq) + HSO_4^-(aq)$$

Even if moderate amounts of the base are added, it accepts the OH^- ions to form water and carbonate ions.

In the human body, many substances play a role in buffering the body. This is important to enable chemical reactions to proceed without alteration of pH.

Phosphate salt is one of the salts used during the regulation of blood pH by the kidney. Organic substances like proteins and haemoglobin also accept ions.

The biological importance of this is that cells and tissues can only function properly at round neutrality; they cannot tolerate fluctuations in pH.

Macromolecules

A macromolecule is a giant molecule made from many repeating units of simple molecules. Molecules built like this are known as **polymers**. The individual units are known as **monomers**. The units are joined by a process known as **condensation** polymerization, which means loss of water occurs.

They can be broken down again by the opposite process called **hydrolysis**. Macromolecules may include polysaccharides, proteins, lipids, and nucleic acids.

Carbohydrates

These are substances which contain the elements carbon, hydrogen and oxygen and have the general formula $C_x(H_2O)_y$, where x and y are variable numbers; their name (hydrate of carbon) is derived from the fact that hydrogen and oxygen are present in the same proportions as in water, namely two hydrogen atoms to one oxygen atom. They are all **aldehydes** or **ketones** and all contain several hydroxyl groups.

Carbohydrates are divided into **three** main classes: monosaccharides, disaccharides, and polysaccharides.

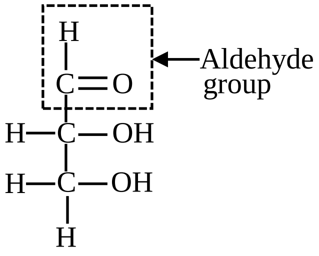
Monosaccharides. These are simple sugars. They have the general formula $(CH_2O)_n$. Letter n can be any number from 3 to 7. They are grouped according to the value of n.

When n=3, trioses; n=4, tetroses; n=5, pentoses; n=6, hexoses.

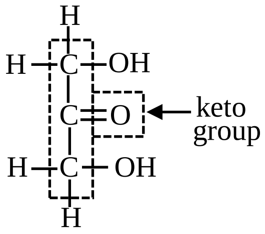
Aldoses and ketoses

In monosaccharides, all the carbon atoms except one have a hydroxyl group attached. The remaining carbon atom is either part of an aldehyde group. This monosaccharide is called an **aldose** or **aldo sugar**. For a keto group then the monosaccharide is called a **ketose** or **keto sugar**. All monosaccharides are aldoses or ketoses.

The simplest monosaccharides are the trioses, glyceraldehyde, and dihydroxyacetone. Glyceraldehyde has an aldehyde group and dihydroxyacetone has a keto group.



glyceraldehyde



dihydroxyacetone

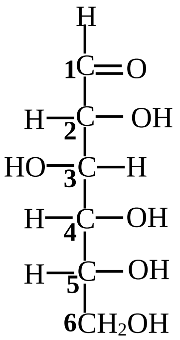
Classification of monosaccharides

Category	Example
Aldotriose	Glyceraldehyde
Aldopentose	Ribose, deoxyribose
Aldohexose	Glucose, galactose
Ketohexose	Fructose

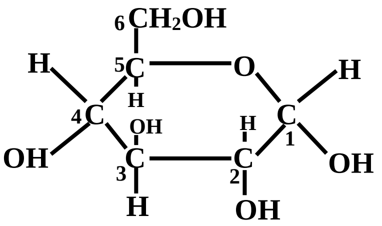
The carbonyl group on all monosaccharides readily donates electrons. This is the property that makes monosaccharides reducing sugars. When heated with Fehling's or with Benedict's reagents they reduce copper (ii) ions to copper (i), forming a brick-red precipitate of copper (i) oxide.

Hexoses. Glucose is the most abundant hexose. Its chemical formula is $C_6H_{12}O_6$. Glucose exists in different shapes. This phenomenon is known as **isomerism**. Each isomer has the same chemical formula but a different structural formula.

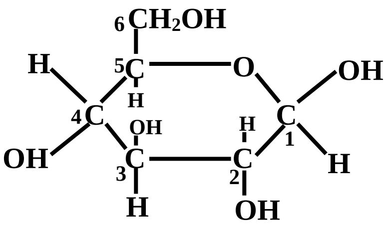
α and **β** glucose are the common isomers of glucose. Ring structures are the same but only the positions of hydrogen and hydroxyl groups on carbon atom 1 are different. In three-dimensional, glucose structure -CH_2OH group is above the ring in both alpha and beta glucose. The -OH group is below carbon atom 1 in alpha glucose but above carbon atom 1 in beta glucose.



Open chain form



α-glucose



β-glucose

The different arrangements of glucose have important biological consequences for example; alpha glucose molecules combine to form starch whereas beta glucose molecules combine to form cellulose.

Functions of monosaccharides

Trioses. $C_3H_6O_3$e.g glyceraldehyde, dihydroxyacetone. They form intermediates in respiration and photosynthesis.

Pentoses $C_5H_{10}O_5$

- Used in the synthesis of nucleic acids, ribose is a constituent of RNA, deoxyribose of DNA.
- Used in the synthesis of some coenzymes, e.g. ribose is used in the synthesis of NAD and NADP
- Synthesis of ATP. This requires ribose.
- Used in the synthesis of Ribulosebisphosphate, a carbon dioxide acceptor in photosynthesis.

Hexoses ($C_6H_{12}O_6$)

- Source of energy when oxidized in respiration (glucose).
- Synthesis of disaccharides; two monosaccharides units can link together to form a disaccharide.
- Synthesis of polysaccharides.

Disaccharides

These are formed when two monosaccharides combine by means of a chemical reaction known as **condensation**. A water molecule is given off during the reaction.

$$C_6H_{12}O_6 + C_6H_{12}O_6 \leftrightarrow C_{12}H_{22}O_{11} + H_2O$$

The bond formed between two monosaccharides as a result of condensation is called a **glycosidic** bond and it normally forms between carbon atoms 1 and 4 of neighbouring units. The process can be repeated many times to build up the giant molecules of polysaccharides. The monosaccharide units are called **residues** once they have been linked. A maltose molecule contains two glucose residues. The most common disaccharides are maltose, lactose, and sucrose.

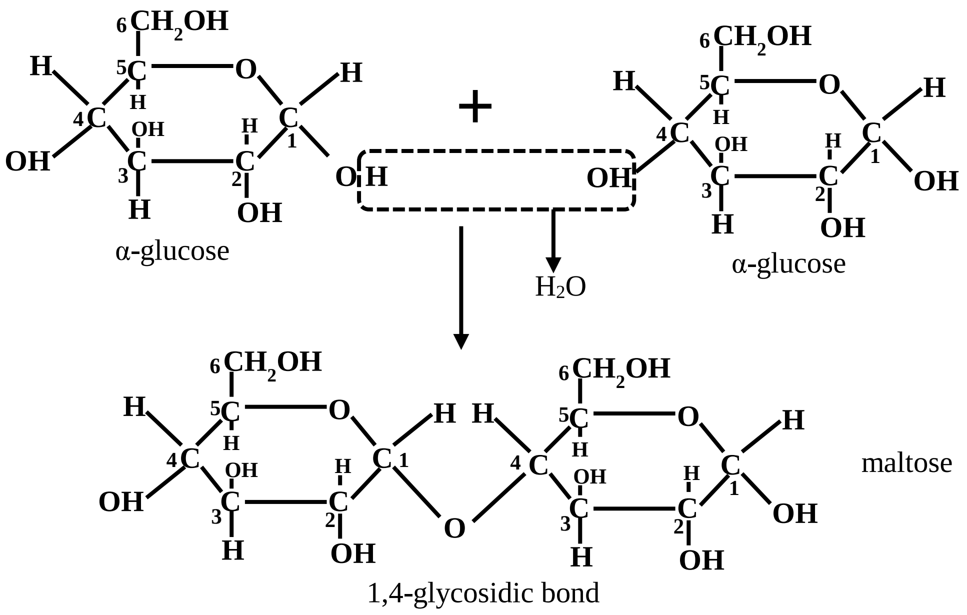
Maltose. This occurs mainly as a breakdown product during digestion of starch by enzymes called **amylases**. This commonly occurs in animals and in germinating seeds. In seeds, it is made use of in brewing beer when barley grain is used as the source of starch. Germination of the barley is stimulated and this results in the conversion of the starch to maltose, a process known as **malting**.

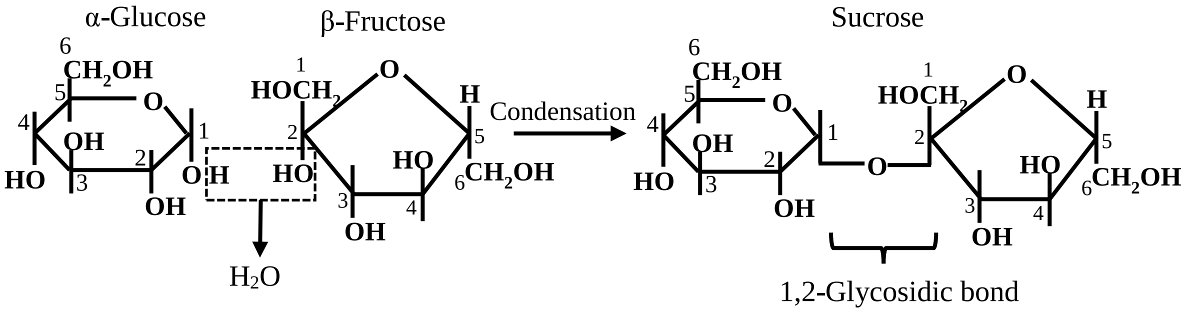
Lactose, or milk sugar. This is found exclusively in milk and is an important energy source for young mammals. It is digested slowly and steadily releases energy.

Sucrose, or cane sugar. This is the most abundant disaccharide in nature. It is most commonly found in plants, where it is transported in large quantities through phloem tissues. It makes a good transport sugar because it is very soluble, and can, therefore, be moved efficiently in high concentrations. It is also chemically unreactive.
It is consumed in large amounts to sweeten many foods.

It is formed when one α-glucose and one β-fructose join in a condensation reaction. A bond is formed between the carbon atom 1 of the α-glucose ring and carbon atom 2 of the β-glucose. It is thus called an α-1, 2-glycosidic linkage. It is at these atoms that the carbonyl groups occur in both glucose and fructose. There are no free carboxyl groups in sucrose which are therefore a non-reducing sugar. Sucrose can be easily hydrolysed into monosaccharides by boiling with dilute hydrochloric acid or by incubating it with the enzyme **sucrase** (**invertase**)

Formation of glycosidic bond in sucrose by condensation





Test for reducing sugars

All monosaccharides and some disaccharides, including maltose and lactose are reducing sugars. They can carry out a type of chemical reaction known as **reduction**. Sucrose is the only common non-reducing sugar.

Benedict's solution and Fehling's solution are used. Reducing sugars reduce copper contained in these solutions, from a valence of 2 to a valence of 1. In both tests, the alkaline solution of copper (ii) sulphate which is reduced to insoluble copper (i) oxide is used.

Functions of simple sugars in living organisms

- ✓ Lactose forms the main sugar in milk.
- ✓ Glucose forms the major of energy in most living organisms.
- ✓ Maltose is produced by the breakdown of amylose in many germinating seeds.
- ✓ Sucrose is the major form of the transport of carbohydrates in plants.

Polysaccharides

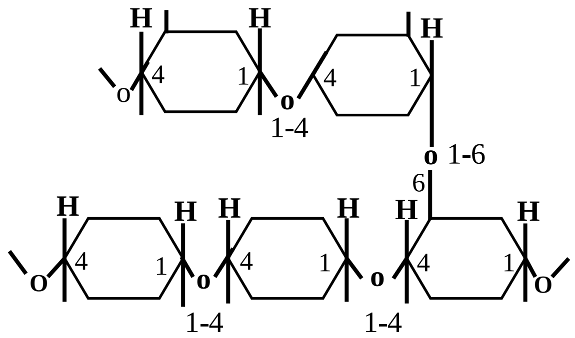
They are used as food and energy stores and as structural materials. They are convenient storage molecules for several reasons:

- ✓ their large size makes them more or less insoluble or less insoluble in water, so they exert no osmotic or chemical influence in the cell,
- ✓ they fold into compacts shapes,
- ✓ they are easily converted to sugars by hydrolysis when required. They are polymers of monosaccharides.

