OXFORD IB DIPLOMA PROGRAMME

IN COOPERATION WITH ib

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BIOLOGY

COURSE COMPANION

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OXFORD

2 MOLECULAR BIOLOGY

Introduction

Water is the medium for life. Living organisms control their composition by a complex web of chemical reactions that occur within this medium. Photosynthesis uses the energy in sunlight to supply the chemical energy needed for life and cell respiration releases this energy when it is needed. Compounds of carbon, hydrogen and oxygen are used to supply and store energy. Many proteins act as enzymes to control the metabolism of the cell and others have a diverse range of biological functions. Genetic information is stored in DNA and can be accurately copied and translated to make the proteins needed by the cell.

2.1 Molecules to metabolism

Understanding

- → Molecular biology explains living processes in terms of the chemical substances involved.
- → Carbon atoms can form four bonds allowing a diversity of compounds to exist.
- → Life is based on carbon compounds including carbohydrates, lipids, proteins and nucleic acids.
- → Metabolism is the web of all the enzyme catalysed reactions in a cell or organism.
- → Anabolism is the synthesis of complex molecules from simpler molecules including the formation of macromolecules from monomers by condensation reactions.
- → Catabolism is the breakdown of complex molecules into simpler molecules including the hydrolysis of macromolecules into monomers.

Applications

- → Urea as an example of a compound that is produced by living organisms but can also be artificially synthesized.

Skills

- → Drawing molecular diagrams of glucose, ribose, a saturated fatty acid and a generalized amino acid.
- → Identification of biochemicals such as carbohydrate, lipid or protein from molecular diagrams.

Nature of science

- → Falsification of theories: the artificial synthesis of urea helped to falsify vitalism.

▲ Figure 1 A molecular biologist at work in the laboratory

Molecular biology

Molecular biology explains living processes in terms of the chemical substances involved.

The discovery of the structure of DNA in 1953 started a revolution in biology that has transformed our understanding of living organisms. It raised the possibility of explaining biological processes from the structure of molecules and how they interact with each other. The structures are diverse and the interactions are very complex, so although molecular biology is more than 50 years old, it is still a relatively young science.

Many molecules are important in living organisms including one as apparently simple as water, but the most varied and complex molecules are nucleic acids and proteins. Nucleic acids comprise DNA and RNA. They are the chemicals used to make genes. Proteins are astonishingly varied in structure and carry out a huge range of tasks within the cell, including controlling chemical reactions of the cell by acting as enzymes. The relationship between genes and proteins is at the heart of molecular biology.

The approach of the molecular biologist is reductionist as it involves considering the various biochemical processes of a living organism and breaking down into its component parts. This approach has been immensely productive in biology and has given us insights into whole organisms that we would not otherwise have. Some biologists argue that the reductionist approach of the molecular biologist cannot explain everything though, and that when component parts are combined there are emergent properties that cannot be studied without looking at the whole system together.

Synthesis of urea

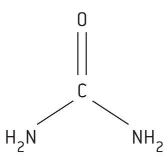
Urea as an example of a compound that is produced by living organisms but can also be artificially synthesized.

Urea is a nitrogen-containing compound with a relatively simple molecular structure (figure 2). It is a component of urine and this was where it was first discovered. It is produced when there is an excess of amino acids in the body, as a means of excreting the nitrogen from the amino acids. A cycle of reactions, catalysed by enzymes, is used to produce it (figure 3). This happens in the liver. Urea is then transported by the blood stream to the kidneys where it is filtered out and passes out of the body in the urine.

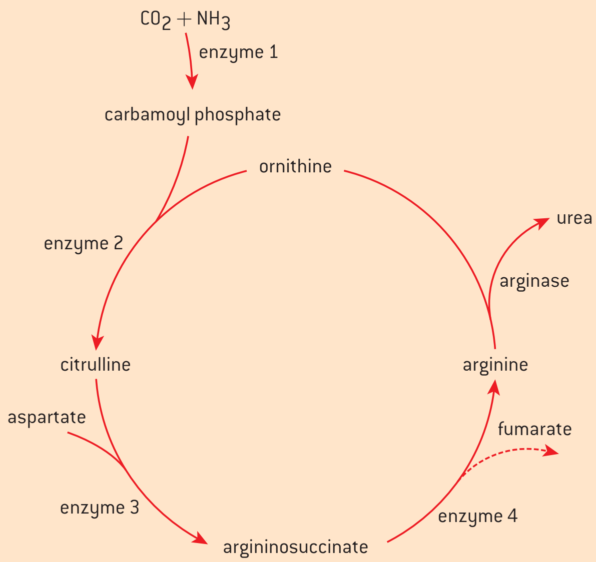
Urea can also be synthesized artificially. The chemical reactions used are different from those in the liver and enzymes are not involved, but the urea that is produced is identical.

ammonia + carbon dioxide → ammonium carbamate
→ urea + water

About 100 million tonnes are produced annually. Most of this is used as a nitrogen fertilizer on crops.



