THE SIGNIFICANCE OF WATER TO LIVING ORGANISMS

Water is of immense importance to all living organisms. It is used by them in many different ways. These uses can be explained by referring to the properties of water.

Water is used as a **coolant**
- refer to thermal properties.

Water is used as a **transport medium**
- refer to cohesion, solvent properties and thermal properties.

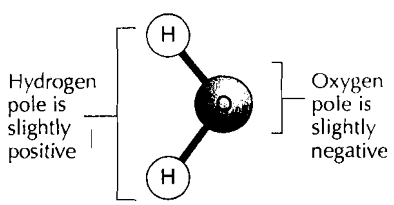
Water is used as a **habitat**
- refer to cohesion and thermal properties.

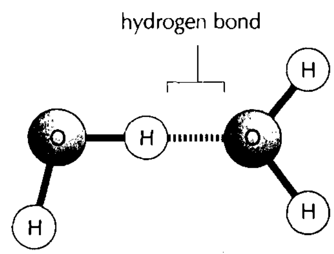
POLARITY AND HYDROGEN BONDING IN WATER

Water molecules consist of two hydrogen atoms bonded to an oxygen atom. The hydrogen atoms have a slight positive charge and the oxygen atom has a slight negative charge. So, water molecules have two poles (they are dipoles) – a positive hydrogen pole and a negative oxygen pole (below left). This feature of a molecule is called **polarity**.

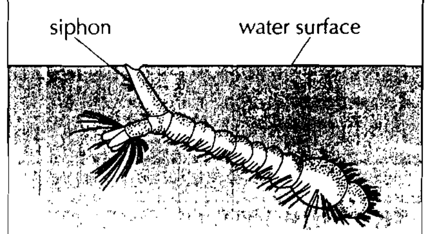
A bond can form between the positive pole of one water molecule and the negative pole of another. This is called a hydrogen bond (below centre). In liquid water, many of these bonds form.

Water molecule





Mosquito larva in water



THE PROPERTIES OF WATER

Name of the property	Outline of the property	Significance of the property to living organisms
Transparency	Light can pass through water	Light can reach structures inside living organisms such as chloroplasts in plant cells and the retina in the human eye. It can also reach organisms that use freshwater or seawater as their habitat
Cohesion	Water molecules stick to each other because of the hydrogen bonds that form between them.	Strong pulling forces can be exerted to suck columns of water up to the tops of the tallest trees in their transport systems. These columns of water rarely break
	At a surface, the cohesion of water molecules can make it difficult for small objects to break through	Some animals such as mosquito larvae use the surface of water as a habitat (above). Though they are denser than water they remain on the surface and do not sink
Solvent properties	Many different substances dissolve in water because of its polarity. Inorganic particles such as sodium ions and organic substances such as glucose can dissolve	The solvent properties of water allow many substances to be carried dissolved in water in the blood of animals and the sap of plants
Thermal properties: heat capacity	Water has a large heat capacity. This means that large amounts of energy are needed to raise its temperature. The energy is needed to break some of the hydrogen bonds. This heat energy is given out again when the water is cooled	The temperature of water tends to remain quite stable. This is useful for organisms such as fish that use water as a habitat. Blood, which is mainly composed of water, can carry heat from warmer parts of the body to cooler parts
Thermal properties: boiling and freezing points	The boiling point of water (100 °C) is relatively high, because, to change it from a liquid to a gas, all of the hydrogen bonds between the water molecules have to be broken	In natural habitats on Earth, water rarely boils. Living organisms could not survive if the water inside them boiled
	Water also freezes at a relatively high temperature, but because it becomes less dense as it cools to freezing point, ice forms at the surface first	The ice that forms on the surface of lakes or seas insulates the water underneath, so living organisms can survive there
Thermal properties: the cooling effect of evaporation	Water can evaporate at temperatures below boiling point. Hydrogen bonds have to be broken to do this. The heat energy needed to break the bonds is taken from the liquid water, cooling it down	Evaporation of water from plant leaves (transpiration) and from the human skin (sweat) has useful cooling effects

Organic and inorganic compounds

ELEMENTS FOUND IN LIVING ORGANISMS

Living organisms contain many chemical elements, some in large quantities and some in very small amounts. The three commonest chemical elements of life are carbon, hydrogen and oxygen. They are part of all the main organic compounds in living organisms. Examples of other elements that are needed are shown in the table opposite.