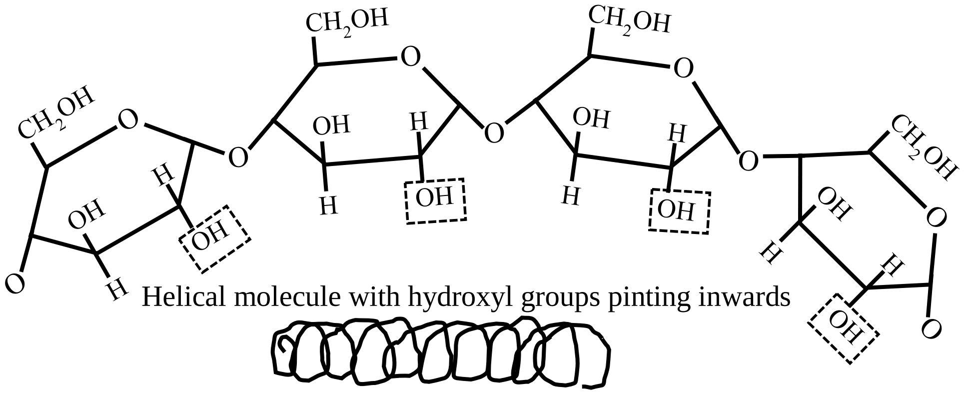
Starch. This is a polymer of α-glucose molecules. It is the major fuel in plants but is absent from animals where the equivalent is glycogen. Starch has two components, amylose, and amylopectin.

- ➢ **Amylose** has a straight-chain structure consisting of several thousands of glucose residues joined by 1, 4-glycosidic bonds. These bonds cause the chain to coil helically into a more compact shape. Plants store glucose as amylose or amylopectin, glucose polymers collectively called starch. Glucose storage in polymeric form minimizes osmotic effects.

- **Amylopectin** is also compact as it has many branches, formed by 1, 6-glycosidic bonds. It has up to twice as many glucose residues as amylose. A suspension of amylose in water gives a blue-black colour with iodine-potassium iodine solution, whereas a suspension of amylopectin gives a red-violet colour. This forms the basis of the test for starch. The branches produce a compact structure & provide multiple chains ends at which enzymatic cleavage can occur.



The long chains in starch are coiled into a helix and the orientation of the glucose sub-units is such that most of the OH groups potentially capable of forming hydrogen bonds projecting inwards. So there are no cross-linkages in starch making it not suitable to form structures. The chain is coiled into a helix forming, in effect a cylinder in which most OH groups capable of forming cross-linkages projects into the interior. There are six glucose units for every complete turn of the spiral.



Helical molecule with hydroxyl groups pinting inwards

Starch molecules accumulate to form starch grains. These are visible in many plant cells, notably in the chloroplasts of leaves. It is used in storage organs such as the potato tuber, and in seeds and legumes. The grains appear to be made of layers of starch and are usually of characteristic size and shape for a given species.

Suitability of starch as a storage substance

- It is insoluble and therefore does not have any osmotic effects within cells, i.e. it does not tend to draw water into the cells.
- Being insoluble, it does not easily diffuse out of cells.
- It is compact, so a lot of it can be stored in a small space.
- When hydrolysed it forms glucose, which is both easily transported and readily used in respiration, to provide energy in the form of ATP. Starch is never found in animal cells.

Test for starch

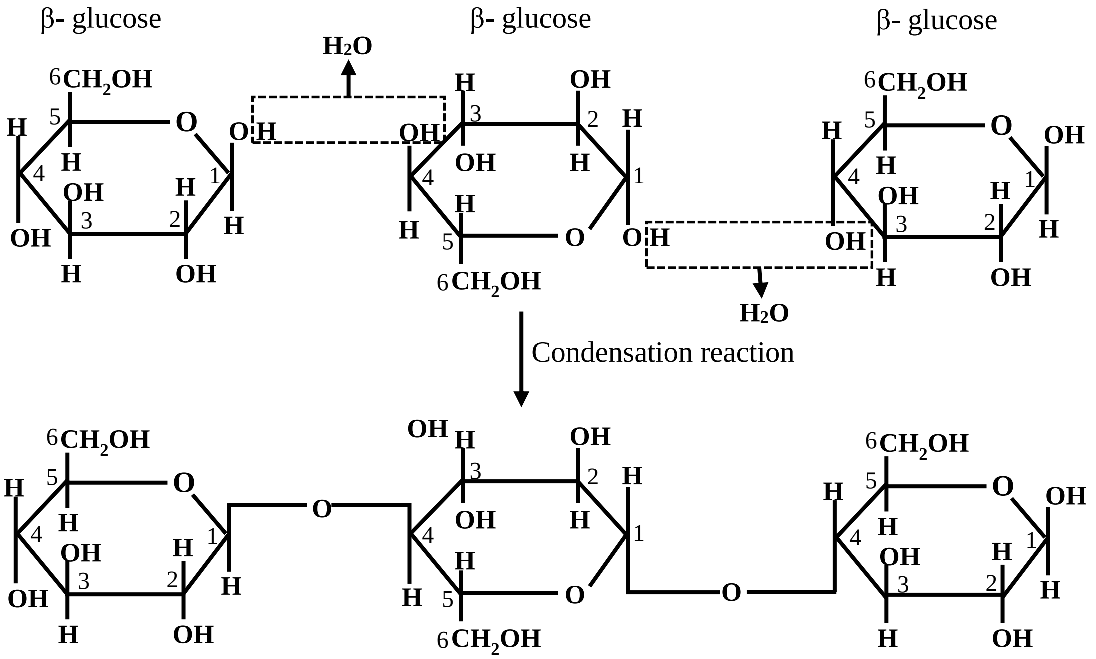
Starch is easily detected by its ability to turn the iodine in potassium iodide solution from a yellow colour to blue-black. The colouration is due to the iodine molecules becoming fixed in the centre of the helix of each starch molecule. It is important that this test is carried out at room temperature (or below), as high temperatures cause the starch helix to unwind, releasing the iodine, which then returns to its usual yellow colour.

Glycogen

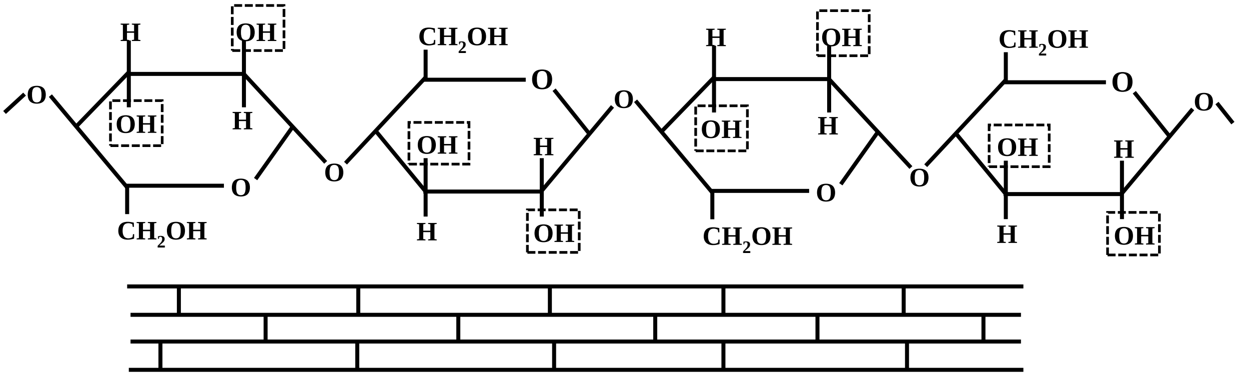
This is the animal equivalent to starch. It is a polysaccharide made from α-glucose and stored by many fungi. In vertebrates, glycogen is stored in the liver and muscles, both are centers of high metabolic activity, where it provides a useful energy reserve. Its conversion back to glucose is controlled by hormones, particularly glucagone.

Cellulose. This is made up of many straight chains each containing as many as 10,000 sugar units. Each chain is made up of many β glucose units joined together in such a way that the OH groups are on both sides of the chain. These are capable of forming hydrogen bonds with neighbouring OH groups resulting in the formation of bundles of cross-linked parallel chains.

When two β glucose molecules line up, the -OH group on carbon atom 1 can only line up alongside the -OH group on carbon atom 4 if one of the molecules is rotated at 180^0 to the other. This is because of the -OH group on carbon atom 1 projects below the ring and the -OH group on atom 4 projects above the ring. This rotation of successive residues is the underlying reason why cellulose has a different structure to starch.



cellulose



Straight chain molecule with hydroxyl groups pointing on alternate sides

The strength of the glycosidic bonds, together with the cross-links between adjacent chains, makes it tough like rubber. Cellulose is found in chains massed together to form ribbon-like fibres. They are laid down in layers, the microfibrils of each layer run roughly parallel with each other but at an angle to those in other layers.

In the cell wall, the cellulose microfibrils are embedded in a gel-like organic matrix containing hemicellulose. Hemicellulose is a short polysaccharide that binds tightly to the cellulose microfibrils, linking them together into a complex three-dimensional network. This forms a material of great strength which prevents the cells from bursting when water enters by osmosis and also helps to determine the shapes of cells.

It is fully permeable to water and solutes. This is because the matrix is made up of minute water-filled channels through which free diffusion of salts, sugars can take place. The molecules of the matrix are hydrophilic.
Cellulose is also an important food source for some animals, bacteria, and fungi.

Lignin. This is a polymer of various sugars and amino acids. It is deposited in the spaces between the cellulose molecules which makes the cell wall rigid rendering it impermeable. It serves as a waterproof cement. This is called **lignification** and occurs in plant cell walls concerned with providing strength and conducting water. Once lignification is complete the protoplasm can no longer absorb materials from outside the cell, which therefore dies. The lignified tissue is always dead. Its function of providing mechanical strength is entirely due to its lignocellulose composition. It can transport water and salts, this is because lignification involves loss of the protoplasm, resulting in the formation of a hallow-waterproof tube.

The commercial importance of cellulose

- It is used in the manufacture of paper, cellophane, celluloid, rayon and various plastics.
- Cellulose derivatives such as cellulose nitrate are used in the manufacture of lacquers, films, and explosives.
- Cellulose in cotton is used to make fabrics.

Dietary fiber. They don't undergo digestion. Fibers contain sugars linked by bonds that cannot be broken down by human enzymes.

Pasta and whole-grain pieces of bread contain complex carbohydrates, which are long strands of glucose molecules. A fiber derived from plant sources contains polysaccharides such as cellulose, hemicellulose, pectin, gums, mucilages, and lignins.

The indigestible fibers do not provide energy. Cellulose, hemicellulose, and lignin make up the structural part of plants and are classified as an **insoluble** fiber because they usually do not dissolve in water. Hemicellulose is a non-starch carbohydrate polymer made of glucose, galactose, xylose, and other monosaccharides; it can be found in whole grains.

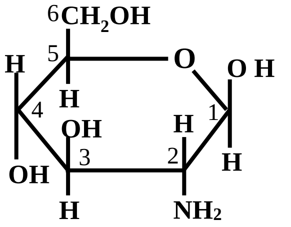
In contrast, pectins, mucilages, and gums are classified as **soluble fibers** because they dissolve or swell in water. They are not broken down by human enzymes, but instead can be metabolized (or fermented) by **bacteria** present in the large intestine. Pectin is a fiber made of galacturonic acid and other monosaccharides. Because it absorbs water and forms a gel, it is often used in jams and jellies. Sources of pectin include citrus fruits, apples, strawberries, and carrots. Mucilages and gums are similar in structure. Mucilages are dietary fibers that contain galactose, manose, and other monosaccharides; and gums are dietary fibers that contain galactose, glucuronic acid, and other monosaccharides. Sources of gums include oats, legumes, guar, and barley

Other sugar compounds

Sugars like hexoses and pentoses readily link up with other molecules to form more elaborate compounds. Some sugars contain nitrogen: they are called **amino sugars**. A polysaccharide that contains amino sugars is called a **mucopolysaccharide**. They are found in the basement membrane of epithelia, the matrix of connective tissue, the synovial fluid in vertebrate joints, and in the cell wall of prokaryotes. They also occur in chitin.

Chitin. This is a strong carbohydrate chemically related to cellulose. It is a polymer made up of many glucosamine units (glucose in which one –OH is replaced by –$NHCOCH_3$).
Glucosamine is one of the simplest amino sugars. The OH group at position 2 is replaced by an amino group (NH_2). Amino sugars can form long chains like other sugars. Chitin is a polymer of acetylglucosamine.

Glucosamine



Chitin forms long, straight chains similar to cellulose. Chitin is the second most abundant carbohydrate. Chitin is found in the exoskeleton of insects and other arthropods. Chitin is also found in the wall of fungal hyphae.

LIPIDS

These are water-insoluble organic substances. Lipids are formed by condensation reactions between fatty acids and alcohol.

Classification of lipids

1. Simple lipids (Fats & Waxes).
2. Compound or conjugated lipids.
3. Derived Lipids.
4. Lipid-associating substances.

Constituents of lipids

Fatty acids. These contain the acidic group –COOH and are so named because some of the larger molecules in the series occur in fats. They have the general formula R-COOH where R is hydrogen or a group such as $-CH_3$, $-C_2H_3$. The long chain of carbon and hydrogen atoms forms the hydrocarbon chain.

Many of the properties of all lipids are determined by this tail, including their solubility in water. The tails are said to be hydrophobic, meaning water-hating (*hydro*, water, *phobos*, fear)

Fatty acids contain one or more double bonds, such as oleic acid they are then said to be unsaturated. Fatty acids and lipids lacking double bonds are called **saturated**.