▲ Figure 2 Molecular diagram of urea



▲ Figure 3 The cycle of reactions occurring in liver cells that is used to synthesize urea

Urea and the falsification of vitalism

Falsification of theories: the artificial synthesis of urea helped to falsify vitalism.

Urea was discovered in urine in the 1720s and was assumed to be a product of the kidneys. At that time it was widely believed that organic compounds in plants and animals could only be made with the help of a "vital principle". This was part of vitalism – the theory that the origin and phenomena of life are due to a vital principle, which is different from purely chemical or physical forces. Aristotle used the word psyche for the vital principle – a Greek word meaning breath, life or soul.

In 1828 the German chemist Friedrich Wöhler synthesized urea artificially using silver isocyanate and ammonium chloride. This was the first organic compound to be synthesized artificially. It was a very significant step, because no vital principle had been involved in the synthesis. Wöhler wrote this excitedly to the Swedish chemist Jöns Jacob Berzelius:

> *In a manner of speaking, I can no longer hold my chemical water. I must tell you that I can make urea without the kidneys of any animal, be it man or dog.*

An obvious deduction was that if urea had been synthesized without a vital principle, other organic compounds could be as well. Wöhler's achievement was evidence against the theory of vitalism. It helped to falsify the theory, but it did not cause all biologists to abandon vitalism immediately. It usually requires several pieces of evidence against a theory for most biologists to accept that it has been falsified and sometimes controversies over a theory continue for decades.

Although biologists now accept that processes in living organisms are governed by the same chemical and physical forces as in non-living matter, there remain some organic compounds that have not been synthesized artificially. It is still impossible to make complex proteins such as hemoglobin, for example, without using ribosomes and other components of cells. Four years after his synthesis of urea, Wöhler wrote this to Berzelius:

> *Organic chemistry nowadays almost drives one mad. To me it appears like a primeval tropical forest full of the most remarkable things; a dreadful endless jungle into which one dare not enter, for there seems no way out.*

Activity

Carbon compounds

Can you find an example of a biological molecule in which a carbon atom is bonded to atoms of three other elements or even four other elements?

Titin is a giant protein that acts as a molecular spring in muscle. The backbone of the titin molecule is a chain of 100,000 atoms, linked by single covalent bonds.

Can you find an example of a molecule in your body with a chain of over 1,000,000,000 atoms?

Carbon compounds

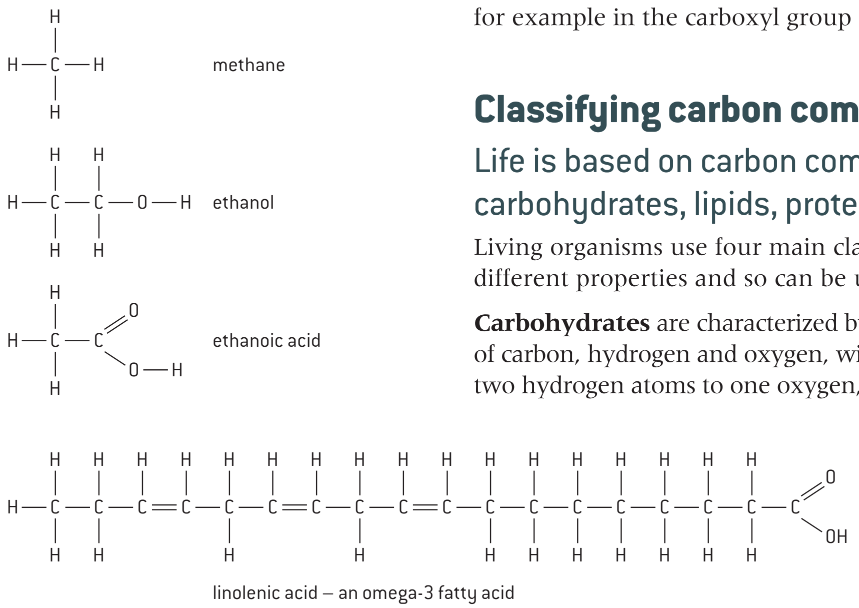
Carbon atoms can form four bonds allowing a diversity of compounds to exist.

