Biochemical molecules

Unit 2

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2.1 Inorganic and organic molecules

By the end of this section you should be able to:

- Group biochemical molecules as inorganic and organic.
- Explain which chemical elements are found most often in biochemical molecules.
- Describe the properties of water.
- Explain the importance of water to living organisms.

Classification of inorganic and organic molecules

Biological molecules can be classified into two main types:

- inorganic molecules
- organic molecules

So, what is the difference between the two? Look at the formulae of the molecules in table 2.1.

***Table 2.1** Examples of inorganic and organic molecules*

Some inorganic molecules	Some organic molecules
Calcium carbonate $CaCo_3$	Glucose $C_6H_{12}O_6$
Carbon dioxide Co_2	Glycine (an amino acid) $C_2H_5NO_2$
Water H_2O	Linoleic acid (a fatty acid) $C_{18}H_{32}O_2$
Iron III oxide Fe_3O_4	Methane CH_4

Can you see that the organic molecules always contain both carbon and hydrogen? Inorganic molecules may contain one or the other (or neither), but not both.

Different organic molecules contain different combinations of carbon and hydrogen. They may also contain other chemical elements. Most biological organic molecules contain oxygen in addition to carbon and hydrogen and some also contain nitrogen.

Which chemical elements are found most frequently in living organisms?

Look at the periodic table below. This has all the chemical **elements** arranged in such a way that similar elements are placed in the same column – or group.

The elements that are highlighted are the ones that are used to build nearly all biological molecules. What do you notice about their position in the periodic table? Can you find out the importance of this?

Very few other elements are used to build biological molecules, although other elements do have specific functions in biological systems. Some elements that are important for humans are calcium (Ca) for bones, teeth and muscles, chlorine (Cl) for digesting food, fluorine (F) for tooth enamel and iron (Fe) to help blood carry oxygen around the body.

Activity 2.1: Grouping molecules

Make a table like table 2.1. Place the following substances in the correct columns.

$C_{12}H_{22}O_{11}$ (sucrose)

CO (carbon monoxide)

$C_5H_{10}O_4$ (deoxyribose)

$C_{18}H_{36}O_2$ (stearic acid – a fatty acid)

NO_2 (nitrogen dioxide)

H_2SO_4 (sulphuric acid)

$C_3H_6O_3$ (lactic acid)

$C_6H_{14}N_2O_2$ (lysine – an amino acid)

$C_{10}H_{16}N_5O_{13}P_3$ (ATP)

NaCl (sodium chloride)

KEY WORD

element *a substance that is made of only one kind of atom*

Figure 2.1 The periodic table

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh		118 Uuo
			58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
			90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

The most common elements in many cells are:

Hydrogen (H) 59%

Oxygen (O) 24%

Carbon (C) 11%

Nitrogen (N) 4%

Others (such as phosphorus (P) and sulphur (S)) 2% combined

(The percentages given are averages for many different cells.)

Activity 2.2: Library search

See if you can find out:

- the functions of sodium (Na), potassium (K) and phosphorus (P) in humans
- how chlorine helps us to digest our food

Atoms of elements can join together to form molecules. We call this forming a chemical **bond**. Sometimes two atoms of the same element join together to form a **molecule** of that element – for example, we breathe in oxygen molecules, each made of two oxygen atoms. This is why the formula for oxygen gas is O_2. Atoms of one element can join with atoms of another element to make a molecule of a **compound**. The atoms are always present in the same ratio in all the molecules of the compound.

Each atom can make a certain number of bonds with other atoms; this is called its **valency**. See table 2.2 below.

Table 2.2 The number of bonds (valencies) of atoms of the elements most commonly used to build biological molecules.

Element	Number of bonds formed (valency)
Carbon (C)	4
Hydrogen (H)	1
Oxygen (O)	2
Nitrogen (N)	3
Sulphur (S)	2 (sometimes 4 or 6)
Phosphorus (P)	5

So, whilst a carbon atom can bond with four hydrogen atoms, each hydrogen atom can only bond with one carbon. Because carbon

KEY WORDS

atoms *the smallest particles of a chemical element*

bond *the energy that joins atoms together to form a molecule*

molecule *a number of atoms bonded together*

compound *a substance made from molecules containing more than one kind of atom in a fixed ratio*

valency *the number of bonds an atom can make with other atoms* can bond with four other atoms, it can make large molecules with chains of carbon atoms. These are the organic molecules that are the basis of life.

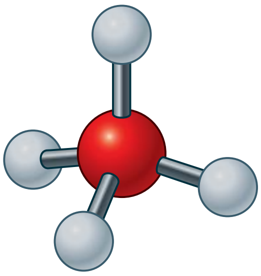


***Figure 2.2** The structure of methane. In a molecule of methane, a carbon atom bonds with four hydrogen atoms. Each hydrogen atom only bonds with one carbon atom.*

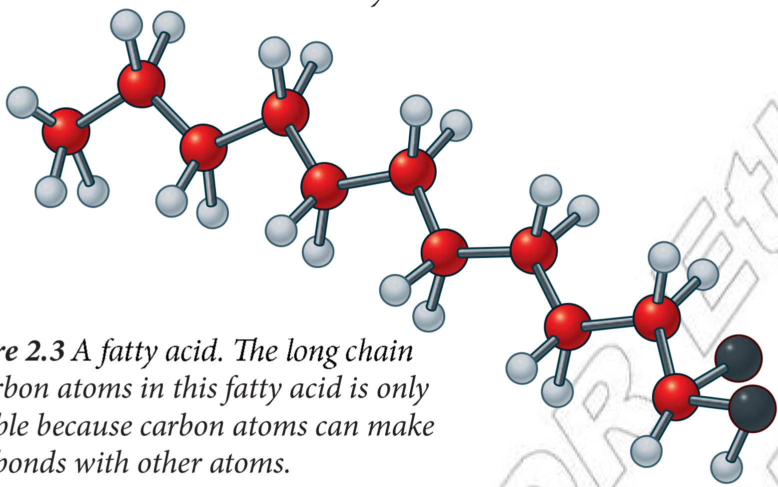


***Figure 2.3** A fatty acid. The long chain of carbon atoms in this fatty acid is only possible because carbon atoms can make four bonds with other atoms.*

Water, water everywhere?

Well, not quite everywhere. Water covers three-quarters of the planet and on the remaining one-quarter, which is land, water is often not very far away. It may be in streams, rivers, ponds, lakes or in huge underground aquifers.

And, of course, it is in all living things. Most cells are about 70% water and some are as high as 90%.

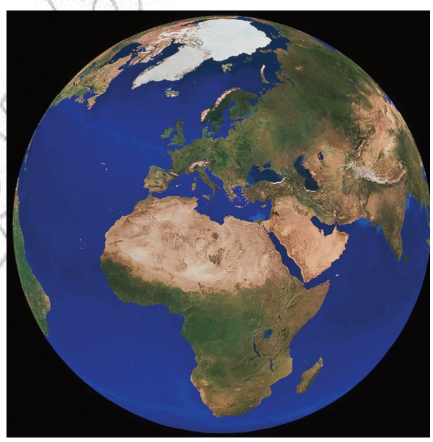


***Figure 2.4** Water covers three-quarters of the Earth's surface.*

> Water is the name of a substance. It is the only substance that exists in three states – solid, liquid and gas – at temperatures commonly found on Earth. Solid water is ice, liquid water we call water and gaseous water is steam.

What is water?

Just about everyone knows the chemical formula for water – H_2O. Water is made of molecules, each of which contains two hydrogen atoms bonded to one oxygen atom.

Notice that the molecule is not 'straight' it is bent into a 'v' shape. Also, the molecule forms what we call a 'dipole'. Part of the molecule has a slight negative charge (δ–) and other parts have a slight positive charge (δ+).

What is less well known is that in a mass of water (such as the water in a glass or the water in a pond), all the water molecules are interlinked! Besides the bonds joining the hydrogen atoms to the oxygen atom, there are very weak bonds – called **hydrogen bonds** – that join the oxygen in one water molecule (the slightly negative part) to the hydrogen in another water molecule (the slightly positive part).

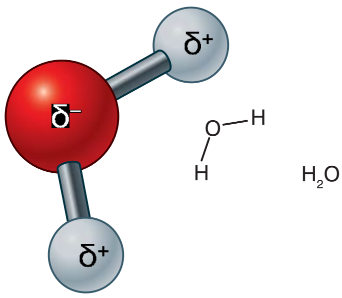


***Figure 2.5** A molecule of water*

KEY WORD

hydrogen bonds *bonds that join the oxygen in one water molecule to the hydrogen in another*

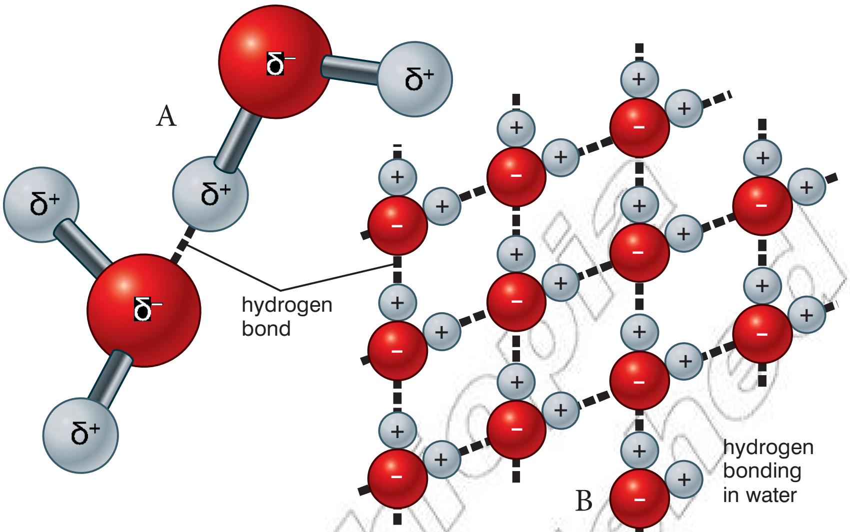


Figure 2.6 *Hydrogen bonding in water.*
A Two water molecules hydrogen-bonded together
B Many water molecules hydrogen-bonded together

The hydrogen bonds in water keep breaking and reforming as the molecules move around, but there is always some bonding between the molecules in a mass of water.

DID YOU KNOW?

Hydrogen bonds are found in many biological molecules. Hydrogen bonds hold the two strands of a DNA molecule together and help to hold protein molecules in shape.

Why is water so important to living things?