Unsaturated fatty acids melt at much lower temperatures than saturated fatty acids. Oleic acid, for example, is the chief constituent of olive oil and is liquid at normal temperatures (melting point 13.4^{0}C), whereas palmitic and stearic acids (63.1 ^{0}C and 69.6^{o}C) are solid at normal body temperatures.

Essential fatty acids. These are fatty acids that cannot be synthesized in the human body and must be taken in adequate amounts in the diet. They are required for normal growth and metabolism. They include linoleic, linolenic, arachidonic, eicosapentaenoic acid, docosahexaenoic.

The location of the first double bond in unsaturated fatty acids affects omega-3 fatty acids and omega-6 fatty acids.

Omega-3 fatty acid, the first double bond is between the third and fourth carbon from the omega end, Example: Alpha-linolenic acid, one of the two essential fatty acids.

Omega-6 fatty acid, the first double bond is between the sixth and seventh carbon from the omega end, Example: Linoleic acid, one of the two essential fatty acids

Omega-3, Linolenic found in coldwater fish, dissolves blood clots, lowers blood pressure, dilates the arteries.

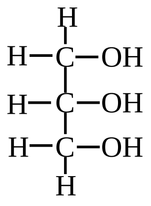
Source: vegetable oils such as corn oil, linseed oil, peanut oil, olive oil, cottonseed oil, soybean oil, and many other plant oils, cod liver oil and animal fats.

Name and occurrence of some fatty acids

Name of fatty acid	General formula	Saturated/ unsaturated	occurrence
Butyric	C_3H_7COOH	Saturated	Butterfat
Linoleic	$C_{17}H_{31}COOH$	Unsaturated	Linseed oil
Oleic	$C_{17}H_{33}COOH$	Unsaturated	All fats
Palmitic	$C_{15}H_{31}COOH$	Saturated	Animal and vegetable fats
Cerotic	$C_{25}H_{51}COOH$	Saturated	Wool oil
Arachidic	$C_{19}H_{39}COOH$	Saturated	Peanut oil
Stearic	$C_{17}H_{39}COOH$	Saturated	Animal and vegetable fats

Glycerol

This is an alcohol that contains three carbon atoms each linked to a hydroxyl group.



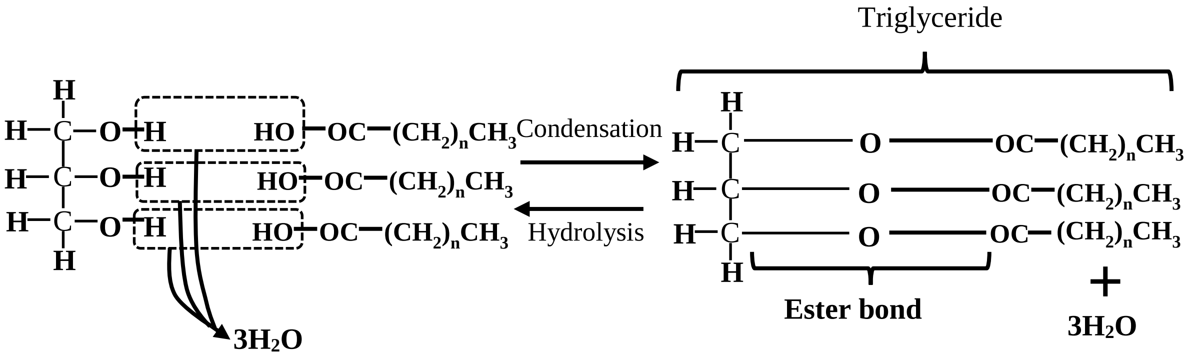
$$CH_2OH-CHOH-CH_2OH$$

Formation of lipids

The carboxyl groups of fatty acids react with the hydroxyl groups of glycerol to form acylglycerols (glycerides) and water. The bonds formed between the two components are called **ester linkages** and the process is known as **esterification**. If only one hydroxyl group is esterified, the product is a monoacylglycerol (monoglyceride), if two a diacylglycerol (diglyceride), and if three a triglycerol (triglyceride).

Most lipids are triglycerides. They are made from the alcohol glycerol.

Glycerol has three hydroxyl groups, all of which can combine with a fatty acid. Usually, all three undergo condensation reactions. And the lipid formed is therefore called **triglyceride**.



Properties of triglycerides

- ✓ They exist as fats (solids) or oils (liquids) at 20°C. The higher the proportion of unsaturated fatty acids, the more likely they are to be liquid at a given temperature.
- ✓ They are non-polar. They do not form hydrogen bonds with water molecules and therefore do not dissolve in water (they are hydrophobic).
- ✓ They are less dense than water and therefore float.
- ✓ Their tails vary in length according to the particular fatty acids used.

Functions of triglycerides

- ✓ They are energy stores. They have a higher calorific value than carbohydrates. A given mass of lipid yields more energy on oxidation than an equal mass of carbohydrates. This is because lipids have a higher proportion of hydrogen and less proportion of oxygen compared with carbohydrates.
- ✓ They insulate the body against heat loss. Animal store extra fat below the dermis of the skin when hibernating.
- ✓ They provide buoyancy in aquatic animals such as whales, they have lipids in the form of blubber.
- ✓ When oxidised, they provide metabolic water useful to desert animals such as kangaroo rats.

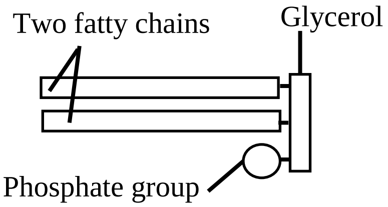
NB. Plants usually store oils rather than fats. Seeds, fruits and chloroplasts are often rich in oils and some seeds are commercial sources of oils, for example, the coconut, castor bean, soybeans, and sunflower seed.

Phospholipids

These are lipids containing a phosphate group. They are usually formed when one of the three -OH groups of glycerol combine with phosphoric acid instead of a fatty acid. The other two -OH groups combine with fatty acids.

- ✓ The molecule consists of a phosphate head with two hydrocarbon tails from the two fatty acids.
- ✓ The phosphate head carries an electrical charge which makes it soluble in water (hydrophilic).
- ✓ The tails are insoluble in water. One end of the molecule is soluble and the other is not. They are therefore **amphipathic**. This is important in the formation of membranes.

Illustration of a phospholipid



The fatty acids which make up phospholipids have a consistent length which allows them to form neat bilayers. Phospholipids usually have fatty acids that are **saturated** or **unsaturated**. The unsaturated fatty acids add **fluidity** to a bilayer because tails do not pack tightly together, they also allow faster transport of substances across the bilayer.

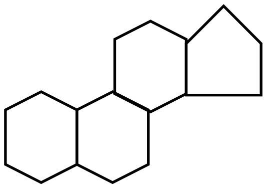
Glycolipids

They are an association of lipids with carbohydrates. The carbohydrate forms a polar head to the molecule. Glycolipids are also found in membranes.

Steroids

Steroids are lipids characterized by a carbon skeleton consisting of four fused rings. The **steroid nucleus** is a fused ring system consisting of three cyclohexane rings and one cyclopentane ring. Attachment of different groups to the core steroid structure leads to a wide variety of steroid compounds, including cholesterol, bile salts, and steroid hormones.

Simplified steroid



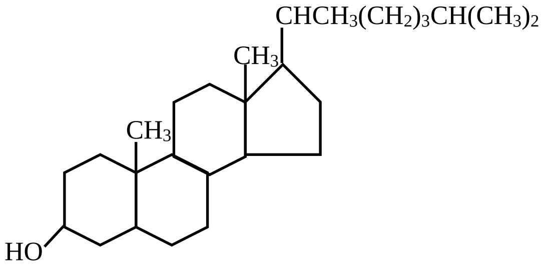
- **Cholesterol** is the most abundant steroid in animals. It’s a major component of cell membranes and affects the fluidity of the membrane.

Cholesterol is called a *sterol* because it contains an alcohol group.

The liver can synthesize all the cholesterol that animals need. It synthesizes more cholesterol when dietary intake is low. Excessive blood cholesterol is associated with atherosclerosis, the formation of gallstones and other cardiovascular-related diseases. Cholesterol is a precursor for the synthesis of many steroids.

Cholesterol and testosterone are almost identical except for the side groups on C3 and C17.

Cholesterol



- **Bile salts** are synthesized from cholesterol in the liver, they are stored in the gall bladder and released into the upper small intestine to help break down fats and oils. When cholesterol accumulates in the gall bladder can lead to gallstones. Presence of a gallstone in the bile duct can cause severe pain.

Lipoproteins

They are water-soluble complexes of lipids. They are soluble in water because their surface is polar. The polar head groups of phospholipids and the hydroxyl groups of cholesterol form a polar layer on the surface of the lipoprotein.

Waxes

Waxes are esters of long-chain saturated and unsaturated fatty acids (having 14-36 carbon atoms) with long-chain alcohol (having 16-30 carbon atoms).

They are low- melting, stable solids which appear in nature in both plants and animals.

Plants produce waxes on the surfaces of their leaves, stems, and fruits to prevent water loss and protect against pests. Animals produce waxes on their fur or feathers to provide a water-proof coating.

Functions of lipids

- Lipids are a concentrated source of energy. One-gram fat gives 9 K calories.
- They serves as a cushion for the vital organs and protects them from external shocks or injuries.
- Lipids are the structural materials of cells and membranes.
- Lipids are the carrier/reservoir of fat-soluble vitamins
- In food preparations, lipids serve as a binding agent. It also enhances the palatability of foods
- Cholesterol is used in the formation of plasma membranes and is also used for the synthesis of adrenal cortical hormones, vitamin D3, and bile acids.
- **Electrical insulation**. Myelin sheath in the membranes of Schwann cells, which form the sheaths around the axons of neurons, electrically isolates the cell plasma membrane. This makes it possible for the nerve impulse to pass down the axon.
- **Heat insulation**. Fats conduct heat slowly and are therefore useful insulators in endothermic animals such as mammals. They are stored beneath the skin nest to for subcutaneous fats. It retains heat in the skin. Some aquatic animals have a subcutaneous fat called **blubber** which forms an effective heat insulator.
- **Buoyancy**. Because they are less dense than water, lipids aid buoyancy in aquatic vertebrates such as sharks, seals, and whales. Sharks have fatty livers that make up to 25% of their body volume and contain a lipid, squaline with a specific gravity of only 0.86.
- Oils on bird feathers are important in keeping aquatic varieties birds on the surface of water.
- **Waterproofing**. Animal skins produce oil secretions, e.g from the sebaceous glands in mammals, which waterproof the body. Oils also coat the fur, helping to repel water which would otherwise wet it and reduce its effectiveness as an insulator. Birds spread oil over their feathers, from a special gland near the cloaca, for the same

purpose. An insect has a waxy cuticle to prevent evaporation loss in the same way that plant leaves have one to reduce transpiration.

- ✓ Wax is used by bees to construct their honeycombs.
- ✓ Some plant scents are fatty acids or their derivatives. They aide the attraction of insects for pollination.

Test for lipids

The test for lipids is known as the emulsion test. Using a completely dry and grease-free test tube, 2 cm^3 of the sample being tested is added plus 5 cm^3 of ethanol. The contents are mixed thoroughly to dissolve any lipid in the sample. When 5 cm^3 of water is added and the mix shook gently, a cloudy-white colour is formed. This confirms the presence of lipids.

For the control, the procedure is repeated using water instead of the sample; the final solution remains clear.

The cloudy colour is due to any lipid in the sample being finely dispersed in the water to form an emulsion. Light passing through this emulsion is refracted as it passes from oil droplets to water droplets, making it appear cloudy.

PROTEINS

They are polymers from amino acids. Some proteins form complexes with other molecules containing phosphorus, iron, zinc, and copper. There are 20 different amino acids that are commonly found in naturally occurring in proteins.

Amino acids

Amino acids are the basic units from which proteins are made. There are over 170 amino acids in cells and tissues, but 20 are commonly found in proteins. Plants make all amino acids they require from a simpler substance.

Animals are unable to synthesise all the proteins they need. They obtain some amino acids directly from their diet. These are termed **essential amino acids**.

Non-essential amino acids can be synthesized by animals from essential amino acids by the **transamination process**.

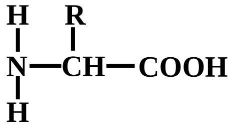
Essential amino acids are only described as essential because they cannot be synthesized.

Structure of amino acid

It is made up of a central carbon atom, known as the α-carbon. Attached to it are four components.

- ✓ an acidic carboxyl group, -COOH,
- ✓ a basic amino group, $-NH_2$.
- ✓ a hydrogen atom.
- ✓ R-group is a variable part of the molecule. This gives each amino acid its uniqueness.

Structure of an amino acid



$$\begin{array}{lll} H & R & \\ | & | & \\ N- & CH- & COOH \\ | & & \\ H & & \end{array}$$

The simplest amino acid is glycine, where R is simply hydrogen.