Carbon is only the 15th most abundant element on Earth, but it can be used to make a huge range of different molecules. This has given living organisms almost limitless possibilities for the chemical composition and activities of their cells. The diversity of carbon compounds is explained by the properties of carbon.

Carbon atoms form covalent bonds with other atoms. A covalent bond is formed when two adjacent atoms share a pair of electrons, with one electron contributed by each atom. Covalent bonds are the strongest type of bond between atoms so stable molecules based on carbon can be produced.

Each carbon atom can form up to four covalent bonds – more than most other atoms, so molecules containing carbon can have complex structures. The bonds can be with other carbon atoms to make rings or chains of any length. Fatty acids contain chains of up to 20 carbon atoms for example. The bonds can also be with other elements such as hydrogen, oxygen, nitrogen or phosphorus.

Carbon atoms can bond with just one other element, such as hydrogen in methane, or they can bond to more than one other element as in ethanol (alcohol found in beer and wine). The four bonds can all be single covalent bonds or there can be two single and one double covalent bond, for example in the carboxyl group of ethanoic acid (the acid in vinegar).



▲ Figure 4 Some common naturally-occurring carbon compounds

Classifying carbon compounds

Life is based on carbon compounds including carbohydrates, lipids, proteins and nucleic acids.

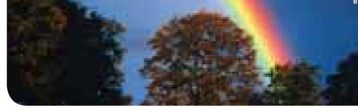
Living organisms use four main classes of carbon compound. They have different properties and so can be used for different purposes.

Carbohydrates are characterized by their composition. They are composed of carbon, hydrogen and oxygen, with hydrogen and oxygen in the ratio of two hydrogen atoms to one oxygen, hence the name carbo*hydrate*.

Lipids are a broad class of molecules that are insoluble in water, including steroids, waxes, fatty acids and triglycerides. In common language, triglycerides are fats if they are solid at room temperature or oils if they are liquid at room temperature.

Proteins are composed of one or more chains of amino acids. All of the amino acids in these chains contain the elements carbon, hydrogen, oxygen and nitrogen, but two of the twenty amino acids also contain sulphur.

Nucleic acids are chains of subunits called nucleotides, which contain carbon, hydrogen, oxygen, nitrogen and phosphorus. There are two types of nucleic acid: ribonucleic acid (RNA) and deoxyribonucleic acid (DNA).



Drawing molecules

Drawing molecular diagrams of glucose, ribose, a saturated fatty acid and a generalized amino acid.

There is no need to memorize the structure of many different molecules but a biologist should be able to draw diagrams of a few of the most important molecules.

Each atom in a molecule is represented using the symbol of the element. For example a carbon atom is represented with C and an oxygen atom with O. Single covalent bonds are shown with a line and double bonds with two lines.

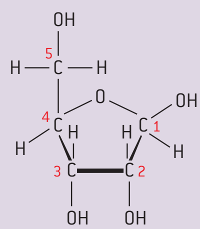
Some chemical groups are shown with the atoms together and bonds not indicated. Table 1 gives examples.

Name of group	Full structure	Simplified notation
hydroxyl	—O—H	–OH
amine	—N(—H)(—H)	$-NH_2$
carboxyl	—C(=O)—O—H	–COOH
methyl	—C(—H)(—H)—H	$-CH_3$

▲ Table 1

Ribose

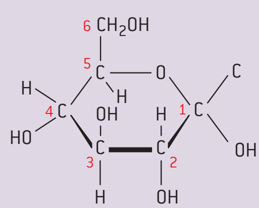
- The formula for ribose is $C_5H_{10}O_5$
- The molecule is a five-membered ring with a side chain.
- Four carbon atoms are in the ring and one forms the side chain.
- The carbon atoms can be numbered starting with number 1 on the right.
- The hydroxyl groups (OH) on carbon atoms 1, 2 and 3 point up, down and down respectively.



▲ Ribose

Glucose

- The formula for glucose is $C_6H_{12}O_6$
- The molecule is a six-membered ring with a side chain.
- Five carbon atoms are in the ring and one forms the side chain.
- The carbon atoms can be numbered starting with number 1 on the right.
- The hydroxyl groups (OH) on carbon atoms 1, 2, 3 and 4 point down, down, up and down respectively, although in a form of glucose used by plants to make cellulose the hydroxyl group on carbon atom 1 points upwards.