EXAMPLES OF CHEMICAL ELEMENTS AND THEIR ROLES

Element	**Role in plants or animals**
Nitrogen	Part of the amine groups of amino acids and therefore proteins
Calcium	Needed to make the mineral that strengthens bones and teeth.
Phosphorus	Part of the phosphate groups in ATP and DNA molecules
Iron	Needed to make hemoglobin and thus to carry oxygen in blood
Sodium	Used in neurons (nerve cells) for the transmission of nerve impulses

ORGANIC AND INORGANIC COMPOUNDS

Living organisms contain many chemical compounds. Some of them are organic and some are inorganic. Organic compounds are defined as compounds containing carbon that are found in living organisms.
There are a few carbon compounds that are inorganic even though they can be found in living organisms. These are all simple carbon compounds that are also widely found in the environment. Carbon dioxide, carbonates and hydrogen carbonates are three examples of inorganic carbon compounds. Three types of organic compound are found in large amounts in living organisms – carbohydrates, lipids and proteins.

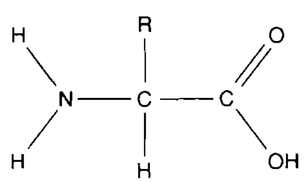
ATOMS AND IONS

An atom is a single particle of a chemical element. If an atom either gains or loses electrons it becomes an ion. Atoms are uncharged particles and ions are charged – they have either positive or negative charges. For example, if a sodium atom (Na) loses an electron, it becomes a sodium ion (Na^+).

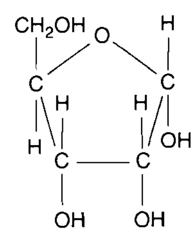
THE SUBUNITS OF ORGANIC COMPOUNDS

The molecules of many organic compounds are large and may seem complex, but they are built up using small and relatively simple subunits. Some important subunits are shown below.

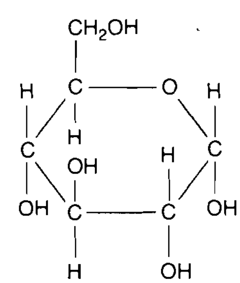
Subunits of proteins, carbohydrates and lipids



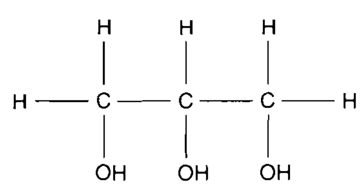
amino acids
(general structure)



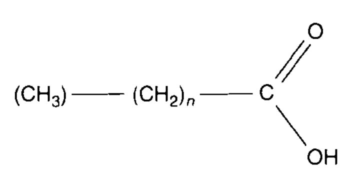
ribose
(a monosaccharide)



glucose
(a monosaccharide)



glycerol

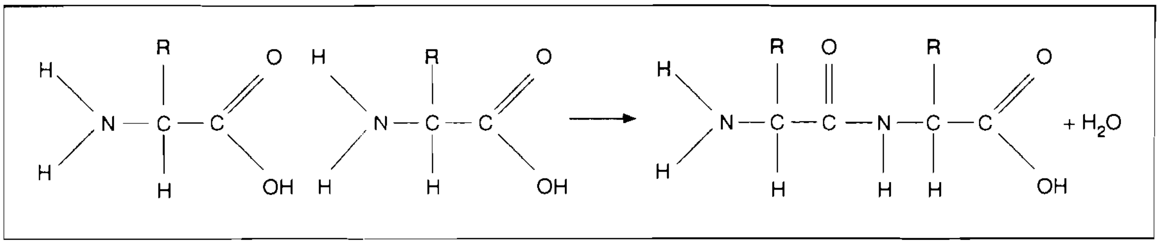


fatty acids
(general structure)

CONDENSATION REACTIONS

In a condensation reaction two molecules are joined together to form a larger molecule. Water is also formed in the reaction. For example, two amino acids can be joined together to form a dipeptide by a condensation reaction. The new bond formed is a **peptide linkage**.

Condensation of two amino acids to form a dipeptide and water



Further condensation reactions can link amino acids to either end of the dipeptide, eventually forming a chain of many amino acids This is called a **polypeptide**.

In a similar way, condensation reactions can be used to build up carbohydrates and lipids. The basic subunits of lipids are monosaccharides. Two monosaccharides can be linked to form a disaccharide and more monosaccharides can be linked to a disaccharide to form a large molecule called a **polysaccharide**. Fatty acids can be linked to glycerol by condensation reactions to produce lipids called **glycerides**. A maximum of three fatty acids can be linked to each glycerol, producing a triglyceride.

HYDROLYSIS REACTIONS

Large molecules such as polypeptides, polysaccharides and triglycerides can be broken down into smaller molecules by hydrolysis reactions. Water molecules are used up in hydrolysis reactions. Hydrolysis reactions are the reverse of condensation reactions.