The table below shows the 20 common amino acids

Essential amino acids	Non-essential amino acids
Leucine	Alanine (R-group is $-CH_3$)
Arginine	Asparagine
Lysine	Aspartic acid (R-group is CH_2-COOH)
Methionine	Cysteine (R-group is CH_2-SH)
Phenylalanine	Proline
Threonine	Glutamic acid
Tryptophan	Serine (R-group is CH_2-OH)
Histidine	Glutamine
Isoleucine	Glycine (R-group is -H)
Valine	Tyrosine

Rare amino acids. A small number of rare amino acids occur in proteins of an organism. They are made from some of the common amino acids. For example, hydroxylproline is made from proline, and is found in the protein collagen, hydroxylysine is made from lysine, and is also found in collagen. There is no **DNA** code for the rare amino acids, and they are made from their parent amino acids.

Amphoteric nature of amino acids

They contain both an acid and a basic part. They exist as ions and can carry both a positive charge on the basic part and a negative charge on the acid part. They form a dipole and therefore described as zwitterions.

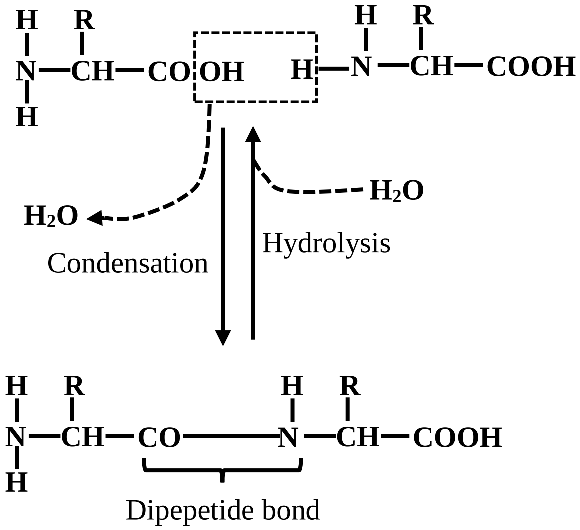
The acidic property is derived from the carboxyl group which can donate a proton so the molecule becomes negatively charged when in an alkaline solution.

The basic properties are derived from the amino group which can take up a proton so the molecule becomes positively charged in an acidic solution. They buffer the body because they can donate or receive protons.

Formation of a protein

A protein is formed by condensation polymerization of amino acids bonded by polypeptide bonds. Two amino acids form dipeptide, and more than two amino acids bonded together for a polypeptide. A polypeptide forms the primary structure of proteins; the linear arrangement of amino acids bonded together by only peptide bonds.

Formation of a dipeptide

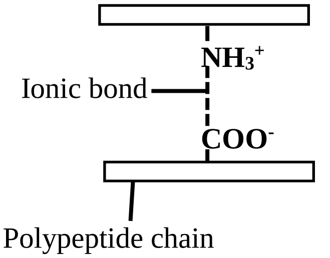


Bonds used in protein structure

Apart from the peptide bonds which are formed from the carboxylic and the amino groups of amino acids, other bonds exist as a result of variations in the R-groups. They include the following:

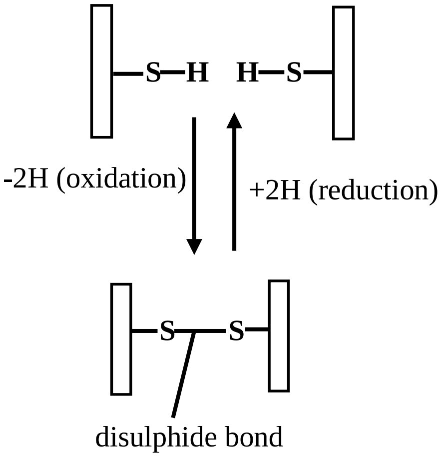
- ✓ **Ionic bond**. Acidic and basic R groups exist in an ionized (charged) state at a certain pH. The negatively charged acidic R groups and the positively charged basic R groups in protein, attract each other forming ionic bonds. These bonds are much weaker than a covalent bond (peptide bonds). They can be broken by changing the pH of the medium. Therefore, changes in pH can disrupt the structure of a protein.

Illustration of ionic bond



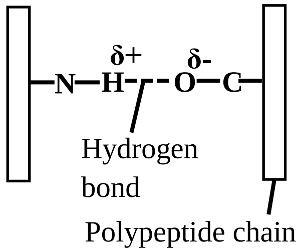
- ✓ **Disulphide bond**. This is formed when amino acids containing sulphydryl groups are close to each other in a protein. When two molecules of cysteine line up alongside each other, neighbouring sulphydryl are oxidised and form a sulphide bond.

Formation of a disulphide bond



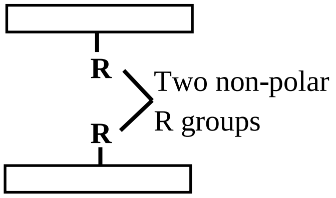
- ✓ **Hydrogen bond**. The hydrogen part of the -OH or -NH groups are usually slightly positively charged. This is because the oxygen and nitrogen atoms pull the bonding pair of electrons leaving hydrogen atom positively charged. The hydrogen is then attracted towards a neighbouring electronegative oxygen or nitrogen atom, such as the O of a C=O and NH groups, contained in another amino acid in the protein. Hydrogen bonds are common in the alpha-helix and silk protein.

Formation of hydrogen bond



- ✓ **Hydrophobic interactions**. These are formed when a polypeptide contains amino acids with non-polar (hydrophobic) R groups. For example, those in the amino acid tyrosine and valine. When a polypeptide chain containing a number of these groups is in aqueous solution, the chains tend to fold so that the maximum number of hydrophobic groups come into close contact and exclude water. The hydrophobic groups tend to point inwards towards the center of the roughly spherical molecule while thee hydrophilic groups face outwards into the aqueous environment, making the protein soluble. This is how many globular proteins fold up.

Illustration of hydrophobic interaction



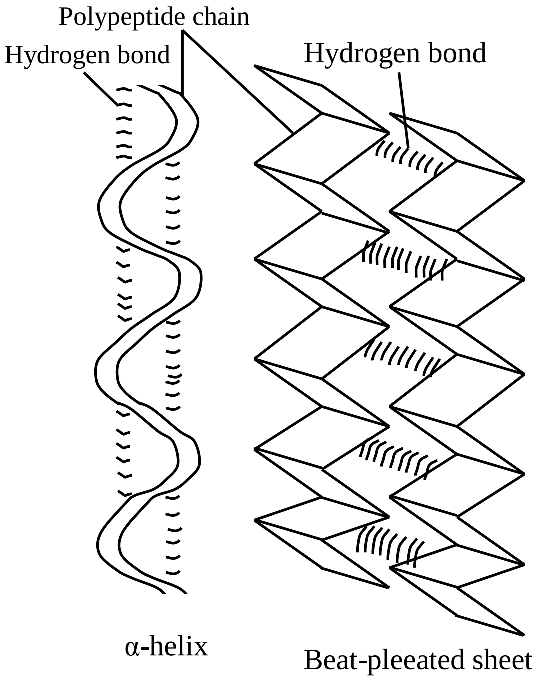
Protein structure

Synthesis of proteins takes place in the cytoplasm by the free ribosomes or ribosomes attached to the endoplasmic reticulum. During the process, the linear arrangement of amino acids takes place to form the primary structure of proteins. However, this undergoes further folding as it passes through the Golgi apparatus to form complex structures. Each protein possesses a characteristic three-dimensional shape, its conformation. There are four separate levels of structure of proteins.

Primary structure. This is the linear sequence of amino acids in a protein. It is determined by inherited genetic information.

Secondary structure. The primary structure coils and folds using hydrogen bonds between repeating constituents of the polypeptide backbone. This forms an **alpha helix** and a folded structure called a **beta-pleated sheet**. **Keratin** is α-helical and fibrous. It is found in hair, wool, nails, claws, beaks, feathers and horns and vertebrate skin. Some α-helical proteins are not entirely α-helical because of certain R groups bond together using other bonds other than hydrogen bonds.

Fibroin a protein that makes up silk is β-pleated. It is made up of more extended adjacent chains than α-helices. The sheets are arranged parallel to each other, running in the same direction or in the opposite direction.



Tertiary structure. This is determined by interactions between R groups, rather than interactions between backbone constituents. The polypeptide chains bend and fold extensively forming a precise, compact globular shape. These interactions between R groups include hydrogen bonds, ionic bonds, hydrophobic interactions, and van der Waals interactions. Strong covalent bonds called disulfide bridges may reinforce the protein's conformation.

Quaternary structure. This results when two or more polypeptide chains form one macromolecule.

Collagen is a fibrous protein consisting of three polypeptides coiled like a rope to form a triple helix.

Hemoglobin is a globular protein consisting of four polypeptides: two α chains each contain 141 amino acids while the two β chains each contain 146 amino acids. The hydrophobic side chains of haemoglobin point inwards to the centre of the molecules, and its hydrophilic chains face outwards making it soluble in water. A mutation that causes one of the hydrophilic amino acids to be replaced by a hydrophobic amino acid, reduces the solubility of haemoglobin causing sickle cell anaemia.

Insulin is made up of 51 amino acids. It has two polypeptide chains held together by disulphide bridges.

Protein Conformation

This is determined by the primary structure, physical and chemical conditions. Alternations in pH, salt concentration, temperature, or other environmental factors can cause a protein to unravel. This loss of a protein's native conformation is called **denaturation.** A denatured protein is biologically inactive.

Denaturation is the loss of the specific three- dimensional shape of a protein molecule. The change may be temporary or permanent, but the amino acid sequence of the protein remains unaffected. During denaturation, the molecule unfolds and can no longer perform its normal biological function

Causes of denaturation of proteins

Heat or radiation. e.g. infra-red or ultraviolet light. Kinetic energy is supplied to the protein causing its atoms to vibrate violently, so disrupting the weak hydrogen and ionic bonds. Coagulation of the protein then occurs.

Strong acids and alkalis and high concentrations of salts. Ionic bonds are disrupted and the protein is coagulated. Breakage of peptide bonds may occur if the protein is allowed to remain mixed with the reagent for a long period of time.

Heavy metals. The positively charged ions of heavy metals (cations) form strong bonds with the negatively charged carboxyl groups on the R groups of proteins and often disrupt ionic bonds. They also reduce the protein's electrical polarity and thus increase its insolubility. This causes the protein to precipitate out of the solution.

Organic solvents and detergents. These reagents disrupt hydrophobic interactions and form bonds with hydrophobic (non-polar) groups. This, in turn, causes the disruption of hydrogen bonding. When alcohol is used as a disinfectant it functions to denature the protein of any bacteria present.

Renaturation of proteins. A protein can spontaneously refold into its original structure after denaturation, provided conditions are suitable.

Classification of proteins according to structure

Globular protein. They include enzymes, haemoglobin, hormones, and antibodies. Tertiary structure is the most common in globular proteins. The polypeptide chains are folded to form a spherical shape. They carry out metabolic functions.

Fibrous proteins

They form long chains that run parallel to one another. The chains are linked by cross-bridges and so form very stable molecules. An example is collagen and keratin. Collagen is found in tissues requiring physical strength, e.g tendons, and walls of blood vessels, bone and the fibres that hold teeth in place. Keratin is found in nails, hooves, and hair.

Intermediate proteins. These are fibrous but soluble. They include fibrinogen which forms insoluble fibrin when blood clots.

Comparison between fibrous and globular proteins

Fibrous proteins	Globular proteins
Repetitive regular sequences of amino acids	Irregular amino acid sequences
Insoluble	Water-soluble; form colloidal suspensions
Support and structural functions	Metabolic functions
Stable structure	Relatively unstable
Polypeptide chains form long parallel strands	Polypeptide chains folded into a spherical shape
Examples include collagen and keratin	Examples include all enzymes, some hormones(like insulin) and haemoglobin

Classification of proteins according to composition

1. Simple proteins, only amino acids form their structure
2. Conjugated proteins, complex compounds consisting of globular proteins and tightly-bound non-protein material; the non-protein material is called a prosthetic group.

Name	Prosthetic group	Location
Phosphoprotein	Phosphoric acid	Casein of milk, Vitellin of egg yolk
Glycoprotein	Carbohydrate	Membrane structure, mucin(a component of saliva)
Nucleoprotein	Nucleic acid	Component of a chromosome, ribosome structure
Chromoprotein	Pigment	Haemoglobin, phytochrome, cytochrome
Lipoprotein	Lipid	Membrane structure
Flavinoprotein	FAD	Important in electron transport

Test for proteins

1. **Biuret test**. This detects peptide links. To a test sample, an equal volume of sodium hydroxide is added at room temperature. This is followed by a few drops of very dilute (0.05%) copper (ii) sulphate solution and the mixture is mixed gently. A purple colouration is formed which indicates the presence of peptide bonds and hence a protein. If no protein is present, the solution remains blue. A control can be carried out using water as a test solution.
2. Use of **Millon's reagent**. This is a solution of mercury(ii) nitrate in nitric acid. Mercury reacts with the thiol groups of amino acids, such as cysteine which is found in many proteins. At the same time, electrostatic forces in the protein molecules break due to the high concentration of hydrogen ions from the acid. The protein becomes denatured and a white precipitated is formed. When heated the precipitate takes on a red colouration if the protein contains the amino acid tyrosine.
3. **Ninhydrin reaction**. When a protein is heated with ninhydrin, the α-amino group forms a blue complex. Proline gives a yellow colour in this reaction.