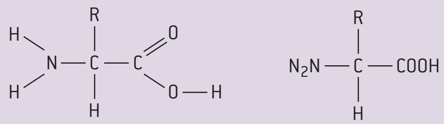
▲ Glucose

Saturated fatty acids

- The carbon atoms form an unbranched chain.
- In saturated fatty acids they are bonded to each other by single bonds.
- The number of carbon atoms is most commonly between 14 and 20.
- At one end of the chain the carbon atom is part of a carboxyl group
- At the other end the carbon atom is bonded to three hydrogen atoms.
- All other carbon atoms are bonded to two hydrogen atoms.

Amino acids

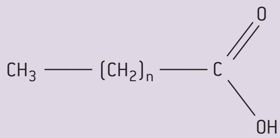
- A carbon atom in the centre of the molecule is bonded to four different things:
  - an amine group, hence the term amino acid;
  - a carboxyl group which makes the molecule an acid;
  - a hydrogen atom;
  - the R group, which is the variable part of amino acids.



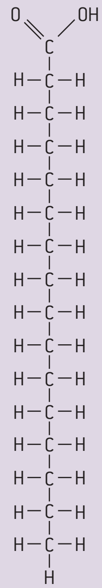
full molecular diagram

simplified molecular diagram

▲ Molecular diagrams of an amino acid



▲ Simplified molecular diagram of a saturated fatty acid



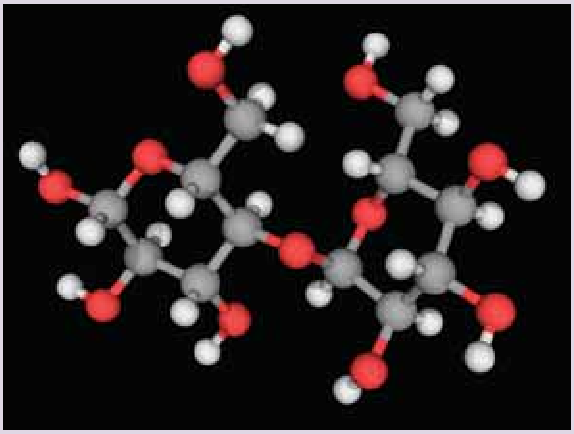
▲ Full molecular diagram of a saturated fatty acid

Identifying molecules

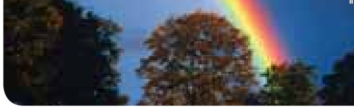
Identification of biochemicals as carbohydrate, lipid or protein from molecular diagrams.

The molecules of carbohydrates, lipids and proteins are so different from each other that it is usually quite easy to recognize them.

- Proteins contain C, H, O and N whereas carbohydrates and lipids contain C, H and O but not N.
- Many proteins contain sulphur (S) but carbohydrates and lipids do not.
- Carbohydrates contain hydrogen and oxygen atoms in a ratio of 2:1, for example glucose is $C_6H_{12}O_6$ and sucrose (the sugar commonly used in baking) is $C_{12}H_{22}O_{11}$
- Lipids contain relatively less oxygen than carbohydrates, for example oleic acid (an unsaturated fatty acid) is $C_{18}H_{34}O_2$ and the steroid testosterone is $C_{19}H_{28}O_2$



▲ Figure 5 A commonly-occurring biological molecule



Metabolism

Metabolism is the web of all the enzyme catalysed reactions in a cell or organism.

All living organisms carry out large numbers of different chemical reactions. These reactions are catalysed by enzymes. Most of them happen in the cytoplasm of cells but some are extracellular, such as the reactions used to digest food in the small intestine. Metabolism is the sum of all reactions that occur in an organism.

Metabolism consists of pathways by which one type of molecule is transformed into another, in a series of small steps. These pathways are mostly chains of reactions but there are also some cycles. An example is shown in figure 3.

Even in relatively simple prokaryote cells, metabolism consists of over 1,000 different reactions. Global maps showing all reactions are very complex. They are available on the internet, for example in the Kyoto Encyclopedia of Genes and Genomes.

Anabolism

Anabolism is the synthesis of complex molecules from simpler molecules including the formation of macromolecules from monomers by condensation reactions.