Polypeptides + Water → Dipeptides or Amino acids

Polysaccharides + Water → Disaccharides or Monosaccharides

Glycerides + Water → Fatty acids + Glycerol

EXAMPLES OF CARBOHYDRATES

Monosaccharides	Glucose, fructose and ribose
Disaccharides	Sucrose (glucose + fructose) Maltose (glucose + glucose)
Polysacharides	Starch (made of glucose subunits) Glycogen (made of glucose subunits, but linked differently from starch)

FUNCTIONS OF LIPIDS

- **Energy storage** – in the form of fat in humans and oil in plants
- **Heat insulation** – a layer of fat under the skin reduces heat loss
- **Buoyancy** – lipids are less dense than water so help animals to float

FUNCTIONS OF CARBOHYDRATES

- **Transport** – glucose is carried by the blood to transport energy to cells throughout the body
- **Energy storage** – energy is stored in the form of glycogen in liver cells

USING CARBOHYDRATES AND LIPIDS IN ENERGY STORAGE

Both lipids and carbohydrates can be used for energy storage in living organisms. Both types of storage compound have advantages. Carbohydrates are usually used for energy storage over short periods and lipids for long-term storage.

Advantages of lipids	Advantages of carbohydrates
1. Lipids contain more energy per gram than carbohydrates so stores of lipid are lighter than stores of carbohydrate that contain the same amount of energy	1. Carbohydrates are more easily digested than lipids so the energy stored by them can be released more rapidly
2. Lipids are insoluble in water, so they do not cause problems with osmosis in cells	2. Carbohydrates are soluble in water so are easier to transport to and from the store

Enzymes and substrates

INTRODUCING ENZYMES

Catalysts speed up chemical reactions without being changed themselves. Living organisms make biological catalysts called **enzymes.** *Enzymes are globular proteins which act as catalysts of chemical reactions.*

Without enzymes to catalyse them, many chemical processes happen at a very slow rate in living organisms. By making some enzymes and not others, cells can control what chemical reactions happen in their cytoplasm.

The structure of enzymes is quite delicate and can be damaged by various substances and conditions. This is called **denaturation**. *Denaturation is changing the structure of an enzyme (or other protein) so that it can no longer carry out its function.* Denaturation is usually permanent.

In chemical reactions, one or more reactants are converted into one or more products. In reactions catalysed by enzymes, the reactants are called **substrates.**

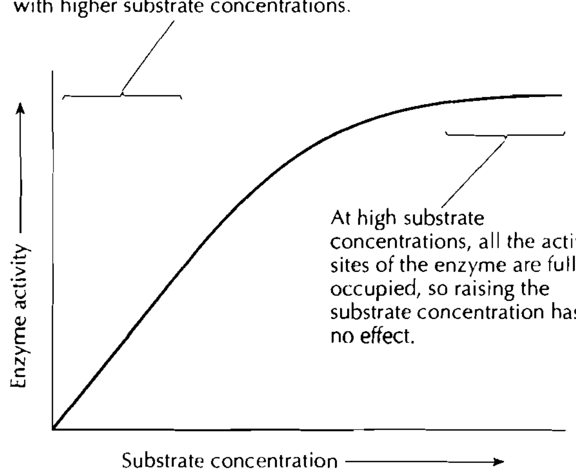
ENZYME–SUBSTRATE SPECIFICITY

Most enzymes are specific – they catalyse very few different reactions. They therefore only have a very small number of possible substrates. This is called enzyme–substrate specificity. The substrates bind to a special region on the surface of the enzyme called the **active site**. *An active site is a region on the surface of an enzyme to which substrates bind and which catalyses a chemical reaction involving the substrates.*

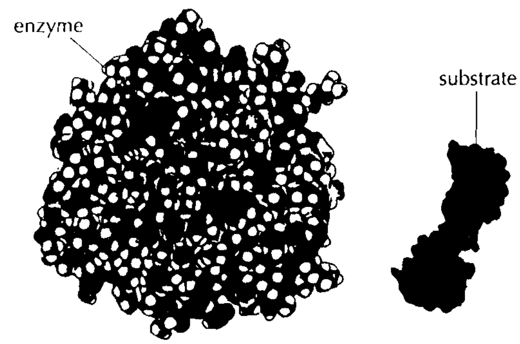
The active site of an enzyme has a very intricate and precise shape. It also has distinctive chemical properties. Active sites match the shape and chemical properties of their substrates. Molecules of substrate fit the active site and are chemically attracted to it (right). Other molecules either do not fit or are not chemically attracted. They do not therefore bind to the active site. This is how enzymes are substrate-specific. The way in which the enzyme and substrate fit together is similar to the way in which a key fits a lock. The enzyme is like the lock and the substrate is like the key that fits it.

EFFECT OF SUBSTRATE CONCENTRATION ON ENZYME ACTIVITY

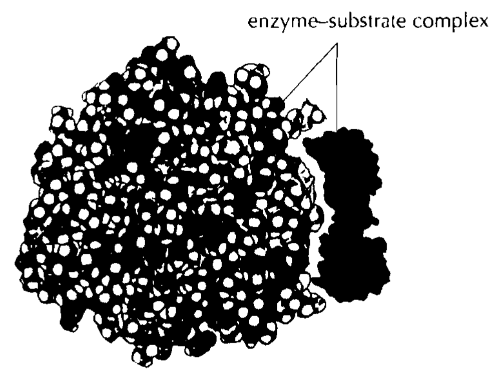
At low substrate concentrations, enzyme activity is directly proportional to substrate concentration. This is because random collisions between substrate and active site happen more frequently with higher substrate concentrations.