Functions of proteins

Reproduction

- ✓ Proteins form hormones like prolactin which induces milk production in mammals.
- ✓ They form Histone which gives structural support to chromosomes.
- ✓ They form Gluten which is a storage protein in seeds that nourishes the embryo.
- ✓ Keratin forms horns and antlers which may be used for sexual display.

Sensitivity and coordination

- ✓ Used to make hormones used are used to transmit information in the body in the form of chemicals.
- ✓ Used to form Rhodopsin/opsin which is visual pigments in the retina, sensitive to light.
- ✓ Proteins are used to form Phytochromes which are plant pigments important in control of flowering, germination, etc.

Support and movement

- ✓ Actin and myosin are used in muscle contraction.
- ✓ Ossein (collagen of bones) forms structural support in bones.
- ✓ Elastin gives strength and elasticity to ligaments.
- ✓ Keratin provides tough protection, eg in scales, nails, hooves, skin.
- ✓ Lipoproteins are used to form structural components of all cell membranes.
- ✓ Sclerotin provides strength in insect exoskeleton.

Respiration and transport

- ✓ Proteins form Haemoglobin, haemoerythrin, haemocyanin and chlorocruorin which transport oxygen in organisms.
- ✓ Proteins form myoglobin which stores oxygen in muscles.
- ✓ Proteins form prothrombin and fibrinogen which are required in blood clotting.
- ✓ Form mucin which keeps the respiratory surface moist.
- ✓ Form antibodies that are essential for the body's defence against bacterial infections.

Growth

- ✓ Proteins form hormones like thyroxine which control growth and metabolism.

Excretion

- ✓ Proteins are used to make hormones like urease and arginase which catalyse reactions in ornithine cycle which forms urea.

Nutrition

- ✓ Proteins are used to make digestive enzymes which catalyse hydrolysis of food during digestion.
- ✓ Proteins form mucin which assists in trapping food in filter feeders. Mucin also prevents autolysis and acts as a lubricant in the gut.
- ✓ Casein forms the storage form of proteins in milk.

Protection

- ✓ Proteins form toxins which may include snake venom and Diphtheria toxin produced by diphtheria bacteria.

VITAMINS

Vitamins are organic constituents of food required in very small amounts for a variety of metabolic purposes. Plants synthesize them, but animals require them in their diet. However some vitamins are synthesized by bacteria in the gut, and others manufactured by the animal itself. **Vitamin D_3**, for example, can be synthesized in the human body and is then activated in the skin by ultra-violet rays.

If a given vitamin is lacking, a characteristic set of symptoms develops in the individual known as a **deficiency disease**. Vitamins **A**, **D**, **E** and **K** are fat-soluble whereas the rest are water-insoluble.

Role of vitamins in metabolism

Some vitamins form coenzymes which play an important role in various metabolic pathways.

Vitamin B_2 (riboflavin)

This combines with certain phosphate compounds to form **flavine adenine dinucleotide** (FAD), an important coenzyme concerned with the transport of hydrogen atoms in cell respiration. It is found in leafy vegetables, fish and eggs. Lack of vitamin B_2 results in lesions of the mouth, eyes, and skin.

Nicotinic acid

It is used to make two coenzymes: **nicotinamide adenine dinucleotide (NAD**), and **nicotinamide adenine dinucleotide phosphate** (**NADP**). In both cases, the nicotinic acid amide forms an effective group that carries hydrogen atoms. They both occur in respiration, but NADP also occurs in photosynthesis where it is used to transport hydrogen atoms derived from water for the subsequent reduction of carbon dioxide. Nicotinic acid is found in meat, fish, and wheat. Lack of it in the diet causes **pellagra**.

Vitamin B_1 (thiamine) and B_5 (pantothenic acid)

Both combine with phosphate compounds to form coenzymes which are involved in the formation of **acetyl coenzyme A**, an important intermediate in cell respiration. Both are found in most animal and plant tissues, but the husk of rice and wheat is particularly rich in B_1 and eggs particularly rich in B_5. Lack of B_1 results in beriberi, characterized by wasting of the muscles, paralysis and circulatory failure, whilst lack of B_5 results in disorders of the nervous system and gut.

Vitamin E (**tocopherol**). This plays a part in the transfer of hydrogen atoms in cell respiration. Lack of vitamin E can cause sterility in animals.

- ***Vitamin A (retinol).*** The proper chemical name of vitamin A is **retinol**. It is found in food of animal origin. The orange pigment carotene, familiar in carrots, and similar pigments called carotenes, are found widely in plants and can be converted to vitamin A during digestion. The structure of carotenes and vitamin A is particularly well adapted for light absorption, both in plants in the form of carotenes and in animals where vitamin A is converted to the light-absorbing molecule **retinal**. The three groups of animals that possess eyes (mollusks, arthropods, and vertebrates) all use retinal as the light-absorbing part of their photoreceptor molecules. Vitamin A is also needed for healthy skin and other epithelial (surface) tissues and is required by young children for growth.

Deficiency disease. A deficiency of vitamin A affects the rods (which react to light intensity) in the eye much more than the cones (which react to colour) and leads at first to a condition known as '**night blindness**'. This is a poor adaptation to conditions of low light intensity when vision is mainly dependent on the rods. Night blindness is caused by a deficiency of retinal in the rods. Eventually, the rods themselves become damaged. At the same time, the conjunctiva and the cornea become drier and uncomfortable. This can lead to a condition known as **xerophthalmia** (*Xero*, dry; *ophthalmia*, eye) with ulcers occurring on the cornea leading to blindness (**keratomalacia**).

Young children are particularly susceptible to vitamin A deficiency because it also reduces growth. Prolonged deficiency can lead to death. The condition is still common in some developing countries and is the most common cause of blindness in children. About 3 million children under the age of 10 years are blind as a result. A person with a healthy diet could be expected to have up to two years' supply in the liver, where it is stored. Average daily consumption in Britain is about twice that needed.

Excess vitamin A. Rare cases have been reported of vitamin A liver poisoning resulting from intake of excess amounts, often from prolonged consumption of large amounts of vitamin pills. Bone damage, hair loss, double vision, vomiting, and other problems may also occur. High intakes (in excess of 3300 pg per day) during pregnancy may cause birth defects. In the UK, pregnant women are generally advised not to take vitamin supplements containing vitamin A unless advised to do so at antenatal classes or by a doctor.

Regular intakes should not exceed 6000 jig per day for adolescents, 7500 |g per day for adult women and 9000 jig per day for adult men.

Vitamin D (**calciferol**). It can be made by the action of sunlight on the skin.

The light-absorbing molecule found in the skin is made from cholesterol. The active part of the light is ultraviolet (UV) light. It can be obtained from oily fish, such as mackerel, sardines and herring, fish-liver oils and egg yolk are exceptions.

Vitamin D is converted in the liver and the kidney (and placenta in pregnant women) to an active form which promotes calcium and phosphate absorption from the intestine.

Deficiency disease. In infants, the deficiency disease is called **rickets** and is caused by too little calcium and phosphate being added to the bones. This makes the bones too weak and soft to support the weight of the body, causing bowing of the legs and bending of the spine.

In adults, it leads to a condition known as **osteomalacia**. Bones are weakened and soften, becoming less mineralised with calcium and phosphate.

Excess vitamin D. This leads to excess calcium uptake. Excess calcium if not excreted is deposited in the kidneys where it causes damage.

Vitamin C (**Ascorbic acid**). It is concerned with the metabolism of connective tissue and the production of strong skin. It is also essential for collagen fibre synthesis. Its deficiency causes scurvy, characterized by weak and bleeding skin of gums, failure of wound-healing, failure of connective tissue formation.

Vitamin H (**Biotin**). It is used as a coenzyme for a number of carboxylation reactions. Involved in protein synthesis and transamination. Its deficiency causes dermatitis and muscle pains.

Vitamin K (**Phylloquinone)**. It is essential for the final stages of prothrombin synthesis in the liver. It is a necessary factor for the blood-clotting mechanism. Its deficiency causes delayed blood clotting.

Vitamin B_6 (**Pyridoxine**). It is converted to a coenzyme for amino acid and fatty acid metabolism. Its deficiency causes depression and irritability, anaemia, Diarrhoea, and Dermatitis.

Vitamin B_{12} (**Cyanocobalamin**). Required in synthesis of RNA proteins, prevents pernicious anaebia. It is found in meat, milk, eggs and cheese.

Folic acid. It is required for formation of red blood corpuscles and synthesis of nucleoproteins. Its deficiency causes **anaemia** particularly in women. It is found in liver, white fish, green vegetables.

Test for vitamin C

Using 0.1% ascorbic acid solution. Add 1 cm^3 of DCPIP solution to a test-tube. Add a test solution containing ascorbic acid drop by drop gently into a test-tube containing DCPIP until the blue colour of DCPIP disappears to form a colourless solution.

Basis of the test

DCPIP is a blue dye which is reduced to a colourless compound by ascorbic acid, a strong reducing agent.

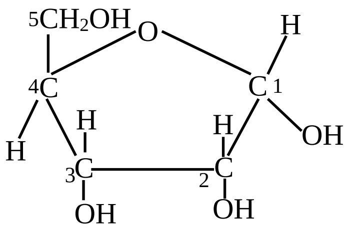
NUCLEIC ACIDS

These form the genetic material of all living organisms, including the simplest virus. They are called nucleic acids because they are mainly found and made in the nucleus. They include DNA and RNA. Nucleic acids are made up of units called **nucleotides**. These are arranged to form extremely long molecules known as **polynucleotides**.

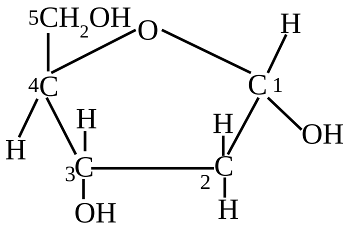
Structure of nucleotides

A nucleotide has three components, a 5-carbon sugar, a nitrogenous base, and phosphoric acid.

1. **Sugar.** The sugar has five carbon atoms; therefore, it is a pentose sugar. There are two types of nucleic acids, depending on the pentose they contain. Those containing ribose are called **ribonucleic acids** or **RNA** and those containing deoxyribose (ribose with an oxygen atom removed from carbon atom 2) are called **deoxyribonucleic acids** or **DNA**



Ribose sugar



Deoxyibose sugar

2. **Bases**. Each nucleic acid contains four different bases. Two derived from **purine** and two from **pyrimidine**. The nitrogen in the rings gives the molecules their basic nature.

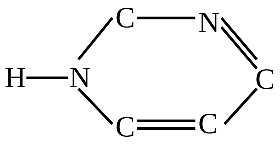
Purines are adenine (A) and guanine (G).

Pyrimidines are thymine (T) and cytosine (C) in DNA, with uracil (U) in place of thymine in RNA.

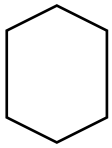
Thymine is chemically very similar to uracil (it is 5-methyl uracil, that is uracil with a methyl group, $-CH_3$, on carbon atom 5).

Purines have two rings and pyrimidines have one ring in their structure.

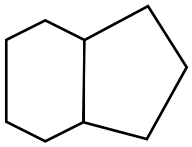
These bases are commonly represented by their initial letters A, G, T, U, and C.



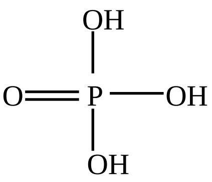
Pyrimidine



Purine

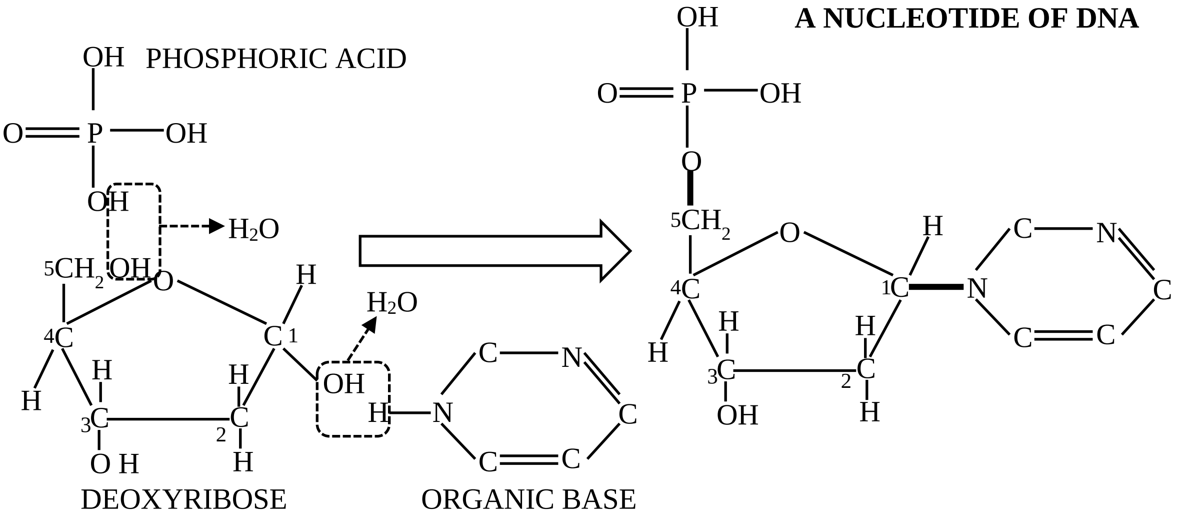


3. **Phosphoric acid (H_3PO_4)**. This gives nucleic acids their acid character.