Metabolism is often divided into two parts, anabolism and catabolism. Anabolism is reactions that build up larger molecules from smaller ones. An easy way to remember this is by recalling that anabolic steroids are hormones that promote body building. Anabolic reactions require energy, which is usually supplied in the form of ATP.

Anabolism includes these processes:

- Protein synthesis using ribosomes.
- DNA synthesis during replication.
- Photosynthesis, including production of glucose from carbon dioxide and water.
- Synthesis of complex carbohydrates including starch, cellulose and glycogen.

Catabolism

Catabolism is the breakdown of complex molecules into simpler molecules including the hydrolysis of macromolecules into monomers.

Catabolism is the part of metabolism in which larger molecules are broken down into smaller ones. Catabolic reactions release energy and in some cases this energy is captured in the form of ATP, which can then be used in the cell. Catabolism includes these processes:

- Digestion of food in the mouth, stomach and small intestine.
- Cell respiration in which glucose or lipids are oxidized to carbon dioxide and water.
- Digestion of complex carbon compounds in dead organic matter by decomposers.

2.2 Water

Understanding

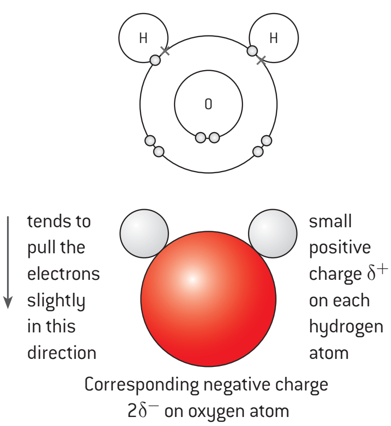
- Water molecules are polar and hydrogen bonds form between them.
- Hydrogen bonding and dipolarity explain the adhesive, cohesive, thermal and solvent properties of water.
- Substances can be hydrophilic or hydrophobic.

Nature of science

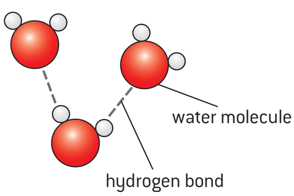
- Use theories to explain natural phenomena: the theory that hydrogen bonds form between water molecules explains water's properties.

Applications

- Comparison of the thermal properties of water with those of methane.
- Use of water as a coolant in sweat.
- Methods of transport of glucose, amino acids, cholesterol, fats, oxygen and sodium chloride in blood in relation to their solubility in water.



▲ Figure 1 Water molecules



▲ Figure 2 The dotted line indicates the presence of an intermolecular force between the molecules. This is called a hydrogen bond

Hydrogen bonding in water

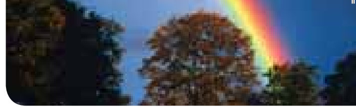
Water molecules are polar and hydrogen bonds form between them.

A water molecule is formed by covalent bonds between an oxygen atom and two hydrogen atoms. The bond between hydrogen and oxygen involves unequal sharing of electrons – it is a polar covalent bond. This is because the nucleus of the oxygen atom is more attractive to electrons than the nuclei of the hydrogen atoms (figure 1).

Because of the unequal sharing of electrons in water molecules, the hydrogen atoms have a partial positive charge and oxygen has a partial negative charge. Because water molecules are bent rather than linear, the two hydrogen atoms are on the same side of the molecule and form one pole and the oxygen forms the opposite pole.

Positively charged particles (positive ions) and negatively charged particles (negative ions) attract each other and form an ionic bond. Water molecules only have partial charges, so the attraction is less but it is still enough to have significant effects. The attraction between water molecules is a "hydrogen bond". Strictly speaking it is an intermolecular force rather than a bond. A hydrogen bond is the force that forms when a hydrogen atom in one polar molecule is attracted to a slightly negative atom of another polar covalent molecule.

Although a hydrogen bond is a weak intermolecular force, water molecules are small, so there are many of them per unit volume of water and large numbers of hydrogen bonds (figure 2). Collectively they give water its unique properties and these properties are, in turn, of immense importance to living things.



Hydrogen bonds and the properties of water

Use theories to explain natural phenomena: the theory that hydrogen bonds form between water molecules explains water's properties.

There is strong experimental evidence for hydrogen bonds, but it remains a theory that they form between water molecules. Scientists cannot prove without doubt that they exist as they are not directly visible. However, hydrogen bonds are a very useful way of explaining the properties of water. They explain the cohesive, adhesive, thermal and solvent properties of water. It is these distinctive properties that make water so useful to living organisms.