The very first cells on Earth evolved in water about 3.5 billion years ago. Water has many properties that make it important to living things in a number of ways, such as:

- a place to live
- a transport medium
- a reactant in many chemical reactions
- a place for other reactions to take place
- water is a vital chemical constituent of living cells

Water is a place to live in. Many organisms live in water. Plants and algae both live in water as do many different types of animals

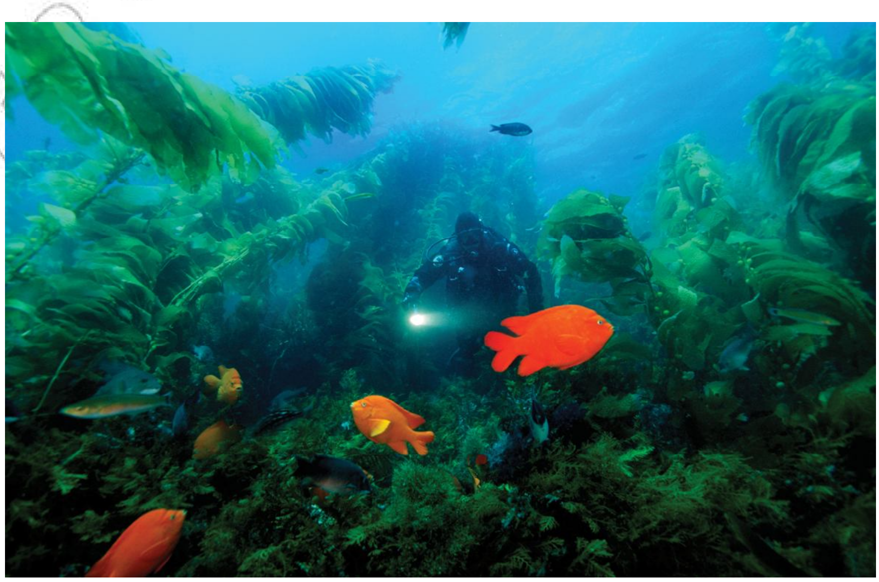


Figure 2.7 *Kelp are giant seaweeds that form 'kelp forests' in which many animals live.*

Water is transparent. This means that light can pass through the water and allow the plants and algae to photosynthesise. It also means that animals can see where they are going. However, water does not allow all light to pass through it and as we go deeper and deeper, less and less light penetrates.

Different wavelengths of light penetrate to different depths. Red and indigo wavelengths are soon lost. Blue and green wavelengths penetrate deeper than others.

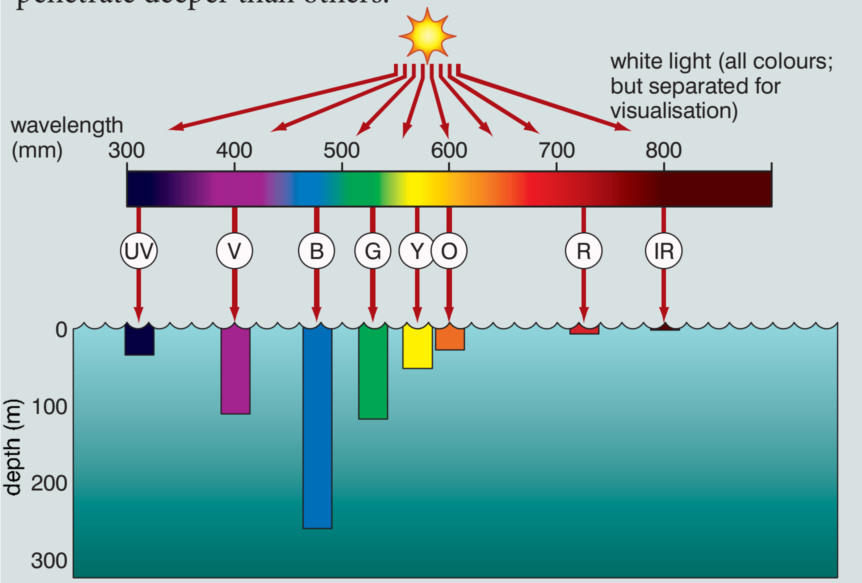


Figure 2.8 *Penetration of different wavelengths of light*

Water has a high specific heat capacity. This means that it takes quite a lot of energy to heat water up. Water also loses heat quite slowly. This has the overall effect that water stays more or less the same temperature – particularly large masses of water, such as oceans and lakes. This is important as the functioning of enzymes in living cells is affected by temperature. Too hot or too cold and the enzymes do not function efficiently and the reactions in the cells controlled by the enzymes are not carried out efficiently.

Ice is less dense than liquid water. It is unusual for the solid form of a substance to float on the liquid form of the same substance, but ice floats on water. This is because water expands when it freezes. So, in cold weather, water freezes from the top down. The ice on the surface then acts as an insulator and slows down the heat loss from the liquid water underneath. So life can continue in relatively warm water underneath the ice all through the cold weather.

Water has a high latent heat of vaporisation. This means that it takes a lot of energy to turn liquid water into water vapour (or steam). In turn this means that water doesn't vaporise too easily and that ponds don't dry up too quickly in hot weather – and the organisms in the pond have a better chance of survival. This property is also important in temperature control.

When we sweat, the energy needed to vaporise the sweat comes from our bodies. This heat is then lost from our bodies and so we cool down. If water vaporised easily, sweating wouldn't be as effective in controlling our body temperature.

KEY WORDS

specific heat capacity *the amount of energy needed to raise the temperature of 1 g of a substance by 1 °C*

density *the mass in kg of 1 dm^3 of a substance (or the mass in g of 1 cm^3 of a substance)*

latent heat of vaporisation *the energy used in converting a liquid to a gas at the same temperature*

DID YOU KNOW?

Water has the highest latent heat of vaporisation of all substances.

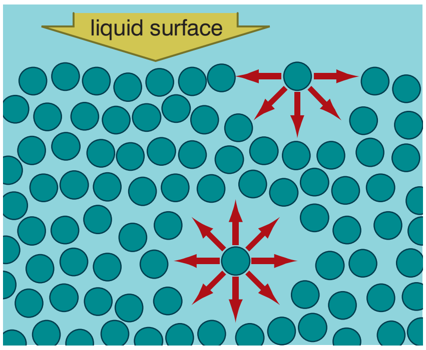


Figure 2.9 The surface tension of water

Water has a high surface tension. The water molecules in the main body of a mass of water are hydrogen-bonded to other water molecules on all sides. But at the surface, there is no hydrogen bonding above. So the 'pull' from the sides is stronger than it would otherwise be and the molecules at the surface are held together more strongly.

This is why some animals can 'walk on water' and why others can attach themselves to the surface of the water and live just below the surface. The water strider in figure 2.10 is just one example of an insect that is so light that the force of the surface tension of the water can support the weight of the insect.

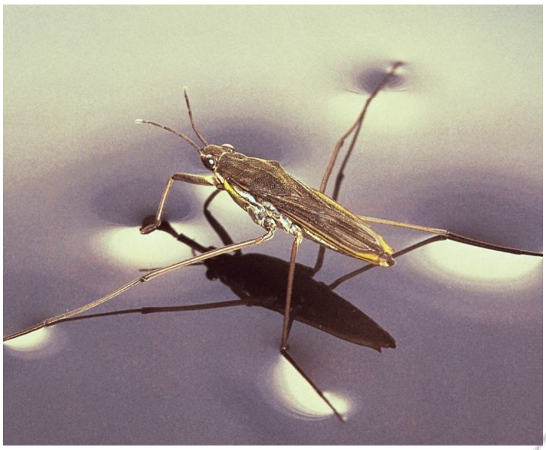


***Figure 2.10** A water strider walking on water*

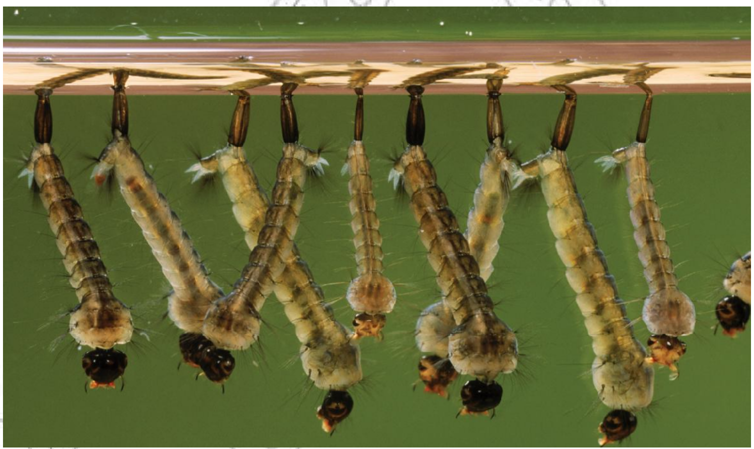


***Figure 2.11** Mosquito larvae*

The mosquito larvae in figure 2.11 hang from the surface of the water by their breathing tubes. The surface tension is sufficiently strong to hold their weight.

DID YOU KNOW?

Water dissolves more substances and in greater quantities than any other liquid.

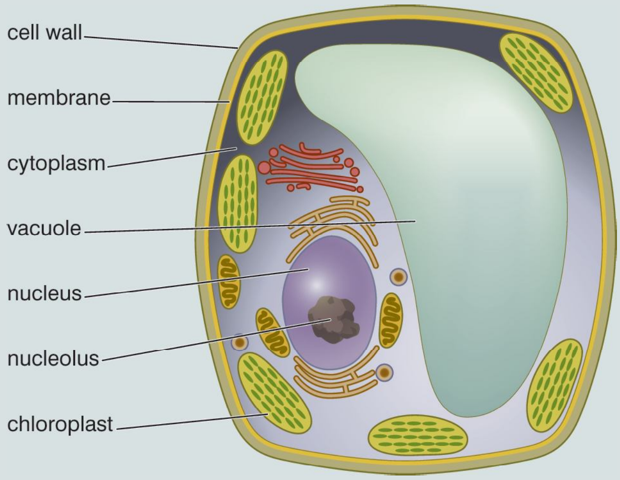
KEY WORD

surface tension *the tension at the surface of a liquid resulting from unbalanced forces acting on the molecules at the surface*

Water is a good solvent for many substances Many organic and inorganic substances important to life dissolve in water, but don't dissolve either at all or as well in other liquids. Water is very versatile. Because these substances dissolve in water, they can be transported in a water-based transport medium. Biological mechanisms such as active transport, diffusion and facilitated diffusion move the substances into and out of the water (in the transport medium). In mammals, the plasma of blood is 90% water. This is forced through the system of veins arteries and capillaries by the heart. In plants water carries dissolved minerals upwards from the roots to other parts of the plants in the xylem vessels. Water in the phloem tubes carries dissolved organic substances all over the plant.