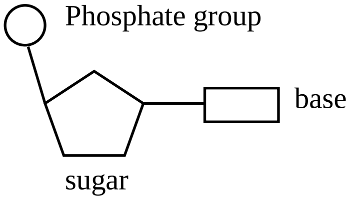


Formation of nucleotide

The combination of a sugar with a base occurs with the elimination of water and therefore is a condensation reaction. A nucleotide is formed by further condensation with phosphoric acid. Different nucleotides are formed according to the sugars and bases used.



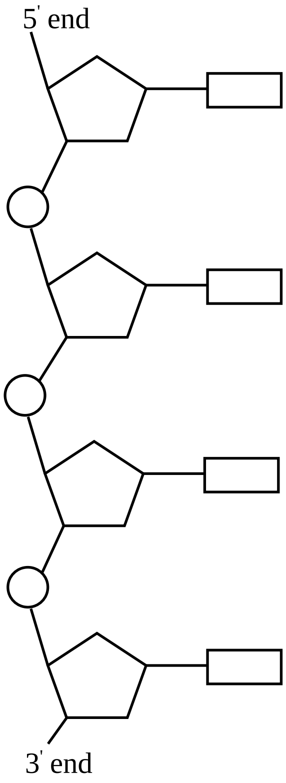
Simplied nucleotide



Nucleotides are not only used as building blocks for nucleic acids, but they form several important coenzymes, including adenosine triphosphate (ATP), cyclic AMP, coenzyme A, nicotinamide adenine dinucleotide (NAD) and its phosphate NADP, and flavine adenine dinucleotide (FAD).

Formation of dinucleotides and polynucleotides

Two nucleotides join to form a **dinucleotide** by condensation between the phosphate group of one with the sugar of the other. The process is repeated up to several million times to make a polynucleotide. An unbranched sugar-phosphate backbone is thus formed



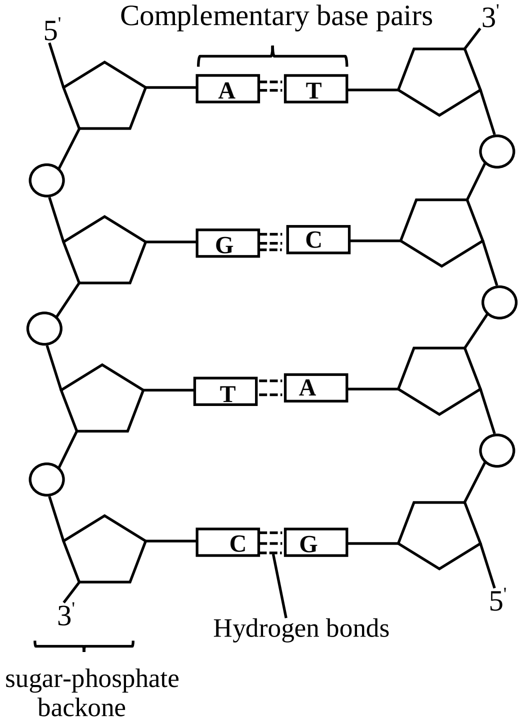
Structure of DNA

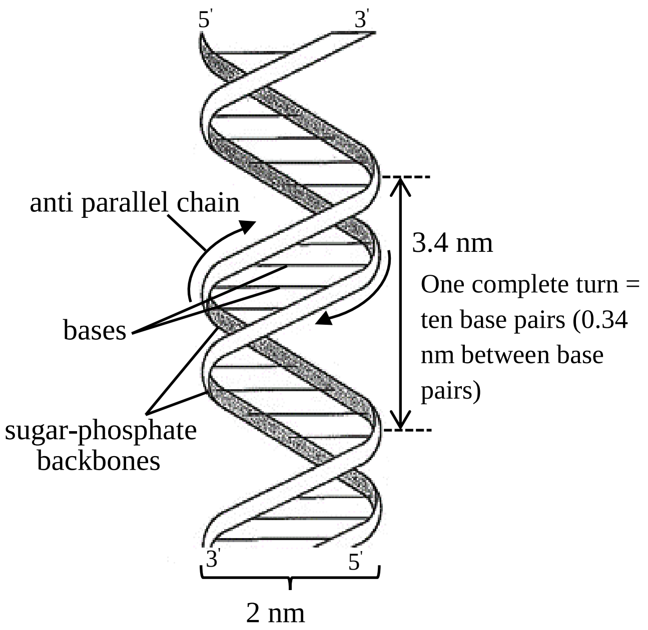
DNA is made up of two helical chains of polynucleotides held together by the pairing of bases between neighbouring chains. The bases are held together by hydrogen bonds. Adenine pairs with thymine, and guanine with cytosine; the adenine-thymine pair has two hydrogen bonds.

Each chain forms a right-handed helical spiral and the two chains coil around each other to form a double helix. The chains run in opposite directions, that is are **antiparallel**. Each chain has a sugar-phosphate backbone with bases which project at right-angles and hydrogen bond with the bases of the opposite chain across the double helix. The width between the two backbones is constant and equal to the width of a base pair that is the width of a purine plus a pyrimidine.

Along the axis of the molecule, the base pairs are 0.34 nm apart, accounting for the regularity indicated by X-ray diffraction. A complete turn of the double helix comprises 3.4 nm, or ten base pairs. Basing on the rules of base pairing, the sequence in one chain determines that in the other. The two chains are thus said to be **complementary**.

Diagrammatic structure of DNA





Structure of RNA

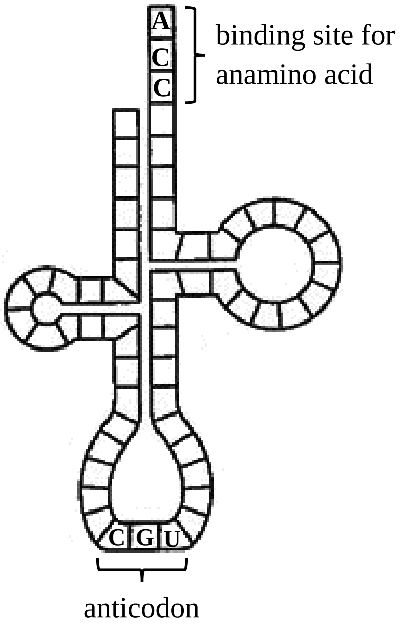
Ribonucleic acid (RNA) is a polymer made up of repeating mononucleotide sub-units. It forms a single strand in which the pentose sugar is always ribose and the organic bases are adenine, guanine, cytosine, and uracil. There are three types of RNA, all of which are important in protein synthesis:

- ✓ ribosomal RNA (rRNA),
- ✓ transfer RNA (tRNA),
- ✓ messenger RNA (mRNA),
- ✓ Ribosomal RNA (rRNA).

Ribosomal RNA. It is a large, complex molecule which is a major component of ribosomes, making up over half of their mass. It has a sequence of organic bases which is very similar in all organisms.

Transfer RNA (**tRNA**). It is a relatively small molecule that is made up of around 80 nucleotides. It is manufactured by DNA and makes up 10-15% of the total RNA in a cell. It has a single-stranded chain folded into a clover-leaf shape, with one end of the chain extending beyond the other. This extended chain always has an organic base sequence of cytosine-cytosine-adenine. This is the part of the tRNA molecule to which amino acids are attached. There are at least 20 types of tRNA, each able to carry a different amino acid. At the opposite end of the tRNA molecule is a sequence of three other organic bases, known as the **anticodon**. For each amino acid, there is a different sequence of organic bases on the anticodon. During protein synthesis, this anticodon pairs with the complementary three organic bases that make up the triplet of bases on mRNA, known as the **codon**.

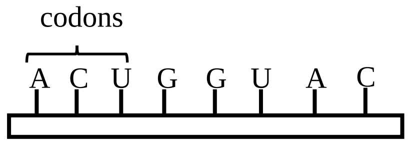
Clover-leaf structure of tRNA



Messenger RNA (**mRNA**). It is made up of thousands of mononucleotides. It is a long strand that is arranged in a single helix. It is formed by the DNA in the nucleus in the process called transcription. There is a great variety of different types of mRNA according to the part of DNA being transcribed.

Once formed, mRNA leaves the nucleus via pores in the nuclear envelope and enters the cytoplasm, where it associates with the ribosomes. There it acts as a template upon which proteins are built. It possesses the correct sequence of many triplets of organic bases that code for specific polypeptides. It is also easily broken down and therefore exists only for as long as it is needed to manufacture a given protein.

messenger-RNA



Differences between RNA and DNA

RNA	DNA
Single polynucleotide chain	Double polynucleotide chain
Small molecular mass	Larger molecular mass
Pentose sugar is ribose	Pentose sugar is deoxyribose
It contains uracil	Has thymine
The ratio of adenine and uracil to cytosine and guanine varies.	The ratio of adenine and thymine to cytosine and guanine is one
Found both in the nucleus and cytoplasm	Found in the nucleus except in prokaryotic cells
Amount varies from cell to cell	The amount is constant for all cells of a species except gametes and spores
Chemically less stable	Chemically stable
May be temporary, existing for a short period	Permanent
Three basic forms	Only one basic form

ENZYMES

An enzyme is a biological catalyst protein in nature that speeds up biochemical reactions in living cells. The chemical (or chemicals) which an enzyme works on is called its **substrate**. Enzymes control and catalyse all metabolic processes.

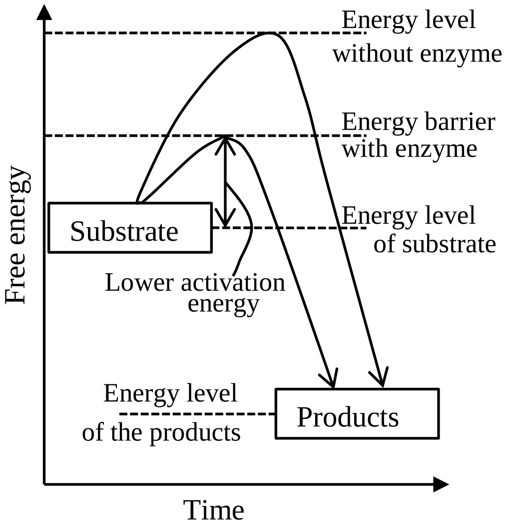
Metabolism is the sum total of all the chemical reactions going on in cells. It is divided into two types: **anabolism and catabolism**. Catabolic reactions involve the breakdown of molecules and usually release energy. Anabolic reactions involve the synthesis of molecules and usually require energy.

Properties of enzymes

- All are globular proteins.
- Being proteins, they are coded for by DNA.
- They are very efficient. A small amount of catalyst brings about the change of a large amount of substrate.
- They are highly specific, an enzyme will generally catalyse only a single reaction.
- The catalysed reaction is reversible.
- Their activity is affected by pH, temperature, substrate concentration, and enzyme concentration.
- Enzymes lower the activation energy of the reactions they catalyse
- Enzymes possess active sites where the reaction takes place. These sites have specific shapes

Activation energy. This is the energy required to make the substances react. Enzymes work by reducing the activation energy required for a chemical reaction to take place. They speed up the overall rate without altering, to any great extent, the temperature at which it occurs.

How enzymes lower the activation energy



Brfore a reaction take place, it mist overcome an energy barrier by exceeding its activation energy. Enzymes operate by lowering this activation energy and thus permit the reaction to occur more rapidily.

Naming and classifying enzymes

Enzymes can be divided into two main groups: intracellular and extracellular.

Intracellular enzymes catalyse reactions inside cells. Extracellular enzymes are produced by cells and catalyse reactions outside cells. They include the digestive enzymes that break down food in the gut.

There are usually **two** types of nomenclature

- Named by adding attaching a suffix **-ase** to the name of the substrate on which it acts. Thus, maltase acts on maltose, lipase on lipid, urease on urea. Pepsin and trypsin, both found in the mammalian gut, attack proteins and are hence known as proteases.
- Named **according to t**he type of reaction they catalyse.

1. **Oxidoreductases**. This group of enzymes oxidizes substrates. There are two kinds of these enzymes. **Oxidases** which catalyse the transfer of hydrogen to molecules of oxygen. An example is the **cytochrome oxidase** which catalyse the oxidation of reduced cytochrome.