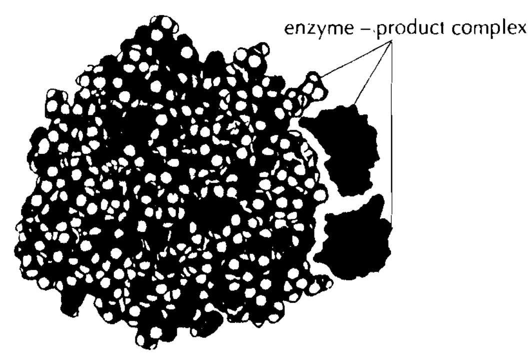
Stages in enzyme catalysis



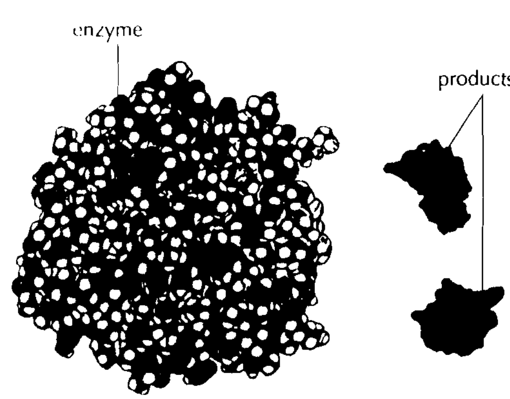
Substrate molecules are in continual random motion. If one collides with the active site it can bind to it.



The substrate fits the active site. If other molecules collide with the active site they do not fit and fail to bind.



The active site catalyses a chemical reaction. The substrates are turned into products.



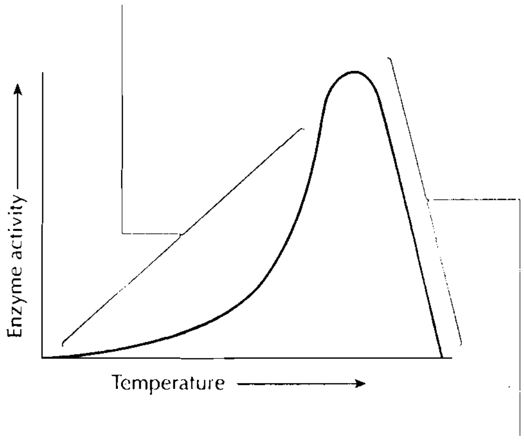
The products detach from the active site, leaving it free for more substrate to bind.

FACTORS AFFECTING ENZYME ACTIVITY

Wherever enzymes are used, it is important that they have the conditions that they need to work effectively. Temperature, pH and substrate concentration all affect the rate at which enzymes catalyse chemical reactions. The figures on page 14 and below show the relationships between enzyme activity and substrate concentration, temperature and pH.

EFFECT OF TEMPERATURE

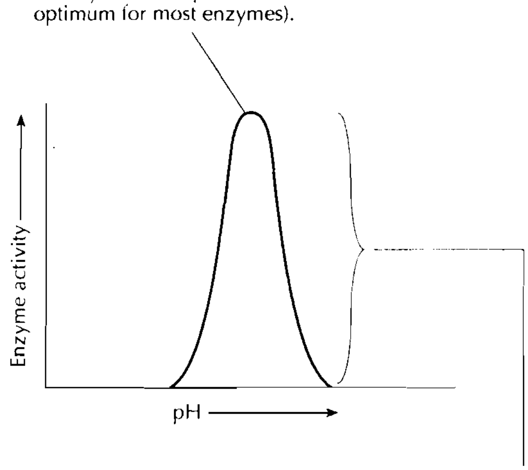
Enzyme activity increases as temperature increases, often doubling with every 10 °C rise. This is because collisions between substrate and active site happen more frequently at higher temperatures due to faster molecular motion.



At high temperatures enzymes are denatured and stop working. This is because heat causes vibrations inside enzymes which break bonds needed to maintain the structure of the enzyme.

EFFECT OF pH

Optimum pH at which enzyme activity is fastest (pH 7 is optimum for most enzymes).



As pH increases or decreases from the optimum, enzyme activity is reduced. Both acids and alkalis can denature enzymes.

USING ENZYMES IN BIOTECHNOLOGY

Biotechnology is the use of organisms or parts of organisms to produce things or to carry out useful processes. There are many ways in which enzymes, obtained from living organisms, can be used in biotechnology. Two examples are described below.

The use of pectinase in fruit juice production

Pectin is a complex polysaccharide, found in the cell walls of plants. Pectinase is an enzyme that breaks down pectin by hydrolysis reactions.