It might seem unwise to base our understanding of the natural world on something that has not been proven to exist. However this is the way that science works – we can assume that a theory is correct if there is evidence for it, if it helps to predict behaviour, if it has not been falsified and if it helps to explain natural phenomena.

Properties of water

Hydrogen bonding and dipolarity explain the cohesive, adhesive, thermal and solvent properties of water.

Cohesive properties

Cohesion refers to the binding together of two molecules of the same type, for instance two water molecules.

Water molecules are cohesive – they cohere, which means they stick to each other, due to hydrogen bonding, described in the previous section. This property is useful for water transport in plants. Water is sucked through xylem vessels at low pressure. The method can only work if the water molecules are not separated by the suction forces. Due to hydrogen bonding this rarely happens and water can be pulled up to the top of the tallest trees – over a hundred metres.

Adhesive properties

Hydrogen bonds can form between water and other polar molecules, causing water to stick to them. This is called adhesion. This property is useful in leaves, where water adheres to cellulose molecules in cell walls. If water evaporates from the cell walls and is lost from the leaf via the network of air spaces, adhesive forces cause water to be drawn out of the nearest xylem vessel. This keeps the walls moist so they can absorb carbon dioxide needed for photosynthesis.

Thermal properties

Water has several thermal properties that are useful to living organisms:

- **High specific heat capacity.** Hydrogen bonds restrict the motion of water molecules and increases in the temperature of water require hydrogen bonds to be broken. Energy is needed to do this. As a result, the amount of energy needed to raise the temperature of water is relatively large. To cool down, water must lose relatively large amounts of energy. Water's temperature remains relatively stable in comparison to air or land, so it is a thermally stable habitat for aquatic organisms.
- **High latent heat of vaporization.** When a molecule evaporates it separates from other molecules in a liquid and becomes a vapour molecule. The heat needed to do this is called the latent heat of

vaporization. Evaporation therefore has a cooling effect. Considerable amounts of heat are needed to evaporate water, because hydrogen bonds have to be broken. This makes it a good evaporative coolant. Sweating is an example of the use of water as a coolant.

- **High boiling point.** The boiling point of a substance is the highest temperature that it can reach in a liquid state. For the same reasons that water has a high latent heat of vaporization, its boiling point is high. Water is therefore liquid over a broad range of temperatures – from 0 °C to 100 °C. This is the temperature range found in most habitats on Earth.

Solvent properties

Water has important solvent properties. The polar nature of the water molecule means that it forms shells around charged and polar molecules, preventing them from clumping together and keeping them in solution. Water forms hydrogen bonds with polar molecules. Its partially negative oxygen pole is attracted to positively charged ions and its partially positive hydrogen pole is attracted to negatively charged ions, so both dissolve. Cytoplasm is a complex mixture of dissolved substances in which the chemical reactions of metabolism occurs.

TOK

How do scientific explanations differ from pseudo-scientific explanations?

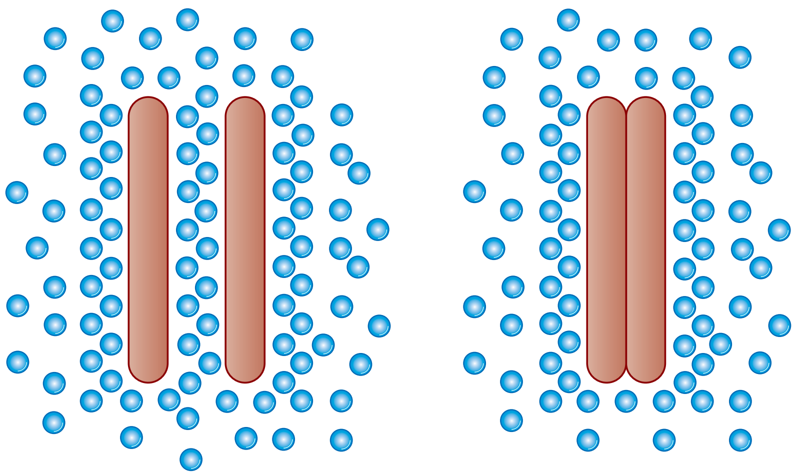
Homeopathy is a practice where remedies are prepared by dissolving things like charcoal, spider venom or deadly nightshade. This "mother tincture" of harmful substance is diluted again and again to the point where a sample from the solution is unlikely to contain a single molecule of the solute. It is this ultra-dilute solution that is claimed to have medicinal properties. The properties are referred to as the "memory of water". Despite the large number of practitioners of this practice, no homeopathic remedy has ever been shown to work in a large randomized placebo-controlled clinical trial.