   Dehydrogenases. These catalyse the oxidation of substrates by transferring hydrogen to coenzymes such as NAD and NADP. An example is alcohol dehydrogenase which controls the rate at which ethanol is oxidized to ethanol.

$$\text{Ethanol} + 2\text{NAD}^+ \rightleftharpoons \text{ethanal} + 2\text{NADH}$$

In reactions catalyzed by oxidoreductases, substrates are oxidized whereas oxygen or coenzymes are reduced.

2. **Lysases**. These catalyse the addition of a group across a double bond. For example pyruvate decarboxylase. Pyruvic acid is converted into ethanal and carbon dioxide by breakage of its double bond and the addition of a new group to the 'freed' bonds. Ethanal is then converted to alcohol.

$$\text{Pyruvic acid} \xrightarrow{\text{pyruvic decarboxylase}} \text{ethanol + carbon dioxide}$$

3. **Isomerases**. These catalyse rearrangements within a molecule, converting one isomer to another. Isomerases control the conversion of one isomer of a compound to another isomer of the same compound.

$$\text{Glucose-1-phosphate} \xrightarrow{\text{phosphoglucomutase}} \text{Glucose-6-phosphate}$$

The interconversion of sugar isomers in glycolysis is catalysed by isomerase enzymes such as hexosephosphateisomerase.

$$\text{Glucose-6-phosphate} \rightleftharpoons \text{fructose-6-phosphate}$$

4. **Ligases**. These catalyse bond formation between two compounds. The reaction uses energy that comes from hydrolysis of ATP to ADP and phosphate.

$$\text{Amino acid + specific tRNA} \xrightarrow{\text{Aminoacyl-tRNA synthetase + ATP}} \text{Amino acis tRNA complex + ADP + P}_\text{i}$$

5. **Hydrolases**. These catalyse the splitting of a large substrate molecule into smaller products in the presence of water. For example, a disaccharide is broken down into two monosaccharides by the addition of water by the enzyme lactase.

$$\text{Lactose + water} \xrightarrow{\text{lactase}} \text{Glucose + galacose}$$

6. **Transferases**. These catalyse the transfer of a group from one compound to another. For example aminotransferase.

$$\text{Glutamic acid + pyruvic acid} \xrightarrow{\text{aminotransferase}} \alpha\text{-ketoglutaric acid + alanine}$$

The R group on the amino acid, glutamic acid, is exchanged with the R group on a keto acid. A new amino acid, alanine is formed along with a new keto acid, alpha-ketoglutaric acid. This specific type of process is called transamination and it is used to make non-essential amino acids from essential amino acids.

Another example of transferases are the **phosphotransferases** which control the transfer of phosphate groups in respiration.

$$\text{Glucose + ATP} \rightarrow \text{Glucose-6-phosphate + ADP}$$

Transferases can also be **transaminases** which control the transfer of amino groups from one substrate to another.

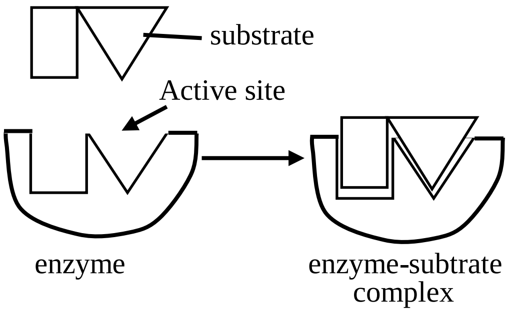
Summary of classification of enzymes

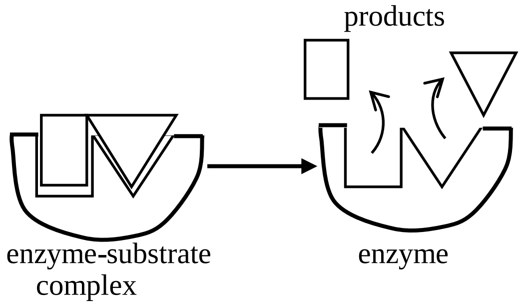
Enzyme group	Type of reaction catalysed	Enzyme examples
1. Oxidoreductases	Transfer of O and H atoms between substances, i.e oxidation-reduction reactions	Dehydrogenases Oxidases
2. Transferases	Transfer of a chemical group from one substance to another	Transaminases Phosphorylases
3. Hydrolases	Hydrolysis reaction	Peptidases Lipases
4. Lyases	Addition or removal of a chemical group other than by hydrolysis	Decarboxylases
5. Isomerases	The rearrangements of groups within a molecule	Isomerases Mutases
6. Ligases	Formation of bonds between two molecules using energy derived from the breakdown of ATP	Synthetases

Mechanism of enzyme action

There is usually two mechanisms which tries to explain enzyme activity

Lock and key hypothesis. Enzymes have a particular shape into which the substrate or substrates fit exactly. The substrate is imagined being like a **key** whose shape is complementary to the enzyme or **lock.** The site where the substrate binds in the enzyme is known as the **active site** and it is this which has the specific shape. The substrate fits into the active site and forms the enzyme/substrate complex, reactions than occur to form an enzyme-product complex, once formed, the products no longer fit into the active site and escape into the surrounding medium, leaving the **active site** free to receive further substrate molecules.





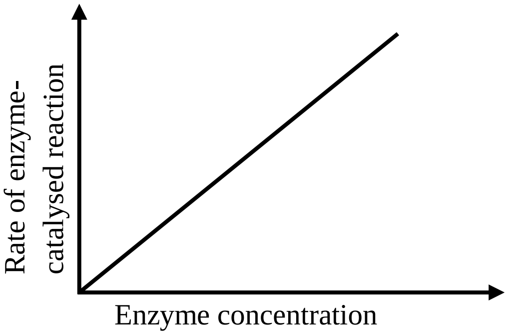
Induced fit hypothesis. Some enzymes have active sites which are flexible structures that can be modified. The active site is modified as the substrate interacts with the enzyme. The amino acids which make up the active site are moulded into a precise shape which enables the enzyme to perform its catalytic function most effectively.

Factors affecting the rate of enzyme reactions

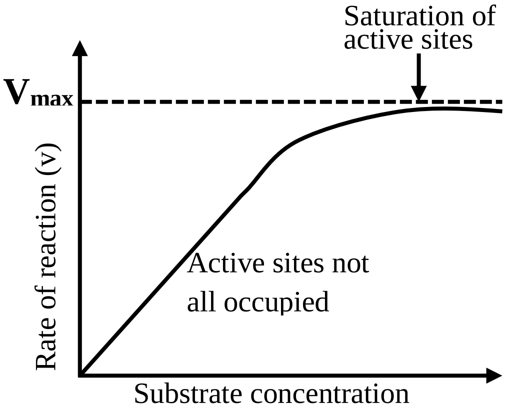
When investigating the effect of a given factor on the rate of an enzyme-controlled reaction, all other factors should be kept **constant** and at **optimum levels** wherever possible.

Enzyme concentration. Provided that the substrate concentration is maintained at a high level, and other conditions such as pH and temperature are kept constant, the rate of reaction is proportional to the enzyme concentration.

Relationship between enzyme concentration and the rate of an enzyme-controlled reaction

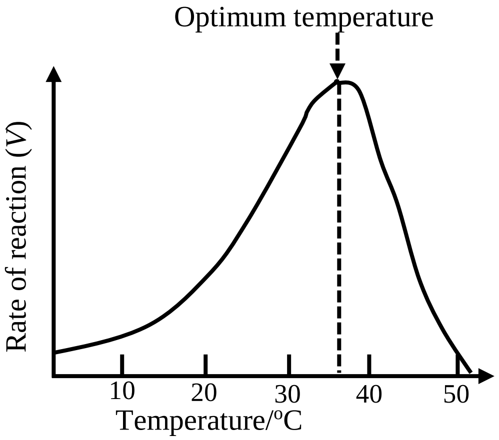


Substrate concentration. For a given enzyme concentration, the rate of an enzyme reaction increases with increasing substrate concentration. More substrates occupy the active sites to produce more products. There comes a point when any further increase in substrate concentration produces no significant change in reaction rate. This is because at high substrate concentrations all the active sites of the enzyme molecules at any given moment are virtually saturated with substrate. Any extra substrate has to wait until the enzyme-substrate complex has released the products before it may itself enter the active site of the enzyme.



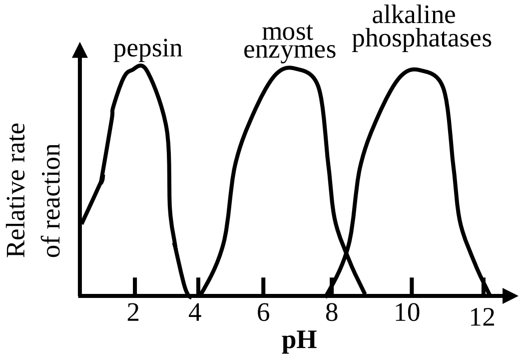
Temperature. An increase in temperature increases the kinetic energy of both the substrate and enzyme. They move more quickly and chances of the substrate bumping into the active site increase. As a result, there is a greater probability of a reaction occurring. The temperature that promotes maximum activity is referred to as the **optimum temperature**. Above this temperature, enzyme activity decreases despite the increasing frequency of collisions. This is because the secondary and tertiary structures of the enzyme become disrupted, and the enzyme is denatured. The enzyme unfolds and the precise structure of the active site is lost. When the temperature is reduced to near or below freezing point, enzymes are **inactivated**. They can regain their catalytic influence when higher temperatures are restored.

Most mammalian enzymes have an optimum temperature ranging from 37°C to 40°C. Enzymes of bacteria living in hot springs may have an optimum temperature of 70°C.



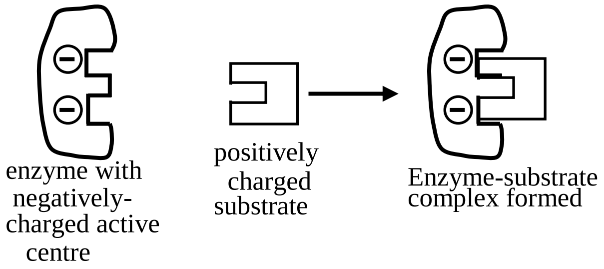
pH. Under conditions of constant temperature, the enzyme works efficiently over a particular narrow pH range. The optimum pH is that at which the maximum rate of reaction occurs.

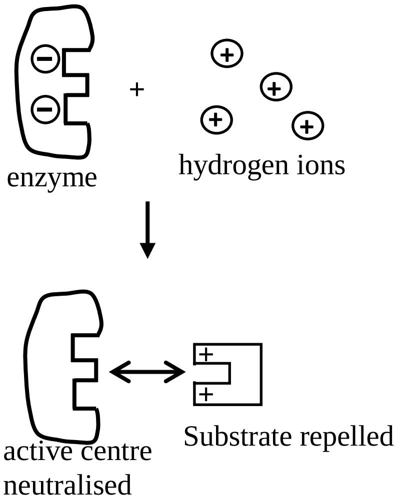
When the pH is altered above or below this value, the rate of enzyme activity reduces. As p.H decreases, acidity increases and the concentration of H^+ ions increases. This increases the number of positive charges, in the medium. An increase in pH increases the concentration of OH^- ions in the medium. Changes in pH alter the ionic charge of the acidic and basic groups and therefore disrupt the ionic bonding which maintains the specific shape of the enzyme. This alters the enzyme shape and its active site. If extremes of pH are encountered by an enzyme, it is denatured.



Apart from the effect in denaturing enzymes, changes in H^+ can alter the ionisation of the amino acid side chains at the active centres of enzymes. Ionisation of substrate molecules can also be affected. The formation of enzyme-substrate complexes sometimes depends on the active centres and substrate molecules having opposite electrostatic charges. If the charges are altered by changes in pH, some enzymes fail to work.

One way in which pH affect an enzyme





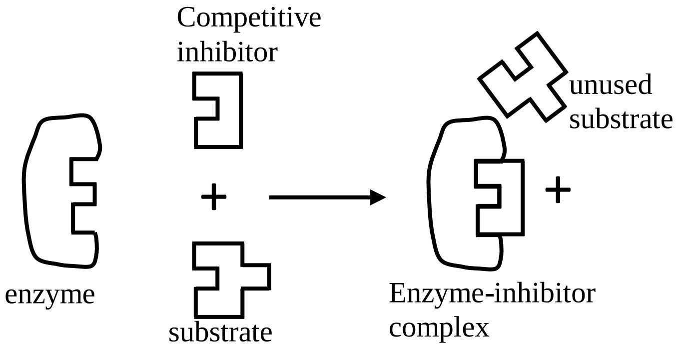
Immobilising enzymes

Enzymes are used as catalysts in many industrial processes. The enzymes are often immobilized by fixing them onto or inside a gel or other substance, which prevents the enzymes from dissolving in the reaction mixture. This means that the product is not contaminated with the dissolved enzyme, and the enzymes can be repeatedly reused. Immobilisation also enables enzymes to work over a wider range of temperature and pH than they are in free solution, probably because the trapped enzyme molecules cannot easily change shape and become denatured. One way of immobilizing enzymes is to trap them inside little balls of calcium alginate.