Water has the ideal viscosity for a transport medium. Viscosity is a measure of how fluid a liquid is – how easily it flows. If water were more viscous (less fluid) than it is – think of tar! – then the heart would not be able to move it through the blood vessels. Also, the water inside cells transports substances around the cell; if it were more viscous, it would damage the delicate organelles in the cells. If water were less viscous (more fluid) than it is, it would flow too easily and, inside cells, the organelles would not be supported. Similarly, in the circulatory system, a less viscous liquid would not move the blood cells around the system as efficiently.

Water and support in cells



When plant cells absorb a lot of water, they swell until their cellulose cell wall won't let them swell any more. In this condition, we say they are turgid. Turgid cells press against each other and this pressure helps to support the plant. If the cells lose water, the pressure decreases and so does the support.

Figure 2.12 *A turgid plant cell*

Figure 2.13
A *A well-watered coleus plant*

B *A coleus plant that has not been well-watered*

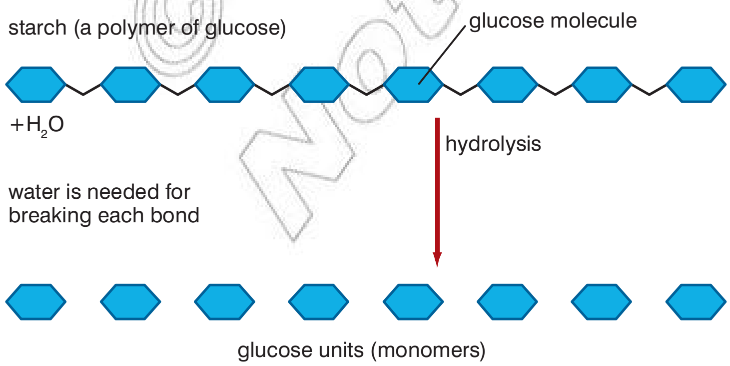
Water as a reactant. Many reactions in living things need water as a raw material. Photosynthesis – the process which begins the process of energy transfer between living things – requires water as one of its reactants. No water, no photosynthesis. Water is also involved in digesting large food molecules into smaller ones. Reactions that use water to split large molecules are called **hydrolysis** reactions. *Hydro* = water; *lysis* = splitting. Water molecules are used to split large food molecules into smaller ones that can be absorbed into the bloodstream.

KEY WORDS

reactant *a substance that takes part in a chemical reaction*

hydrolysis *using water to split large molecules*

A



B

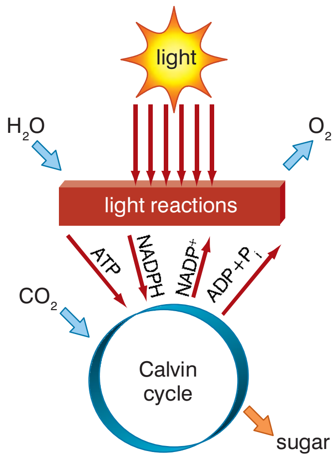


Figure 2.14 A *The hydrolysis of starch* ***B*** *A summary of photosynthesis*

Activity 2.3: Library search

See if you can find out:

- why gas exchange surfaces, like the alveoli in our lungs, are always moist
- the importance of water in excretion

Water is also involved in other reactions. For example, it is involved in reactions with carbon dioxide in red blood cells that are important in the transport of carbon dioxide around the body as hydrogen carbonate ions.

Water as a medium for chemical reactions. Cells function because of the many chemical reactions that are continually taking place in them. Many of these take place on the membrane systems of the cell, but others take place in the liquid 'cytosol' of the cytoplasm. Also, many of the reactions of photosynthesis and respiration take place in the liquid inner regions of chloroplasts and mitochondria. Water is an ideal medium for these reactions – for some of the reasons already discussed:

- It can dissolve many substances – the reactions will only take place effectively in solution.
- It has a low viscosity – the particles can move around and come easily into contact with each other.

So, we can see that, without water, life as we know it could not possibly exist. Water is just too important.

Review questions

Choose the correct answer from A to D.

1. Organic molecules always contain:
   A carbon
   B carbon and oxygen
   C carbon and hydrogen
   D oxygen and hydrogen
2. Which of the following groups of substances are all inorganic?
   A water, sugar, calcium carbonate
   B water, calcium carbonate, carbon dioxide
   C carbon dioxide, amino acid, fatty acid
   D sugar, fatty acid, amino acid
3. Which of the following statements about atoms and molecules is correct?

Option	Atoms	Molecules
A	The simplest particle of an element	Always contain more than one type of atom
B	Combine to form molecules	Always contain just one type of atom
C	The simplest particle of an element	Always contain more than one atom
D	Combine to form particles	Always contain more than one type of atom

4. The six most common elements in living things are:
   A carbon, hydrogen, oxygen, nitrogen, potassium and sulphur
   B carbon, phosphorus, hydrogen, oxygen, potassium and calcium
   C carbon, calcium, hydrogen, oxygen, nitrogen and phosphorus
   D carbon, hydrogen, oxygen, nitrogen, phosphorus and sulphur
5. Water molecules can form hydrogen bonds with other water molecules because:
   A the water molecule contains hydrogen and oxygen
   B part of the molecule is slightly negative
   C part of the molecule is slightly positive
   D all of the above
6. Water has a high specific heat capacity. This means that it:
   A heats up and cools down slowly
   B heats up slowly but cools down quickly
   C heats up quickly but cools down slowly
   D heats up and cools down quickly
7. Photosynthesis is impossible at a depth of 1000 m because:
   A it is too hot
   B only blue light penetrates this far
   C no light penetrates this far
   D it is too cold
8. Which of the following is not true about the viscosity of water?
   A if it were more viscous the heart would not be able to move the blood through the blood vessels
   B if it were less viscous the organelles would not be suspended in the cytoplasm
   C if it were less viscous the heart would not be able to move blood through the blood vessels
   D if it were more viscous the organelles would be damaged in the cytoplasm
9. The high surface tension of water is due to:
   A unbalanced hydrogen bonding in the body of the water
   B balanced hydrogen bonding in the body of the water
   C balanced hydrogen bonding at the surface of the water
   D unbalanced hydrogen bonding at the surface of the water
10. One benefit of ice being less dense than water is:
   A water freezes from the top down and water is insulated under the ice
   B water freezes from the top down and the water under the ice is cooled more quickly
   C water freezes from the bottom up and the remaining water cools more slowly
   D water freezes from the bottom up and the remaining water cools more quickly

Activity 2.4

Make a wall chart summarising why water is so important for living organisms.

2.2 Organic molecules

By the end of this section you should be able to:

- List and describe the structures of organic molecules in living things and state their functions.
- Show the structures and functions of biological molecules using chemical formulae and examples.
- Identify biologically important compounds by conducting simple food tests.
- Appreciate how biological molecules are obtained from different foods.

KEY WORDS

carbohydrate *molecule that contains the elements carbon, hydrogen and oxygen*

starch *a complex carbohydrate that stores chemical energy in plants*

glycogen *a complex carbohydrate that stores chemical energy in animals*

What are carbohydrates and why do we need them?

All **carbohydrates** contain the elements carbon, hydrogen and oxygen. The hydrogen and oxygen atoms in a carbohydrate molecule are present in the ratio of two hydrogen atoms to one oxygen atom (for example, glucose, $C_6H_{12}O_6$, and maltose, $C_{12}H_{22}O_{11}$). Carbohydrates range from very small molecules containing only 12 atoms, to very large molecules containing thousands of atoms.

Carbohydrates have a range of functions:

- They are used to release energy in respiration – glucose is the main respiratory substrate of most organisms.
- Carbohydrates are a convenient form in which to store chemical energy; storage carbohydrates include:
  – **starch** in plants
  – **glycogen** in animals
- Some carbohydrates are used to build structures; structural carbohydrates include:
  – cellulose, which is the main constituent of the primary cell wall of plants
  – chitin, which occurs in the cell walls of fungi and in the exoskeletons of insects
  – peptidoglycan, which occurs in bacterial cell walls

In plasma membranes, carbohydrates are found combined with proteins to form glycoproteins. Glycoproteins often act as antigens – markers for the immune system. The immune system can differentiate between 'self' antigens (those that are normally found in the body) and foreign or 'non-self' antigens. The presence of 'non-self' antigens stimulates an immune response.

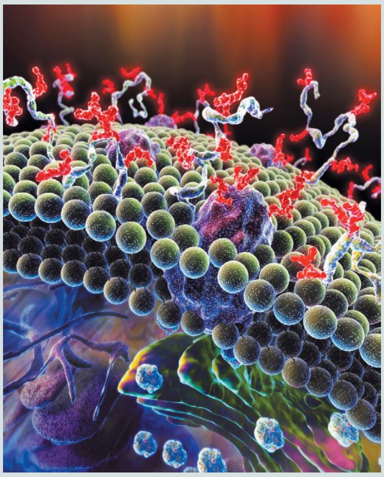


Figure 2.15 *A glycoprotein in a membrane*

What different types of carbohydrates are there?

Monosaccharides are the simplest carbohydrates. A monosaccharide molecule can be thought of as a single sugar unit. Other, more complex, carbohydrates have two or more monosaccharide units joined together.

Monosaccharides can be classified according to how many carbon atoms are present in the molecule.

- A **triose** monosaccharide has three carbon atoms – formula $C_3H_6O_3$. Glycerate phosphate is a triose important in photosynthesis.

- A **pentose** monosaccharide has five carbon atoms – formula $C_5H_{10}O_5$. Ribose is found in RNA nucleotides.
- A **hexose** monosaccharide has six carbon atoms – formula $C_6H_{12}O_6$. Glucose is the hexose produced in photosynthesis and used in respiration.

There are several different trioses, pentoses and hexoses. Each triose has the same number of each kind of atom (hence the formula $C_3H_6O_3$), but the atoms are put together in a different way. They are **isomers** of each other. The same is true for the pentoses and hexoses.

Monosaccharides can be classified in a different way – according to the **functional group** that they possess.

There are two functional groups in monosaccharides:

- the aldehyde group with the formula CHO (monosaccharides with this group are **aldoses**), and
- the ketone group, with the formula C=O (monosaccharides with this group are **ketoses**).

The main significance of this difference is the ability to polymerise. Nearly all the polysaccharides found in living things are polymers of aldose monosaccharides.

Figure 2.16 shows examples of each type of sugar according to both classifications.