Source of enzyme

Pectinase is obtained by artificially culturing a fungus (*Aspergillus niger*). The fungus grows naturally on fruits, where it uses pectinase to soften the cell walls of the fruit so that it can grow through it.

Use of pectinase in biotechnology

Fruit juices are produced by crushing ripe fruits to separate liquid juice from solid pulp. When ripe fruits are crushed, pectin forms links between the cell wall and the cytoplasm of the fruit cells, making the juice viscous and more difficult to separate from the pulp. Pectinase is added during crushing of fruit to break down the pectin.

Advantages

Pectinase makes juice more fluid and easy to separate from the pulp. It therefore increases the volume of juice that is obtained. It also makes the juice less cloudy by helping solids suspended in the juice to settle and be separated from the fluid.

The use of protease in biological washing powder

Protease enzymes break down proteins into soluble peptides and amino acids. Laundry washing powders that contain protease are called biological washing powders.

Source of enzyme

Protease is obtained by culturing a bacterium, *Bacillus licheniformis*, that is adapted to grow in alkaline conditions. This bacterium feeds on proteins in its habitat by secreting protease. The protease has a high pH optimum of between 9 and 10.

Use of protease in biotechnology

Detergents in laundry washing powders remove fats and oils during the washing of clothes, but much of the dirt on clothing is made of protein, not lipids. If protease is added to the washing powder, this protein is digested during the wash. The high pH optimum of the protease allows it to remain active, despite the high pH caused by alkalis in the washing powder.

Advantages

If protease is not used, protein stains on clothes can only removed by using a very high temperature wash. Protease allows much lower temperatures to be used, with lower energy use and less risk of shrinkage of garments or loss of coloured dyes.

Cell respiration and energy

ENERGY AND CELLS

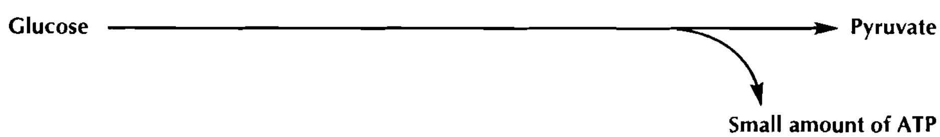
All living cells need a continual supply of energy. This energy is used for a wide range of processes including active transport and protein synthesis. Most of these processes require energy in the form of ATP (adenosine triphosphate). ATP is a chemical substance that can diffuse to any part of the cell and release energy.

Every cell produces its own ATP, by a process called **cell respiration**. In cell respiration, organic compounds such as glucose or fat are carefully broken down. Energy from them is used to make ATP. Cell respiration is defined as *controlled release of energy, in the form of ATP, from organic compounds in cells.*

Cell respiration can be aerobic or anaerobic. Aerobic cell respiration involves the use of oxygen and anaerobic cell respiration does not.

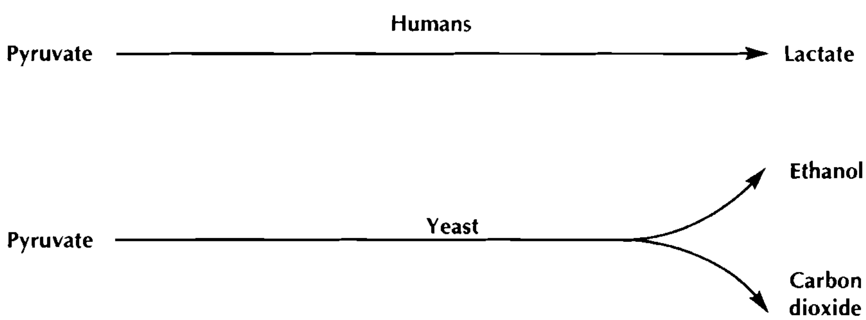
THE USE OF GLUCOSE IN RESPIRATION

Glucose is often the organic compound that is used in cell respiration. Chemical reactions in the cytoplasm break down glucose into a simpler organic compound called pyruvate. In these reactions a small amount of ATP is made using energy released from glucose.



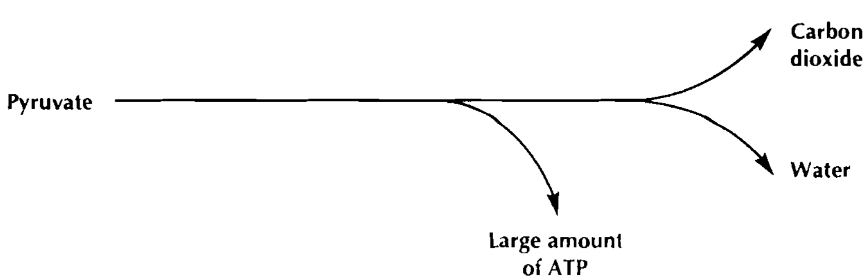
ANAEROBIC CELL RESPIRATION

If no oxygen is available, the pyruvate remains in the cytoplasm and is converted into a waste product that can be removed from the cell. No ATP is produced in these reactions. In humans the waste product is lactate (lactic acid). In yeast the products are ethanol and carbon dioxide.