ENZYME INHIBITION

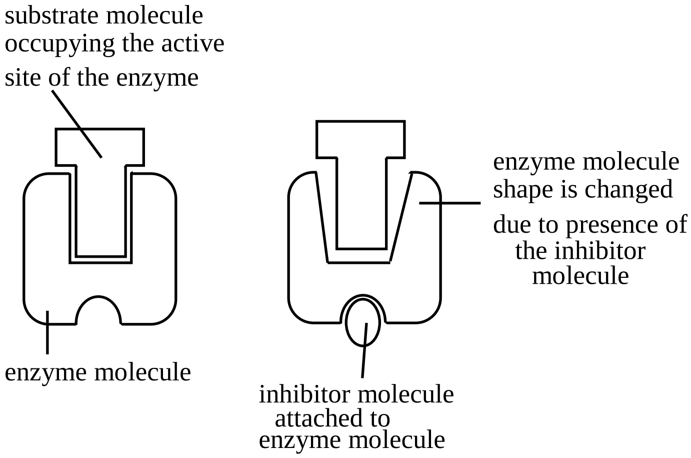
Enzyme inhibitors are substances that reduce the activity of enzymes. Inhibition is a normal part of the regulation of enzyme activity within cells. Many drugs and poisons are enzyme inhibitors. Inhibition may be competitive or non-competitive.

1. **Competitive inhibition**. This occurs when a compound has a structure which is sufficiently similar to that of the normal substrate to be able to fit into the active site. The inhibitor occupies the active site and prevents the true substrate from entering the active site. The genuine substrate and the inhibitor, therefore, compete for the active site**.** A characteristic feature of competitive inhibition is that if the substrate concentration is increased, the rate of reaction increases.



2. **(a) Non-competitive inhibition**. This can be divided into reversible and irreversible.
   Non-competitive reversible inhibition. The inhibitor has no structural similarity to the substrate and combines with the enzyme at a point other than its active site. It does not affect the ability of the substrate to bind with the enzyme, but it makes it impossible for catalysis to take place. The rate of reaction decreases with increasing inhibitor concentration. When inhibitor saturation is reached, the rate of the reaction becomes nil. An increase in substrate concentration does not affect the rate of reaction.

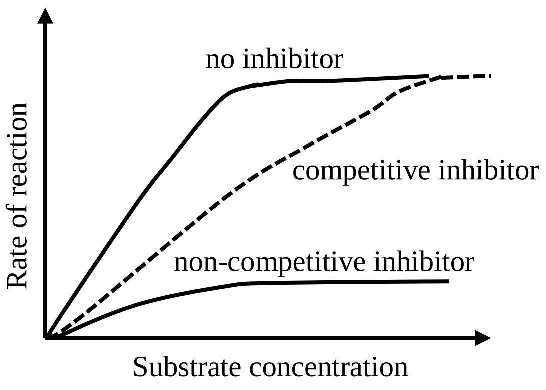
Non-competitive inhibition



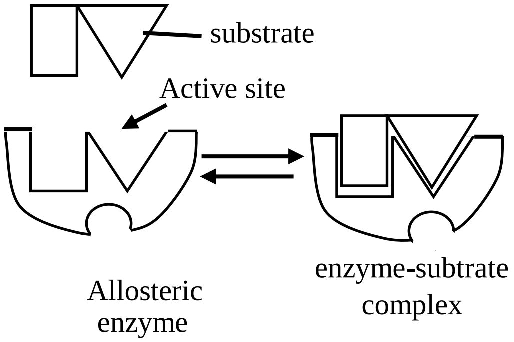
Non-competitive irreversible inhibition. Some chemicals permanently attach on enzymes. Their attachment is irreversible and this reduces the ability of the enzyme to combine with the substrate. Chemicals such as heavy metal ions like mercury (Hg^{2+}), silver (Ag^{+}) and arsenic (As^{+}), or certain iodine-containing compounds completely inhibit some enzymes. They combine permanently with sulphydryl (-SH) groups. These may be in the active site or elsewhere, leading to alteration of enzyme structure. They cause the protein of the enzyme molecule to precipitate. Cyanide is another non-competitive inhibitor. It blocks the action of some enzymes by combining with iron which may be present in a prosthetic group or which may be required as an enzyme activator.

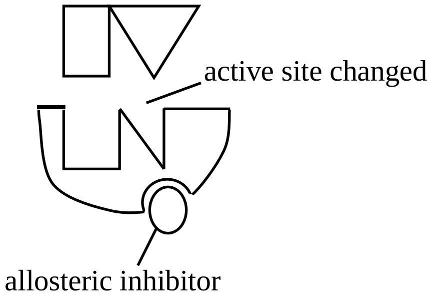
Example. DFP (Diisopropylfluorophosphate) is a nerve gas which was used in warfare. It combines with the amino acids of serine at the active site of the enzyme acetylcholinesterase. This enzyme deactivates the neurotransmitter substance acetylcholine. Neurotransmitters are needed to continue the passage of nerve impulse from one nerve to another across a synaptic gap. When the impulse has been transmitted, acetylcholinesterase functions to deactivate acetylcholine almost immediately by breaking it down. If acetylcholinesterase is inhibited, acetylcholine accumulates and nerve impulses cannot be stopped, causing prolonged muscles contraction. Paralysis occurs and death may result since the respiratory muscles are among those affected. Insecticides like organophosphates such as parathion have similar effects .

Comparative effects of a non-competitive and competitive inhibitor of an enzyme-catalysed reaction



Allosteric enzymes. These are enzymes which are designed to change shape. They are regulated by compounds which act as non-competitive inhibitors. These compounds bind to the enzyme at specific sites away from the active site. They modify enzyme activity by causing a reversible change in the structure of the enzyme's active site. This in turn affects the ability of the substrate to bind to the enzyme. Compounds of this nature are called **allosteric inhibitors**.





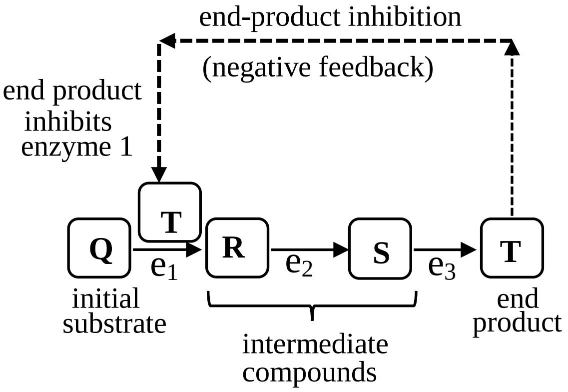
Some allosteric enzymes exist in two different forms, one active and the other inactive. The inactive form of the enzyme is shaped in such a way that the substrate does not fit into the active site. For the enzyme to work it must be transformed into the active form, and this involves changing its shape so that the substrate fits into the active site.

Allosteric enzymes can be inhibited by certain molecules which combine, not with the active site, but with some other part of the enzyme. The inhibitor prevents the enzyme from changing into the active form. Substances which have this effect are known as allosteric inhibitors. Other substances are known to combine with allosteric enzymes in such a way that they react more readily with their substrates.

Allosteric enzymes are used to regulate metabolic pathways. An example of this is provided by one of the reactions of glycolysis, the series of reactions that forms the first part of cell respiration. Cell respiration produces energy (ATP). When ATP is at high concentration, it inhibits one of the enzymes of glycolysis allosterically. When cell metabolism increases and more ATP is used up, the overall concentration of ATP decreases and the inhibitor, ATP, is removed. This is also an example of end-product inhibition.

End-product inhibition (**negative feedback inhibition**). This is the type of inhibition where the end-product of the reaction pathway inhibits some of the enzymes in the whole process. The end product of a metabolic pathway accumulates and allosterically inhibits some of the enzyme controlling the first step of the pathway. Therefore, the product switches off its own production as it builds up. As the product is used up, its production is switched back on again. This is an example of a **negative feedback** mechanism.

Ilustration of end-product inhibition



Application of enzyme inhibition

- ✓ Inhibitors of this kind can be used as drugs to reduce the rate at which undesirable reactions occur in the human body. Inhibiting such reactions is one of the ways of treating some forms of cancer. Another application of competitive inhibition is the use of sulphonamide drugs such as prontosil to combat bacterial infections.
- ✓ Enzyme having very high optimum temperatures are used in biological washing powders.

Enzyme cofactors. These are non-protein components required for efficient activity of enzymes. They may either remain unchanged at the end of a reaction or be regenerated by a later process. There are three types of cofactors.

1. **Inorganic ions** (**enzyme activators**). These mould either the enzyme or the substrate into a shape that allows an enzyme/substrate complex to be formed, hence increasing the chances of a reaction occurring between them and therefore increasing the rate of reaction catalysed by that particular enzyme. For example, salivary amylase activity is increased in the presence of chloride ions.
2. **Prosthetic groups** (for example FAD, haem). These are tightly bound to the enzyme on a permanent basis. Prosthetic groups are organic molecules. They assist the catalytic function of their enzymes, as in flavine adenine dinucleotide (FAD). This contains riboflavin (vitamin B2), the function of which is to accept hydrogen. FAD is concerned with cell oxidation pathways and is part of the respiratory chain in respiration.

   Haem. Haem is an iron-containing prosthetic group. It has the shape of a flat ring (a **'porphyrin ring'** as is found in chlorophyll) with an iron atom at its centre. It has a number of biologically important functions. Electron carrier. Haem is the prosthetic group of cytochromes, where it acts as an electron carrier. In accepting electrons the iron is reduced to Fe(II); in handing on electrons it is oxidised to Fe(III). Oxygen carrier. Haemoglobin and myoglobin are oxygen-carrying proteins that contain haem groups. Here the iron remains in the reduced, Fe(II).

Other enzymes. Haem is found in catalases and peroxidases, which catalyse the decomposition of hydrogen peroxide into water and oxygen. It is also found in a number of other enzymes

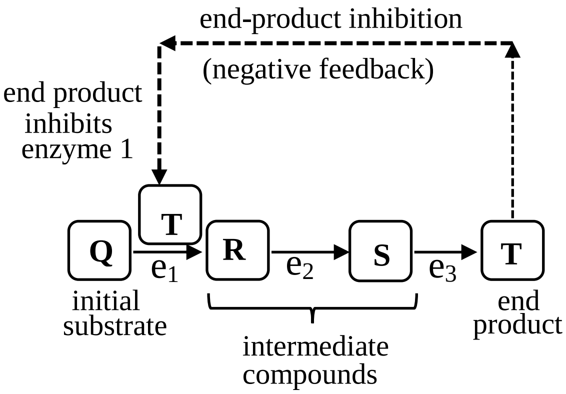
3. **Coenzymes** (**for example NAD, NADP, coenzyme A, ATP**). Coenzymes are organic non-protein molecules not bonded on the enzyme. They do not remain attached to the enzyme between reactions. Many important coenzymes

are derived from vitamins. **Nicotinamide adenine dinucleotide** (**NAD**) and its phosphate ester **nicotinamide adenine dinucleotide phosphate** (**NADP**) are derived from nicotinamide, a B-group vitamin. Riboflavin (Vitamin B_2) forms part of **flavine adenine dinucleotide** (**FAD**). NAD, NADP and FAD are hydrogen acceptors in reactions catalyzed by dehydrogenase enzymes.

Control of metabolic pathways

A structured system is used to control metabolic pathways. This is because many reactions take in any single cell. Metabolic pathways inside a cell are regulated to avoid one pathway interfering with another pathway. Because different enzymes need different conditions, it is therefore necessary to have a structured system for each pathway. The following are some of the ways how enzyme-controlled reactions are regulated.

- ✓ Enzymes are enclosed inside organelles like vesicles. This increases the chances of them coming into contact with their appropriate substrates, and leads to efficiency. These organelles also have varying conditions to suit the specific enzymes available, the cell can then control the metabolic pathways within it.
- ✓ The use of the end-product inhibition. The end product accumulates in excess quantities which inhibit some of the enzymes involved in the pathway.



The end product T, inhibits enzyme 1 which catalyses the initial reaction. When the end product T is used by the cell metabolism, its quantities reduces, and the inihibition is stopped. This mechanism is also termed as negative feedback because the output has a negative effect on the pathway.

Commercial application of enzymes

- ✓ Used in biological washing powders. The powders usually contain proteases which remove food stains such as food, blood, allergens and bacteria.
- ✓ Used in meat tenderizers to soften meat.
- ✓ α-amylase is used in baking industry.
- ✓ Used in sweeteners. Glucose isomerase is used to make the soft drinks and cakes taste sweet.
- ✓ Many are used in industry to make cheese and other dairy products.
- ✓ Used in photographic industry. Protease ficin is used to digest the protein coat on the film when developing the image.
- ✓ Used in paper in paper industry. Amylase is used to remove starch from the raw materials.