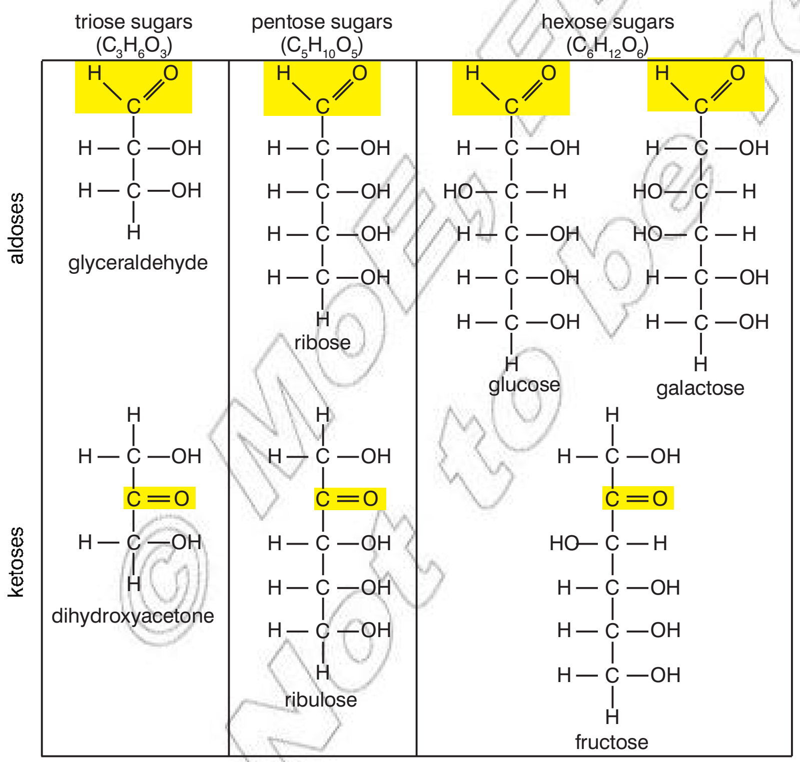


Figure 2.16 *Aldose and ketose monosaccharides*

The structures of the monosaccharides above are shown in a 'straight chain' form. However, in solution, they often change into a 'ring' structure. Figure 2.17 overleaf shows the straight chain and ring forms of two hexose monosaccharides – glucose and fructose.

KEY WORDS

monosaccharide *a single sugar*

isomers *molecules with the same chemical composition, but a different arrangement of atoms*

functional group *a group of atoms within a molecule that behaves in a particular way*

aldoses *monosaccharides with an aldehyde group in the molecule*

ketoses *monosaccharides with a ketone group in the molecule*

It is easy to think that all the atoms of ring molecules lie in the same plane, but this is not so. Figure 2.18 shows a three-dimensional representation of the atoms in α-glucose.

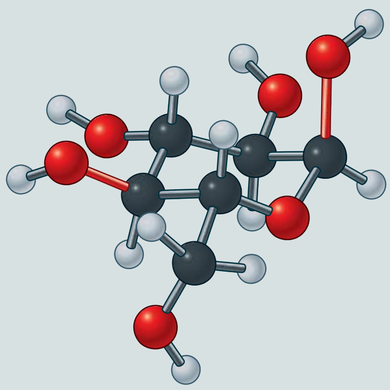


Figure 2.18 A 3-D representation of the α-glucose molecule

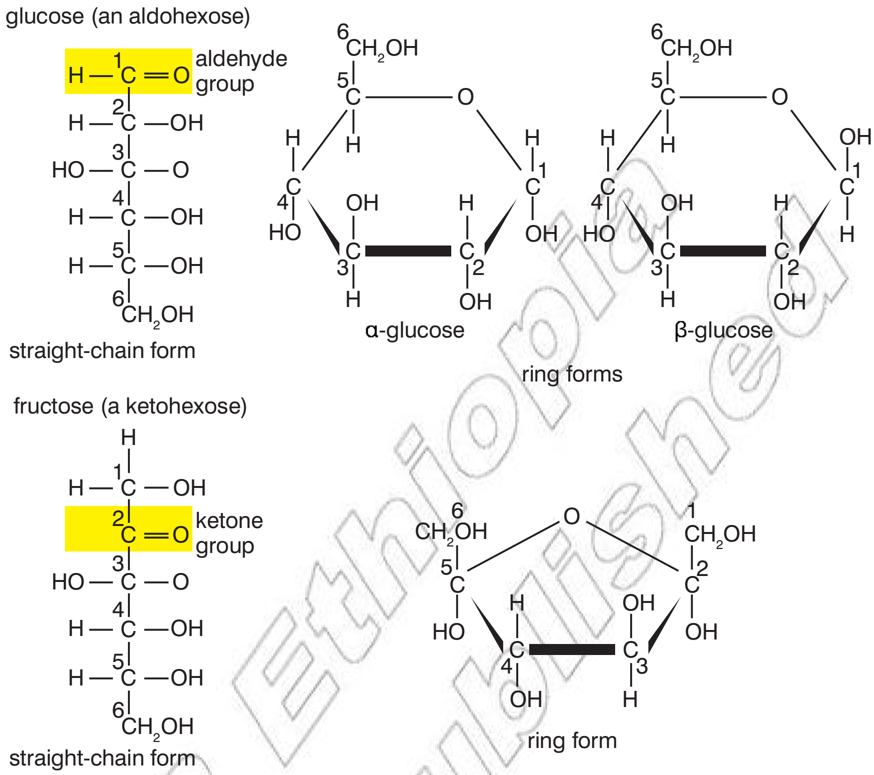


***Figure 2.17** Straight chain forms and ring forms of glucose and fructose*

The straight chain form of glucose can produce two different ring forms – α-glucose and β-glucose. There is only one difference between these two. Can you see it?

The straight chain form of fructose produces only one ring form.

In these structural diagrams, the carbon atoms in the molecules are numbered according to their positions in the molecule.

You do not have to know the position of every carbon, hydrogen and oxygen atom in these molecules. However, if you can remember the simplified structures shown in figure 2.19 this will help you to understand how more complex carbohydrates are formed. These simplified diagrams show the overall shape of the molecule, the position of each carbon atom and the hydrogen and oxygen atoms attached to carbon atoms 1 and 4.

Disaccharide carbohydrate molecules are made by two monosaccharide molecules joining together. For example, a molecule of:

- **maltose** is derived from two α-glucose molecules
- **sucrose** is derived from an α-glucose molecule and a fructose molecule
- **lactose** (milk sugar) is derived from a β-glucose molecule and an α-galactose molecule.

In each of these examples, two hexose monosaccharides have reacted to form a disaccharide molecule. As the formula of a hexose

KEY WORDS

disaccharide *a sugar formed when two monosaccharides join together*

maltose *a disaccharide derived from two α-glucose molecules*

sucrose *a disaccharide derived from an α-glucose molecule and a fructose molecule*

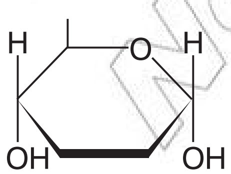


***Figure 2.19** A simplified representation of the structure of α-glucose*

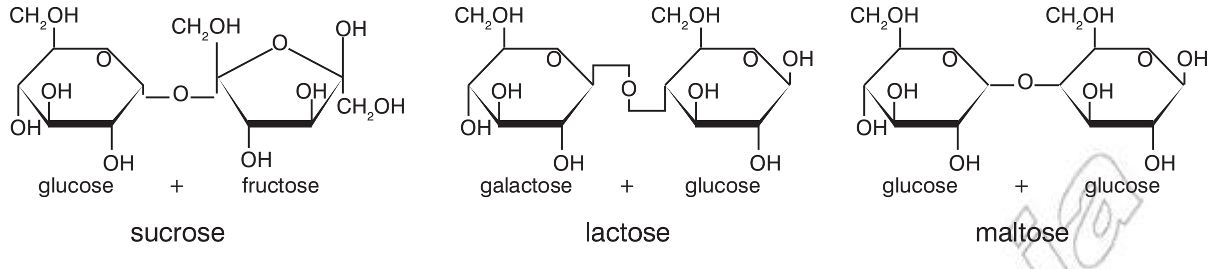


Figure 2.20 The structures of three disaccharides

is $C_6H_{12}O_6$, you might expect the formula of the disaccharides to be $C_{12}H_{24}O_{12}$. In fact, the formula is $C_{12}H_{22}O_{11}$. A molecule of water (H_2O) is formed from a hydroxyl group from one monosaccharide and a hydrogen atom from the other (figure 2.21). This allows a bond to be formed between the two monosaccharide units to make a disaccharide.

The process shown in Figure 2.21 is **condensation**. The bond that holds the two monosaccharide units together is a **glycosidic bond**. It is formed between carbon atom 1 of one α-glucose molecule and carbon atom 4 of the other α-glucose molecule. The full name of the bond is, therefore, a α-1,4-glycosidic bond.

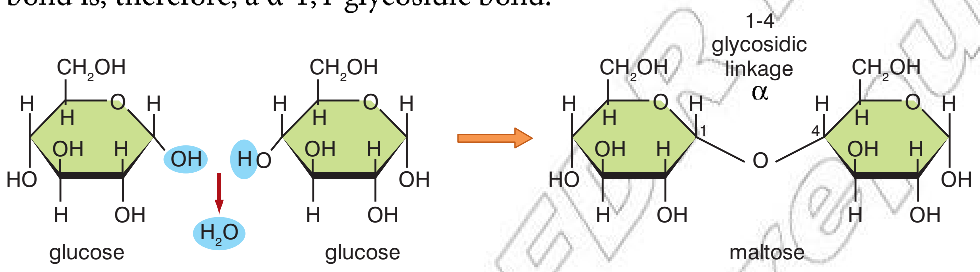


Figure 2.21 Two molecules of α-glucose are joined to form a molecule of maltose (a disaccharide).

The reverse process is hydrolysis (of the disaccharide). This involves 'putting back' the water that was removed during condensation and splitting the molecule into its component, smaller molecules (figure 2.22). This is another example of the use of water to split molecules.

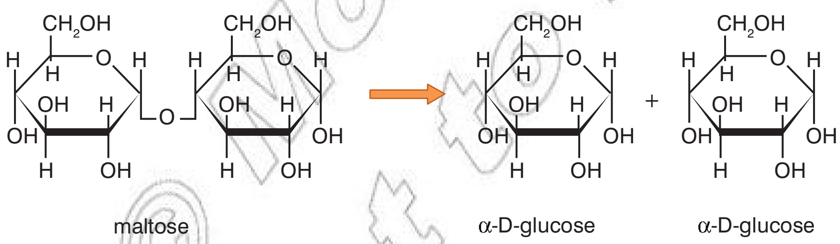


Figure 2.22 Hydrolysis of maltose

Polysaccharides are complex carbohydrates. Their molecules are built as many hundreds of monosaccharide molecules join together by forming condensation links. Starch is a polymer of α-glucose.