Hydrophilic and hydrophobic

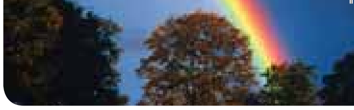
Substances can be hydrophilic or hydrophobic.

The literal meaning of the word hydrophilic is water-loving. It is used to describe substances that are chemically attracted to water. All substances that dissolve in water are hydrophilic, including polar molecules such as glucose, and particles with positive or negative charges such as sodium and chloride ions. Substances that water adheres to, cellulose for example, are also hydrophilic.

Some substances are insoluble in water although they dissolve in other solvents such as propanone (acetone). The term hydrophobic is used to describe them, though they are not actually water-fearing. Molecules are hydrophobic if they do not have negative or positive charges and are nonpolar. All lipids are hydrophobic, including fats and oils



▲ Figure 3 When two nonpolar molecules in water come into contact, weak interactions form between them and more hydrogen bonds form between water molecules



If a nonpolar molecule is surrounded by water molecules, hydrogen bonds form between the water molecules, but not between the nonpolar molecule and the water molecules. If two nonpolar molecules are surrounded by water molecules and random movements bring them together, they behave as though they are attracted to each other. There is a slight attraction between nonpolar molecules, but more significantly, if they are in contact with each other, more hydrogen bonds can form between water molecules. This is not because they are water-fearing: it is simply because water molecules are more attracted to each other than to the nonpolar molecules. As a result, nonpolar molecules tend to join together in water to form larger and larger groups. The forces that cause nonpolar molecules to join together into groups in water are known as hydrophobic interactions.

Comparing water and methane

Comparison of the thermal properties of water with those of methane.

The properties of water have already been described. Methane is a waste product of anaerobic respiration in certain prokaryotes that live in habitats where oxygen is lacking. Methanogenic prokaryotes live in swamps and other wetlands and in the guts of animals, including termites, cattle and sheep. They also live in waste dumps and are deliberately encouraged to produce methane in anaerobic digesters. Methane can be used as a fuel but if allowed to escape into the atmosphere it contributes to the greenhouse effect.

Water and methane are both small molecules with atoms linked by single covalent bonds. However water molecules are polar and can form hydrogen bonds, whereas methane molecules are nonpolar and do not form hydrogen bonds. As a result their physical properties are very different.

The data in table 1 shows some of the physical properties of methane and water. The density and specific heat capacity are given for methane and water in a liquid state. The data shows that water has a higher specific heat capacity, higher latent heat of vaporization, higher melting point and higher boiling point. Whereas methane is liquid over a range of only 22 °C, water is liquid over 100 °C.

Property	Methane	Water
Formula	CH_4	H_2O
Molecular mass	16	18
Density	0.46g per cm^3	1g per cm^3
Specific heat capacity	2.2 J per g per °C	4.2 J per g per °C
Latent heat of vaporization	760 J/g	2,257 J/g
Melting point	−182 °C	0 °C
Boiling point	−160 °C	100 °C

▲ Table 1 Comparing methane and water

▲ Figure 4 Bubbles of methane gas, produced by prokaryotes decomposing organic matter at the bottom of a pond have been trapped in ice when the pond froze

Cooling the body with sweat

Use of water as a coolant in sweat.

Sweat is secreted by glands in the skin. The sweat is carried along narrow ducts to the surface of the skin where it spreads out. The heat needed for the evaporation of water in sweat is taken from the tissues of the skin, reducing their temperature. Blood flowing through the skin is therefore cooled. This is an effective method of cooling the body because water has a high latent heat of vaporization. Solutes in the sweat, especially ions such as sodium, are left on the skin surface and can sometimes be detected by their salty taste.

Sweat secretion is controlled by the hypothalamus of the brain. It has receptors that monitor blood temperature and also receives sensory inputs from temperature receptors in the skin. If the body is overheated the hypothalamus stimulates the sweat glands to secrete up to two litres of sweat per hour. Usually no sweat is secreted if the body is below the target temperature, though when adrenalin is secreted we sweat even if we are already cold. This is because adrenalin is secreted when our brain anticipates a period of intense activity that will tend to cause the body to overheat.