AEROBIC CELL RESPIRATION

If oxygen is available, the pyruvate is absorbed by the mitochondrion. Inside the mitochondrion the pyruvate is broken down into carbon dioxide and water. A large amount of ATP is produced as a result of these reactions. Aerobic cell respiration therefore has a much higher yield of ATP per gram of glucose than anaerobic cell respiration.



INTRODUCING PHOTOSYNTHESIS

Photosynthesis is the process used by plants and some other organisms to produce all their own organic substances (food), using only light energy and simple inorganic substances. It involves many stages and some complex chemical reactions, but it can be outlined in a series of statements.

- Photosynthesis involves an energy conversion. Light energy, usually sunlight, is converted into chemical energy.
- Sunlight is called white light, but it is actually made up of a wide range of wavelengths, including red, green and blue.
- Some substances called pigments can absorb light. The main pigment used to absorb light in photosynthesis is chlorophyll.
- The structure of chlorophyll allows it to absorb some colours or wavelengths of light better than others. Red and blue light are absorbed more than green.
- The green light that chlorophyll cannot absorb is reflected. This makes chlorophyll and therefore chloroplasts and plant leaves look green.
- Some of the energy absorbed by chlorophyll is used to produce ATP.
- Some of the energy absorbed by chlorophyll is used to split water molecules. This is called photolysis of water.
- Photolysis of water results in the formation of oxygen and hydrogen. The oxygen is released as a waste product.
- Carbon dioxide is absorbed for use in photosynthesis. The carbon from it is used to make a wide range of organic substances. The conversion of carbon in a gas to carbon in solid compounds is called carbon fixation.
- Carbon fixation involves the use of hydrogen from photolysis and energy from ATP.

MEASURING RATES OF PHOTOSYNTHESIS

Photosynthesis involves the production of oxygen, the uptake of carbon dioxide and an increase in biomass. Any of these can be used as a measure of the rate of photosynthesis.

Production of oxygen

Aquatic plants (e.g. *Myriophyllum*) release bubbles of oxygen when they carry out photosynthesis. If these bubbles are collected, their volume can be measured.

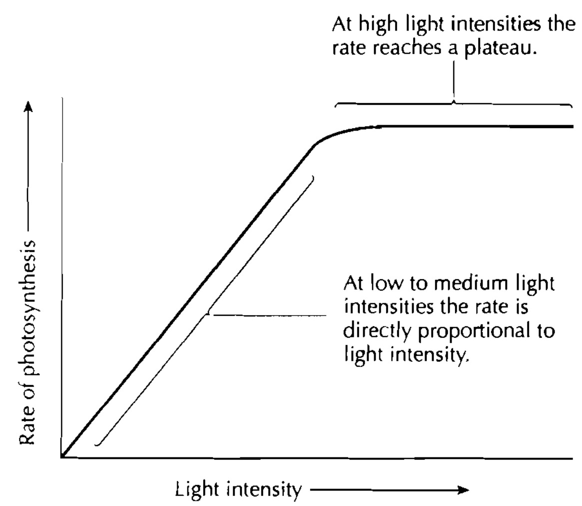
Uptake of carbon dioxide

Leaves take in CO_2 from the air or water around them, but this is difficult to measure directly. If CO_2 is absorbed from water, the pH of the water rises. This can be monitored with pH indicators or with pH meters.

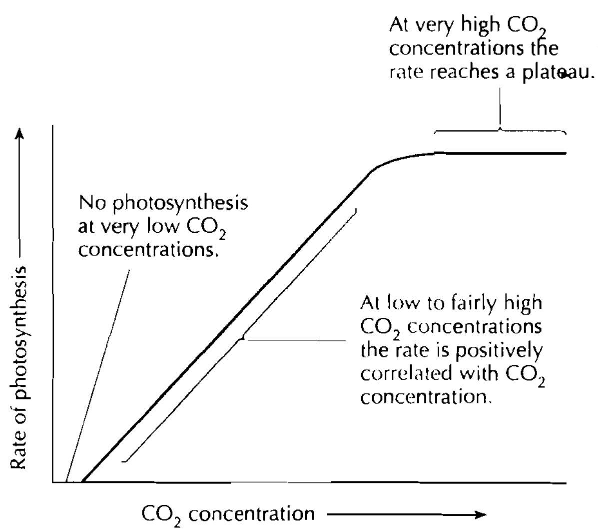
Increases in biomass

If batches of plants are harvested at a series of times and the biomass of the batches is determined, the rate of increase in biomass gives an indirect measure of the rate of photosynthesis in the plants.