Some polysaccharides are storage molecules. These offer a convenient way of storing carbohydrates that will not interfere with the metabolism of cells. Others are structural carbohydrates. As the name suggests, these carbohydrates are used to build structures – like plant cell walls and insect exoskeletons.

KEY WORDS

condensation *the process in which two molecules combine to form a larger molecule, producing a smaller molecule (often water) as a by-product*

glycosidic bond *the bond that holds two monosaccharide units together*

polysaccharide *a carbohydrate whose molecules consist of a number of monosaccharide molecules bonded together*

Condensation does not just occur in the formation of disaccharides, but also in the formation of polysaccharides and other large molecules.

KEY WORDS

amylose *a long unbranched chain of α-glucose molecules*

amylopectin *a chain of α-glucose molecules with many branches*

DID YOU KNOW?

A **macromolecule** is just what you might think – it is a big molecule. Examples include proteins, starch, cellulose, glycogen and DNA. A polymer is also a large molecule – but it is not *just* large. A polymer molecule is made from many smaller, usually *identical*, molecules called **monomers**. Besides being macromolecules, starch, glycogen, cellulose and proteins are polymers. Starch and glycogen are polymers of α-glucose, cellulose is a polymer of β-glucose and proteins are polymers of amino acids.

Starch

Starch is not a single compound but a mixture of **amylose** and **amylopectin**. Both are polymers of α-glucose, but the arrangement of the α-glucose monomers in these compounds is different.

Amylose is a linear molecule containing many hundreds of α-glucose molecules joined by α-1,4-glycosidic bonds. As it is being formed, this long chain winds itself into a helix.

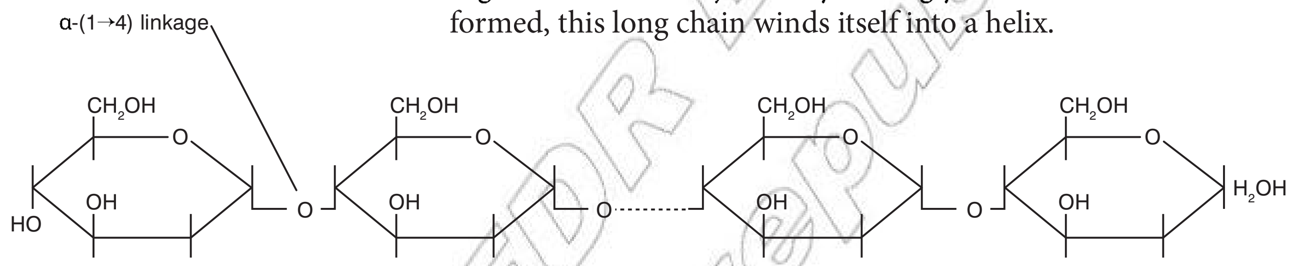
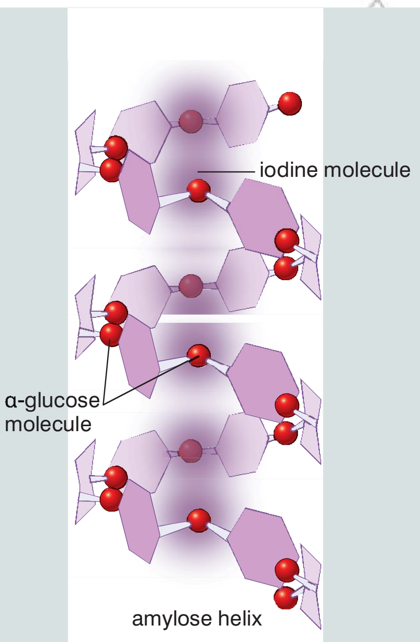


Figure 2.23 *Linkages in amylose*



Why starch stains blue or black or blue-black with iodine

The amylose molecule winds itself into a helix when in contact with water. This allows a reaction to occur between the starch and the iodine solution. Rows of iodine atoms sit inside the amylose helix. This changes the light-absorbing properties of both, so that the amylose–iodine complex appears blue. Starches in different plants have different proportions of amylose and amylopectin. This results in different shades of blue-black with the iodine test, because only the amylose reacts with iodine.

Figure 2.24 *Iodine stains starch blue-black.*

Amylopectin also has a linear 'backbone' of α-glucose molecules joined by α-1,4-glycosidic bonds. But in amylopectin, there are also side branches. These occur at certain points along the chain when a glucose molecule forms an α-1,6-glycosidic bond with another glucose molecule *as well as* the usual α-1,4-glycosidic bond. This results in amylopectin having a branching structure as shown in figure 2.25.

The branched nature of amylopectin means that there are many 'ends' to the molecule. This allows it to be quickly hydrolysed by enzymes acting at the ends of the chains to release glucose for respiration.

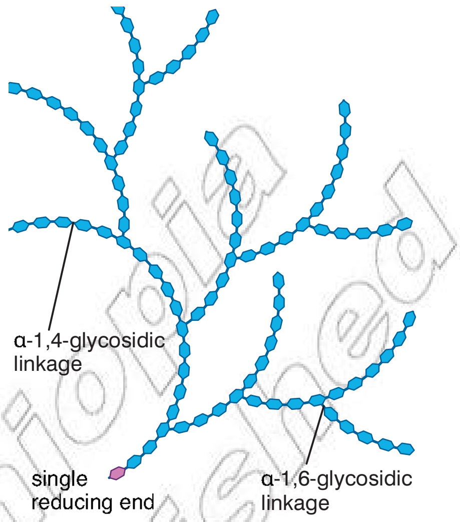


Figure 2.25 *The structure of amylopectin*

How the structure of starch is suited to its function

Starch is a plant storage carbohydrate. How does its structure suit it to this function?

- Both amylose and amylopectin are compact molecules, so many α-glucose molecules can be stored in a small space, without affecting cell metabolism.
- Both amylose and amylopectin are insoluble. If soluble glucose were stored (instead of first being converted to starch), it would draw water, by osmosis, from neighbouring cells and from organelles within the cell. Insoluble starch produces none of these effects.
- In addition, because amylose and amylopectin are insoluble, the molecules cannot move out of cells – they remain in storage organs.
- The branched nature of amylopectin means that there are many 'ends' to the molecule. Therefore, starch can be quickly hydrolysed (by enzymes acting at the ends of the chains) to release glucose for respiration.

DID YOU KNOW?

An enzyme that digests proteins is a *protease*; one that digests lipids is a *lipase*. An enzyme that digests starch is an *amylase* because it acts on the *amylose* and *amylopectin* that make up starch.

Glycogen

Glycogen is a storage carbohydrate in animal cells. It has a similar structure to that of amylopectin – but there are more α-1,6 links, making it much more highly branched. Because of this, it can be hydrolysed even more quickly to release glucose for respiration. This is important because animals have a higher metabolic rate than plants and need to release energy more quickly to 'drive' their metabolic processes.

Cellulose

Cellulose is a polymer of β-glucose molecules joined by β-1,4-glycosidic bonds, formed by condensation reactions. However, because of the different position of the H and OH groups on carbon atom 1 compared to α-glucose, every other glucose unit in the chain is upside down, as shown in figure 2.26. Also, the chain is unbranched.

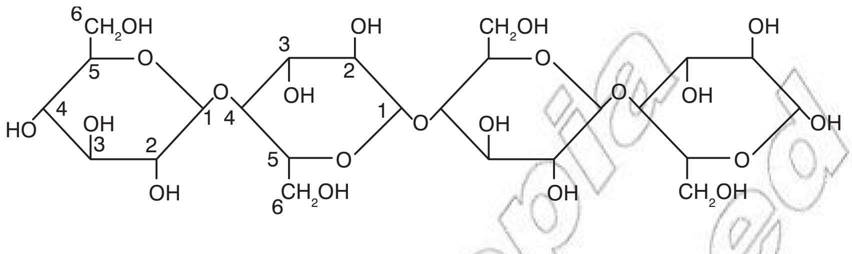


Figure 2.26 The structure of cellulose

Many cellulose molecules lie side by side and hydrogen-bond to each other. This results in the formation of cellulose microfibrils. Many of these microfibrils bond together to form bigger fibres or fibrils, which make up the structure of cell walls. This is shown in figure 2.27.

Activity 2.5

Carbohydrates are very important biological molecules. Make a poster titled CARBOHYDRATES which explains the basic structure of carbohydrates and why they are important to plants and animals.

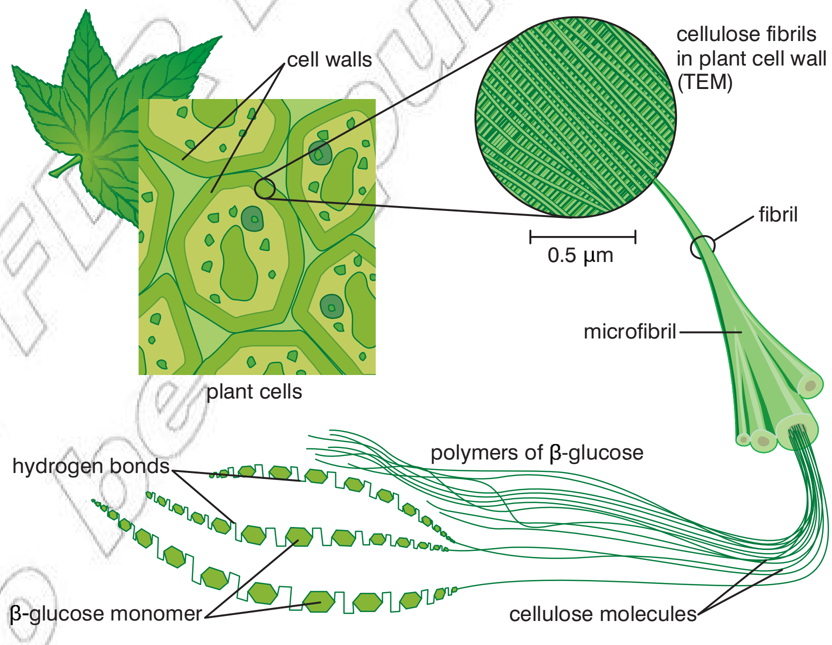


Figure 2.27 How cellulose molecules are organised in plant cell walls

How the structure of cellulose is suited to its function

The cellulose molecule is unbranched. This allows hydrogen bonding and the formation of microfibrils. If it were branched, microfibrils could not form. It is the fibrous nature of cellulose that gives the cell walls their strength, but also gives them some flexibility.

What are lipids?

Like carbohydrates, nearly all lipids contain only the elements carbon, hydrogen and oxygen, but they contain *much* less oxygen than carbohydrates.