There are methods of cooling other than sweating, though many of these also rely on heat loss due to evaporation of water. Panting in dogs and birds is an example. Transpiration is evaporative loss of water from plant leaves; it has a cooling effect which is useful in hot environments.

Transport in blood plasma

Methods of transport of glucose, amino acids, cholesterol, fats, oxygen and sodium chloride in blood in relation to their solubility in water.

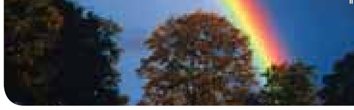
Blood transports a wide variety of substances, using several methods to avoid possible problems and ensure that each substance is carried in large enough quantities for the body's needs.

Sodium chloride is an ionic compound that is freely soluble in water, dissolving to form sodium ions (Na^+) and chloride ions (Cl^-), which are carried in blood plasma.

Amino acids have both negative and positive charges. Because of this they are soluble in water but their solubility varies depending on the R group, some of which are hydrophilic while others are hydrophobic. All amino acids are soluble enough to be carried dissolved in blood plasma.

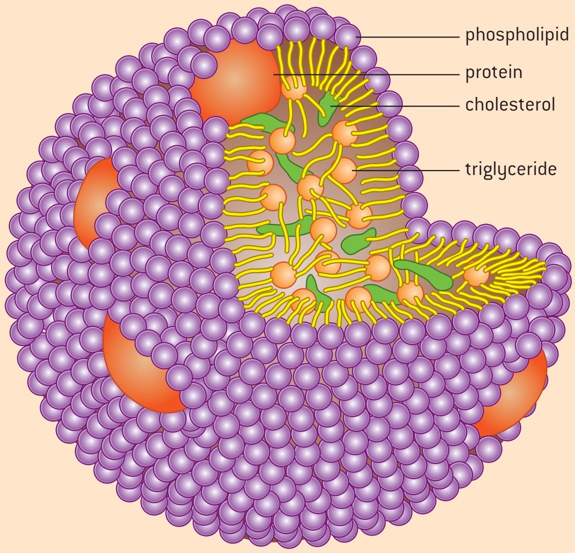
Glucose is a polar molecule. It is freely soluble in water and is carried dissolved in blood plasma.

Oxygen is a nonpolar molecule. Because of the small size of the molecule it dissolves in water but only sparingly and water becomes saturated with oxygen at relatively low concentrations. Also, as the temperature of water rises, the solubility of oxygen decreases, so blood plasma at 37 °C can hold much less dissolved oxygen than water at 20 °C or lower. The amount of oxygen that blood plasma can transport around the body is far too little to provide for aerobic cell respiration. This problem is overcome by the use of hemoglobin in red blood cells. Hemoglobin has binding sites for oxygen and greatly increases the capacity of the blood for oxygen transport.



Fats molecules are entirely nonpolar, are larger than oxygen and are insoluble in water. They are carried in blood inside lipoprotein complexes. These are groups of molecules with a single layer of phospholipid on the outside and fats inside. The hydrophilic phosphate heads of the phospholipids face outwards and are in contact with water in the blood plasma. The hydrophobic hydrocarbon tails face inwards and are in contact with the fats. There are also proteins in the phospholipid monolayer, hence the name lipoprotein.

Cholesterol molecules are hydrophobic, apart from a small hydrophilic region at one end. This is not enough to make cholesterol dissolve in water and instead it is transported with fats in lipoprotein complexes. The cholesterol molecules are positioned in the phospholipid monolayers, with the hydrophilic region facing outwards in the region with the phosphate heads of the phospholipids.



▲ Figure 5 Arrangement of molecules in a lipoprotein complex

2.3 Carbohydrates and lipids

Understanding

- Monosaccharide monomers are linked together by condensation reactions to form disaccharides and polysaccharide polymers.
- Fatty acids can be saturated, monounsaturated or polyunsaturated.
- Unsaturated fatty acids can be cis or trans isomers.
- Triglycerides are formed by condensation from three fatty acids and one glycerol.

Applications

- Structure and function of cellulose and starch in plants and glycogen in humans.
- Scientific evidence for health risks of trans-fats and saturated fats.
- Lipids are more suitable for long-term energy storage in humans than carbohydrates.
- Evaluation of evidence and the methods used to obtain evidence for health claims made about lipids.

Nature of science

- Evaluating claims: health claims made about lipids need to be assessed.

Skills

- Use of molecular visualization software to compare cellulose, starch and glycogen.
- Determination of body mass index by calculation or use of a nomogram.