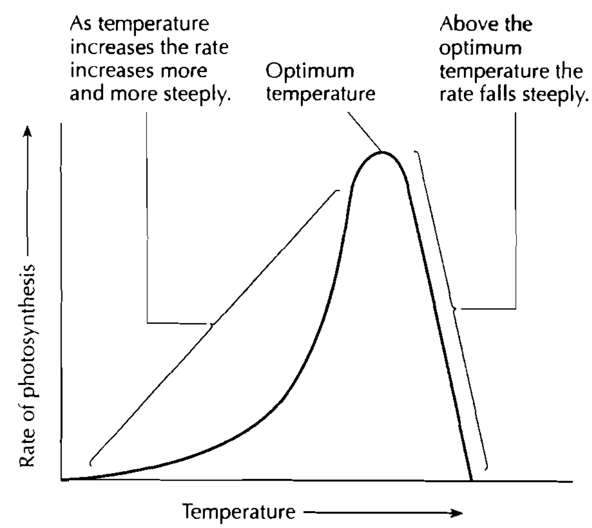
Effect of light intensity on photosynthesis



Effect of CO_2 concentration on photosynthesis



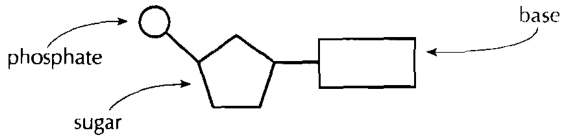
Effect of temperature on photosynthesis



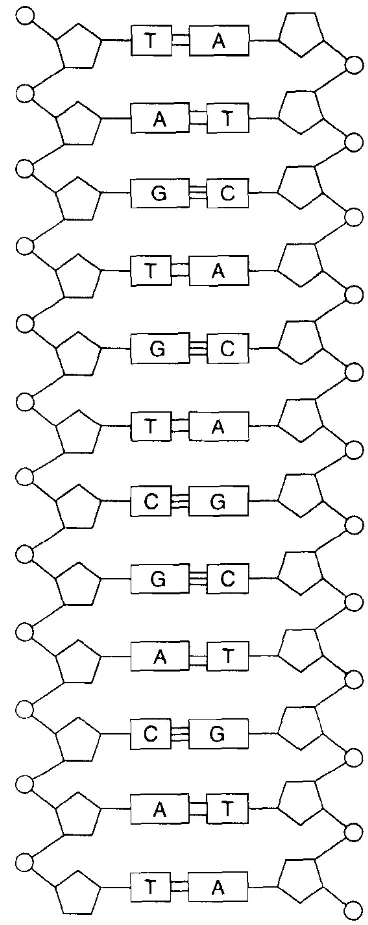
Introducing DNA

THE NUCLEOTIDE SUBUNITS OF DNA

Although DNA is the genetic material of living organisms and is therefore of immense importance, it is made of relatively simple subunits. These are called **nucleotides**. Each nucleotide consists of three parts – a sugar (called deoxyribose), a phosphate group and a base. In diagrams of DNA structure these are usually shown as pentagons, circles and rectangles, respectively. The figure (below) shows how the sugar, the phosphate and the base are linked up in a nucleotide.



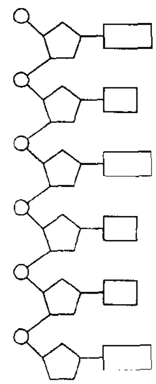
DNA nucleotides do not all have the same base. Four different bases are found – adenine, cytosine, guanine and thymine. These are usually simply referred to as A, C, G and T.



BUILDING DNA MOLECULES

Two DNA nucleotides can be linked together by a covalent bond between the sugar of one nucleotide and the phosphate group of the other. More nucleotides can be added in a similar way to form a strand of nucleotides.

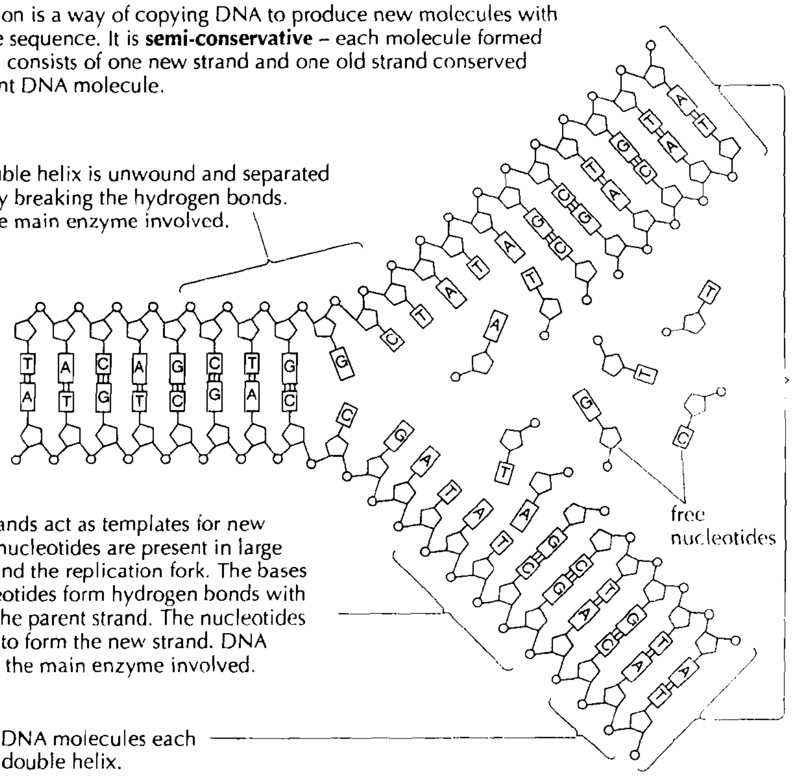
DNA molecules consist of two strands of nucleotides wound together into a double helix. Hydrogen bonds link the two strands together. These form between the bases of the two strands. However, adenine only forms hydrogen bonds with thymine and cytosine only forms hydrogen bonds with guanine. This is called **complementary base pairing**.