Lipids are a varied group of compounds that include:

- **triglycerides** – formed from glycerol and three fatty acids
- **phospholipids** – formed from glycerol, two fatty acids and a phosphate group
- **waxes** – formed from fatty acids and long-chain alcohols

Whilst some lipids have quite large molecules, they are not polymers and, in many cases, their molecules are relatively small. 'The feature that they all share is that are all made from fatty acids and alcohols.

Because of their varied nature, lipids have a range of functions.

Waxes are so insoluble in water that they make excellent water repellents, for example, in coating birds' feathers and the epidermis of the leaves of plants (the waxy cuticle).

Phospholipids are one of the basic components of all cell membranes.

Triglycerides have several functions including:

- respiratory substrate – a molecule of triglyceride yields over twice as many molecules of ATP (twice as much energy) as a molecule of glucose
- thermal insulation – the cells of adipose tissue found under the skin of many animals contain large amounts of triglycerides, which give good thermal insulation
- buoyancy – lipids are less dense than water (oil floats on water), so the presence of large amounts of lipid reduces the density of an animal, making it more buoyant
- waterproofing – the oils secreted by some animals onto their skin are triglycerides

Triglycerides

A triglyceride molecule is an ester formed from one molecule of glycerol and three fatty acid molecules.

A fatty acid molecule consists of a **covalently bonded hydrocarbon chain**, at the end of which is a **carboxyl group**, which has acidic properties. The hydrocarbon chain is non-polar (this means that it has no charge). The carboxyl group (the functional group of the fatty acid) is ionic and dissociates in solution to form COO^- and H^+ (hydrogen ion). The hydrogen ions released make the solution acidic.

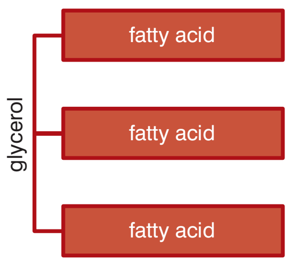


***Figure 2.29** The structure of a triglyceride*

DID YOU KNOW?

Some of the lipids found in the myelin sheath that surrounds nerve cells are **sphingolipids**. These are unusual lipids as they contain nitrogen as well as carbon, hydrogen and oxygen.

Glycerol is a polyhydroxy alcohol. This means it contains more than one hydroxyl (–OH) group. Ethanol, the alcohol in beer and wine, has the formula C_2H_5OH. It is a monohydroxy alcohol and contains only one hydroxyl group:

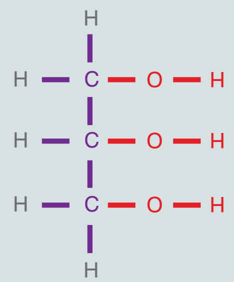


***Figure 2.28** The structure of glycerol*

KEY WORDS

covalently bonded hydrocarbon chain *a chain of carbon atoms, covalently bonded to each other and to one, or more, hydrogen atoms*

carboxyl group *acid radical -COOH. It releases H^+ into aqueous solution to make the solution acidic*

KEY WORDS

saturated fatty acid *all the carbon–carbon bonds in the hydrocarbon chain are single bonds*

monounsaturated fatty acid *one of the carbon–carbon bonds is a double bond*

polyunsaturated fatty acid *more than one carbon–carbon bond is a double bond*

ester bond *the bond that forms between a carboxyl group and a hydroxyl group*

DID YOU KNOW?

You may have seen cooking oils, margarines and other spreads advertised as 'high in polyunsaturates'. This means that the lipids in them contain a high proportion of polyunsaturated fatty acids. Polyunsaturated fatty acids help to prevent cholesterol being laid down in the linings of arteries (atherosclerosis) and so help to prevent heart disease.

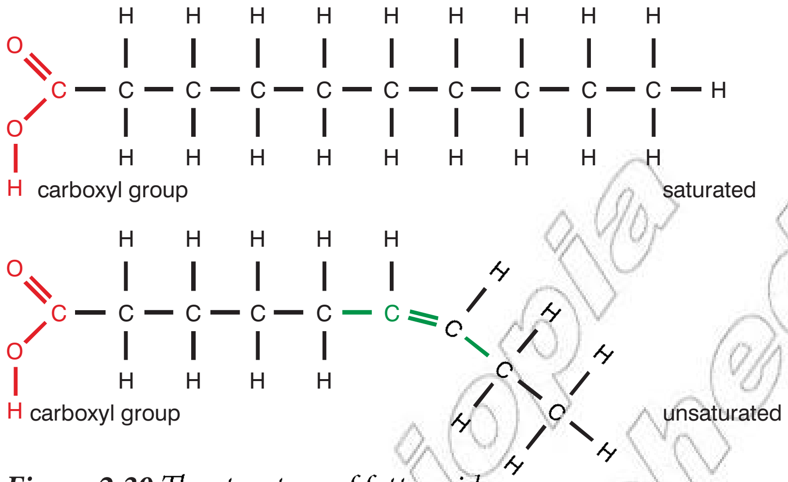


Figure 2.30 The structure of fatty acids

The nature of the hydrocarbon chains in fatty acids can differ in two main ways:

- The number of carbon atoms in the chains can vary.
- Hydrocarbon chains with the same number of carbon atoms can have different numbers of hydrogen atoms.

This is because of the nature of the bonding between the carbon atoms in the chain. If all the carbon–carbon bonds in the hydrocarbon chain are single bonds, the fatty acid is a **saturated fatty acid**. If one of the carbon–carbon bonds is a double bond, then it is a **monounsaturated fatty acid**. If more than one carbon–carbon bond is a double bond, then the fatty acid is a **polyunsaturated fatty acid**.

Sometimes we wish to represent a 'generalised fatty acid'. This means a diagram that shows the general arrangement of the molecule, including the functional group, but that could have any number of carbon atoms in the hydrocarbon chain.

When triglyceride molecules are formed, condensation reactions take place to join three fatty acid molecules to a glycerol molecule. The bonds formed are called **ester bonds**. These ester bonds can be broken by hydrolysis to give glycerol and fatty acids once again.

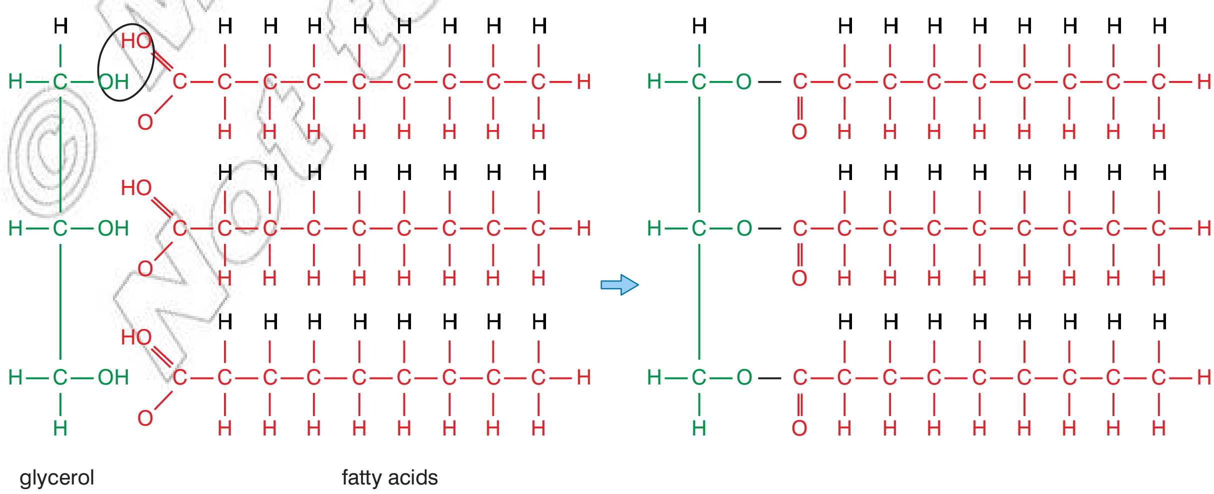


Figure 2.31 The formation of a triglyceride.

Phospholipids

Phospholipids are formed when two fatty acid molecules are bonded to the glycerol and the place of the third is taken by a phosphate group. Since the phosphate group is ionic and the hydrocarbon chains of the two fatty acids are covalently bonded, there are two distinct regions to a phospholipid molecule:

- a **hydrophilic** (water-loving) region, consisting of the phosphate 'head'
- a **hydrophobic** (water-hating) region, consisting of the hydrocarbon 'tails'

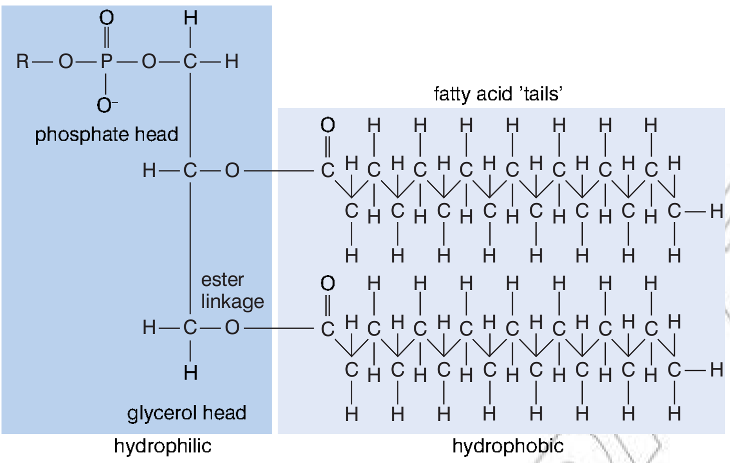


Figure 2.32 *The structure of a phospholipid*

In water, phospholipids become organised into a **bilayer** (two layers sandwiched together). In this configuration, the hydrophilic heads face outwards into the water and the hydrophobic tails face inwards, away from the water. Phospholipid bilayers are the basis of plasma membranes. We will study these in detail in unit 4.

Notice how the structure of a phospholipid has been simplified in figure 2.33. The phosphate head is shown as a ball and the fatty acids as two tails. The glycerol 'backbone' somehow gets lost in the simplification!

KEY WORDS

hydrophilic *water-loving*
hydrophobic *water-hating*
bilayer *two layers sandwiched together*

Activity 2.6

Make a poster titled LIPIDS which explains the basic structure of lipids and why they are important to plants and animals.

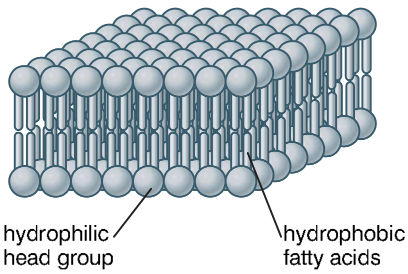


Figure 2.33 *The structure of a phospholipid bilayer*

Why do we need proteins?

Proteins are extremely important substances that are needed to form all living cells. Their molecules contain the elements carbon, hydrogen and oxygen (like carbohydrates and lipids), but they also contain nitrogen and most contain sulphur. Protein molecules are polymers of **amino acids** and so are macromolecules also. But they vary enormously in size; the smallest protein molecules contain fewer than 100 amino acids, whilst the largest contain several thousand.

Proteins have a range of functions; they are important in:

- the structure of plasma membranes – protein molecules form ion channels, transport proteins and surface receptors for hormones, neurotransmitters and other molecules
- the immune system – antigen and antibody molecules are proteins

KEY IDEA

It is the dual hydrophilic–hydrophobic nature of phospholipids that makes them organise into bilayers. Without this property, cell membranes would not be formed.

It is not strictly true to call proteins polymers. In a true polymer, all the monomers are identical (think of amylose and amylopectin in starch, where all the monomers are α-glucose). However, there are usually several different amino acids in any given protein molecule. But, since all amino acids have the same basic structure, we usually refer to proteins as polymers.

KEY WORDS

amino acids *are the building blocks of proteins and have two functional groups – the amino group and the carboxyl group. This allows them to behave both as a base and as an acid*

peptide bond *the bond that links two amino acids*

polypeptide *a linear polymer consisting of amino acid residues bonded together in a chain forming a part or all of a protein molecule*

primary structure *the sequence formed by amino acids*

- the control of metabolism by enzymes – all enzymes are proteins
- the structure of chromosomes – DNA is wound around molecules of the protein histone to form a chromosome

All amino acid molecules are built around a carbon atom (the α-carbon) to which is attached:

- a hydrogen atom
- an amino group ($-NH_2$)
- a carboxyl group ($-COOH$)
- an 'R' group, which represents the other atoms in the molecule, such as a single hydrogen atom, a hydrocarbon chain or a more complex structure

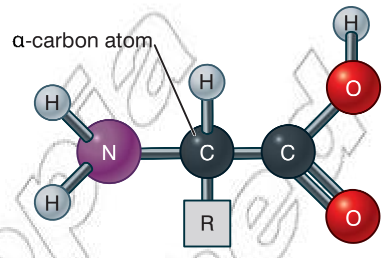


Figure 2.34 *The general structure of an amino acid*

Two amino acids can be joined together by condensation to form a dipeptide. This takes place in much the same way as when two monosaccharides join to form a disaccharide. H and OH are lost to create a molecule of water. The 'H' is lost from the amino group on one amino acid and the 'OH' is lost from the carboxyl group on the other amino acid. 'Spare bonds' are created on each molecule, which then join to form a **peptide bond**, which holds the two amino acids together. This is shown in figure 2.35.

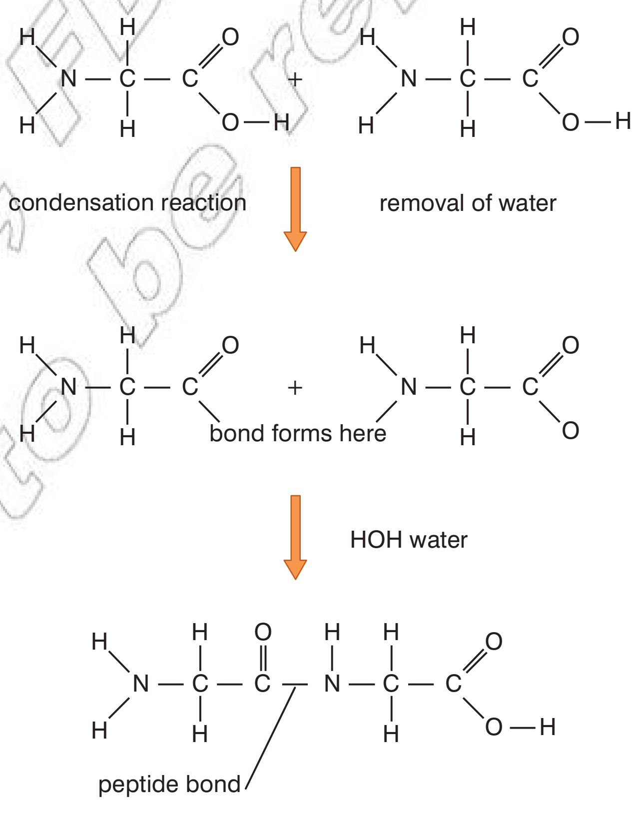


Figure 2.35 *How a dipeptide is formed*

A dipeptide can be enlarged into a **polypeptide** by condensation with more amino acid molecules. Many amino acids joined by peptide bonds form a polypeptide chain; this sequence of amino acids is the **primary structure** of the protein. Once formed, the polypeptide chain folds itself into a **secondary structure**, which is either an **α-helix** or a **β-pleated sheet** (see figure 2.36). The structures are held in place by hydrogen bonds that form between peptide bonds in adjacent parts of the amino acid chain. Both types of secondary structure can exist in different regions of the same polypeptide chain.

A protein molecule can also have a **tertiary structure**. This involves further folding of the secondary structure and the formation of new bonds to hold the tertiary structure in place.

These new bonds include:

- more hydrogen bonds – between the R-groups of some amino acids
- disulphide bridges – between amino acids that contain sulphur
- ionic bonds – between amino acids with positively charged R-groups and those with negatively charged R-groups

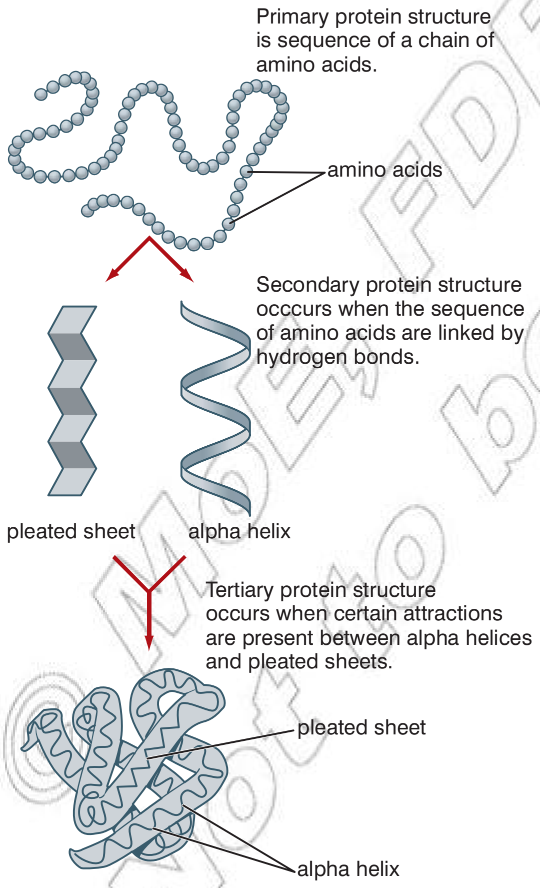


***Figure 2.36** The levels of structure of a protein*

Each protein has a unique tertiary structure and so has a unique configuration (shape) because:

- the primary structure of each protein is coded for by DNA, which determines the type and position of each amino acid in the polypeptide chain

KEY WORDS

secondary structure *formed when a polypeptide chain folds itself into another structure*

α-helix *a coiled secondary structure of a polypeptide*

β-pleated sheet *a folded secondary structure of a polypeptide*

tertiary structure *folding of the secondary structure of a polypeptide by the formation of new bonds to hold it in place*

quaternary structure *structures formed when two or more polypeptide chains (folded into a tertiary structure) become associated in the final structure of the protein*

KEY WORDS

haemoglobin *the oxygen-carrying molecule in the blood*

collagen *fibrous protein found in many tissues in mammals*

DNA *a huge molecule made up of two strands of nucleotides wound into a double helix*

RNA *a molecule made up of one strand of nucleotides*

Activity 2.7

Make a poster titled PROTEINS which explains the basic structure of proteins and why they are important to plants and animals.

- the secondary structure of the molecule is the consequence of its primary structure; some sections of the primary structures form α-helices, others form β-pleated sheets, and
- the secondary structure determines where ionic and hydrogen bonds and disulphide bridges form, so it determines the tertiary structure and shape of the protein molecule.

The tertiary structure of a protein is unique and this gives each protein a specific function. For example:

- the shape of the active site of an enzyme molecule lets it bind with only one substrate and catalyse only one reaction
- the shape of a hormone receptor in the plasma membrane of some cells allows the hormone to bind with this receptor and to target *only* cells that have this receptor
- the shape of an antibody means it can bind with and destroy just one antigen

Some proteins have yet another level of organisation called the **quaternary structure**. In these proteins two, or more, polypeptide chains folded into a tertiary structure become associated in the final structure of the protein. Two important examples are **haemoglobin** (the oxygen-carrying molecule found in red blood cells) and **collagen** (the fibrous protein found in many tissues in mammals).

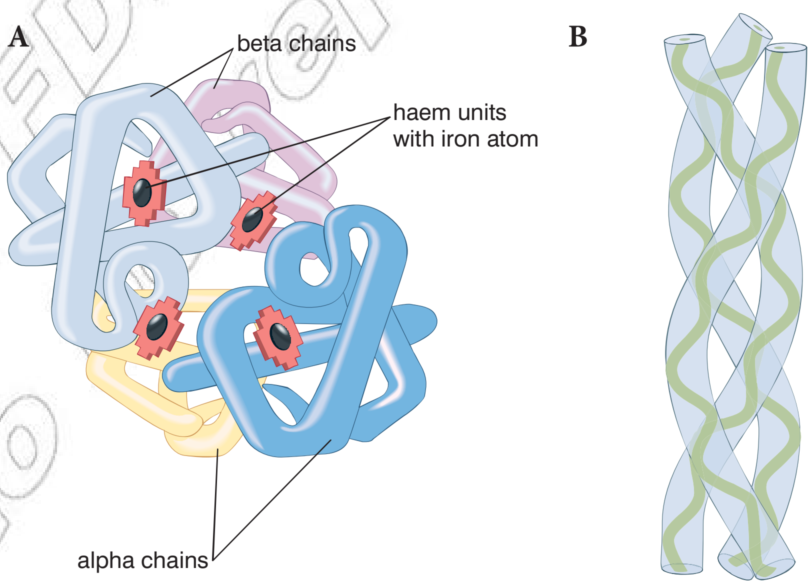


***Figure 2.37A** The four polypeptides in haemoglobin's quaternary structure; **B** The three polypeptides in collagen's quaternary structure*

Proteins are classified into two main groups, according to their molecular shapes:

- **fibrous proteins** that have a tertiary structure that resembles a long string or fibre (for example, collagen and keratin)
- **globular proteins** that have a tertiary structure that resembles a globule or ball (for example, enzymes and receptor proteins).