DNA REPLICATION

DNA replication is a way of copying DNA to produce new molecules with the same base sequence. It is **semi-conservative** – each molecule formed by replication consists of one new strand and one old strand conserved from the parent DNA molecule.

Stage 1
The DNA double helix is unwound and separated into strands by breaking the hydrogen bonds. Helicase is the main enzyme involved.



Stage 2
The single strands act as templates for new strands. Free nucleotides are present in large numbers around the replication fork. The bases of these nucleotides form hydrogen bonds with the bases on the parent strand. The nucleotides are linked up to form the new strand. DNA polymerase is the main enzyme involved.

Stage 3
The daughter DNA molecules each rewind into a double helix.

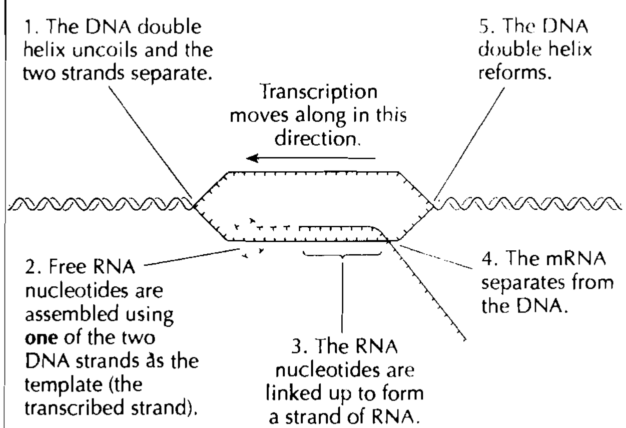
The two daughter DNA molecules are identical in base sequence to each other and to the parent molecule, because of complementary base pairing (A pairs with T and C with G).
Each of the new strands is **complementary** to the template on which it was made and **identical** to the other template.

THE RELATIONSHIP BETWEEN GENES AND POLYPEPTIDES

Polypeptides are long chains of amino acids. There are 20 different amino acids that can form part of a polypeptide. To make one particular polypeptide, amino acids must be linked up in a precise sequence. Genes store the information needed for making polypeptides. The information is stored in a coded form. The sequence of bases in a gene codes for the sequence of amino acids in a polypeptide. The information in the gene is decoded during the making of the polypeptide. There are two stages in this process: **transcription** and **translation**.

TRANSCRIPTION

Genes made of DNA are too valuable to a cell to be used directly when polypeptides are being made. Instead a copy of the gene is made. The copy is RNA, not DNA. It carries the information needed for making a polypeptide out into the cytoplasm so is called messenger RNA (mRNA). The copying of the base sequence of a gene by making an RNA molecule is called **transcription.**



Stages 1, 2 and 3 are all carried out by the enzyme RNA polymerase.
In transcription, the same rules of complementary base pairing are followed as in replication, except that uracil pairs with adenine, as RNA does not contain thymine. The RNA molecule produced therefore has a base sequence that is complementary to the transcribed strand and identical to the other DNA strand except that U replaces T.

THE GENETIC CODE

- The genetic code is a **triplet code** – three bases code for one amino acid. A group of three bases is called a **codon**. There are 64 different codons.
- The genetic code is **degenerate**. This means that it is possible for two or more codons (triplets of bases) to code for the same amino acid.
- The genetic code is **universal**. This means that all living organisms use the same code. Viruses also use this code.

DIFFERENCES BETWEEN DNA AND RNA

DNA and RNA both consist of chains of nucleotides, each composed of a sugar, a base and a phosphate. There are three differences between them.

Feature	DNA	RNA
Number of strands in the molecule	Two strands forming a double helix	One strand only
Type of sugar in each nucleotide	Deoxyribose	Ribose
Types of bases contained	A, C, G and T	A, C, G and U Uracil replaces thymine

TRANSLATION

Translation is carried out by ribosomes, using mRNA and tRNA.