What are nucleic acids?

Biologists discovered two different types of nucleic acid at the end of the nineteenth century:

- **DNA** or **DeoxyriboNucleic Acid** – DNA is the nucleic acid found in chromosomes. Each gene is a short section of DNA that codes for a specific protein and, as a result, determines a particular feature. DNA is the genetic material.
- **RNA** or **RiboNucleic Acid** – RNA is a nucleic acid found both in the nucleus and the cytoplasm. Different types of RNA are involved in allowing a specific gene (DNA) to produce the protein it codes for.

DNA was isolated from animal cells and RNA from yeast cells. It was not until much later that biologists realised that both types are present in all living cells. We shall study the structure and functioning of nucleic acids in more detail in grade 12, but they are very important biological molecules, so we will just outline their structure and functions now. Both types of nucleic acids are made from structures called nucleotides. All nucleotides have the same basic structure.

All nucleotides have the same three components:

- a phosphate group
- a pentose sugar (deoxyribose in DNA nucleotides and ribose in RNA nucleotides), and
- one of four nitrogenous bases – Adenine, Cytosine, Guanine and either Thymine (DNA) or Uracil (RNA).

DNA is a huge molecule made up of two strands of nucleotides wound into a double helix. RNA is much smaller and is single-stranded. Figure 2.39 overleaf shows the structures of both.

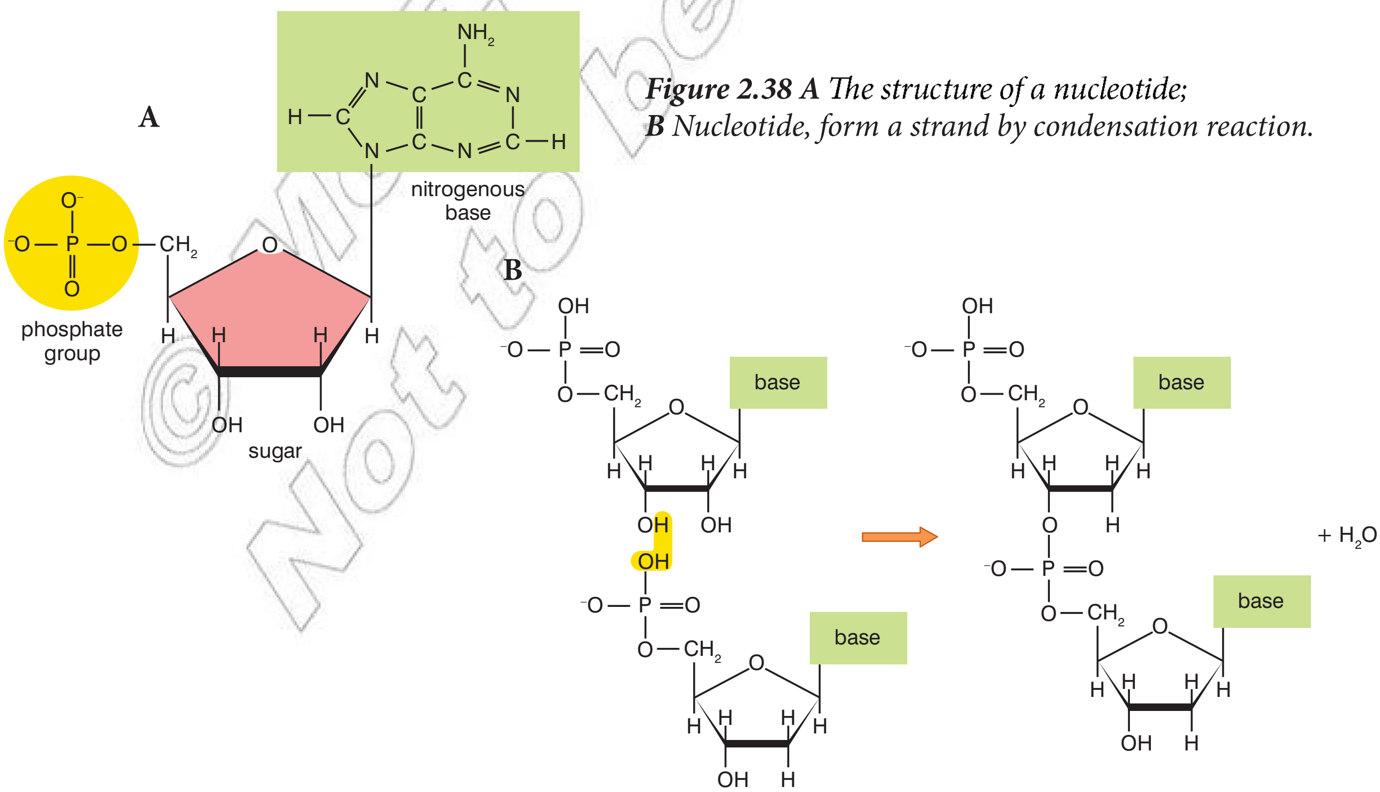


***Figure 2.38 A** The structure of a nucleotide;*
***B** Nucleotide, form a strand by condensation reaction.*

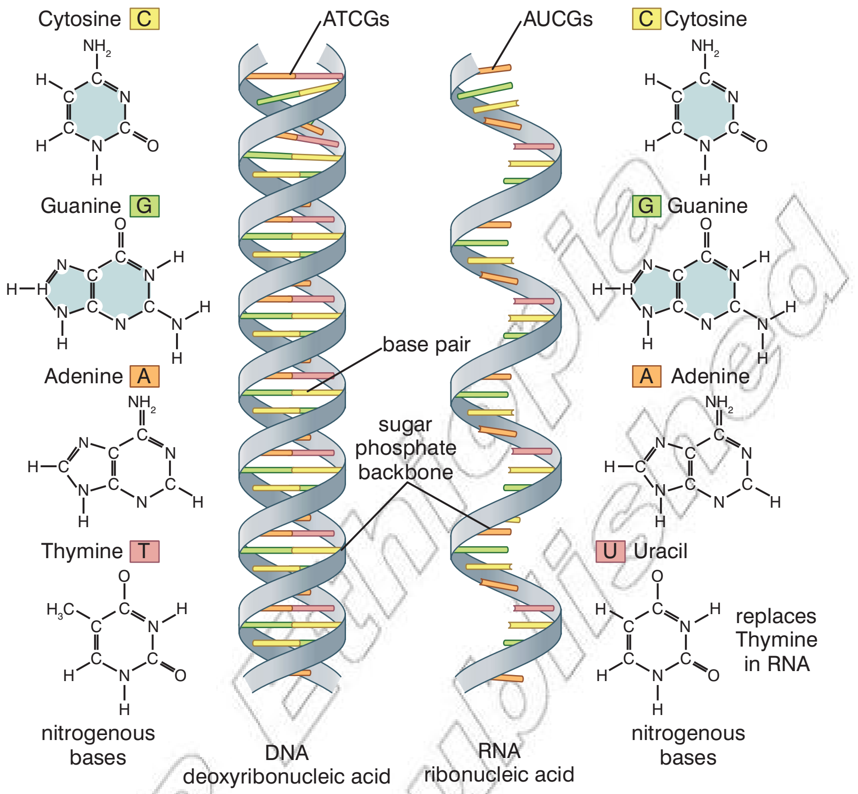


Figure 2.39 The structures of DNA and RNA

DID YOU KNOW?

How DNA is organised in a cell

DNA is found only in the nucleus of a cell. It is associated with proteins called histones to form chromosomes. This is shown in figure 2.40.

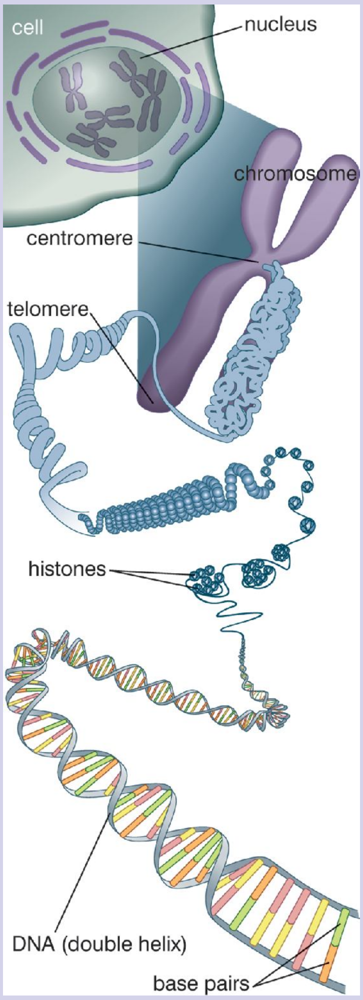


Figure 2.40 Where DNA is found in a cell

Table 2.3 How the structure of nucleic acids relates to their functions

Feature	DNA	RNA
Size	Huge – allows the molecule to carry the code for many different proteins in the genes.	Much smaller – need only code for one protein; small size allows RNA to move out of the nucleus.
Stability	Very stable – ensures that the genes remain the same over generations.	Less stable – is degraded quite quickly so does not carry on coding for a protein.
Number of strands	Two strands – allows coding of genes and replication during cell division.	Single stranded – does not replicate.

How can we find out which biological molecules are in foods?

There are biochemical tests for a range of biological molecules. These include:

- starch
- reducing sugars
- non-reducing sugars
- lipids
- proteins.

Activity 2.8: The iodine test for starch

Starch reacts with a solution of iodine in potassium iodide to give a blue-black colour.

1. Place the solution or food to be tested in a spotting tray/test tube.
2. Add a few drops of iodine solution.
3. Look for a blue-black colour.

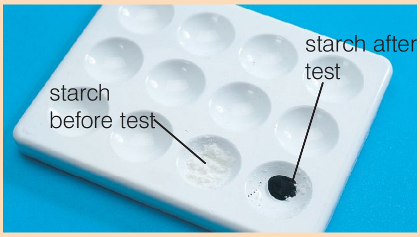


***Figure 2.41** Result of the starch test*

Activity 2.9: The Benedict's test for reducing sugars

Reducing sugars include glucose, fructose, maltose, lactose, but not sucrose (the disaccharide sugar we use on a day-to-day basis in tea and coffee).

Place the solution or food to be tested in a test tube (about 1 cm depth is sufficient).

1. Add 5 cm^3 Benedict's solution.
2. Stand the test tube in a water bath for five minutes.
3. Observe the colour.

A yellow/orange/red colour shows that a reducing sugar is present.

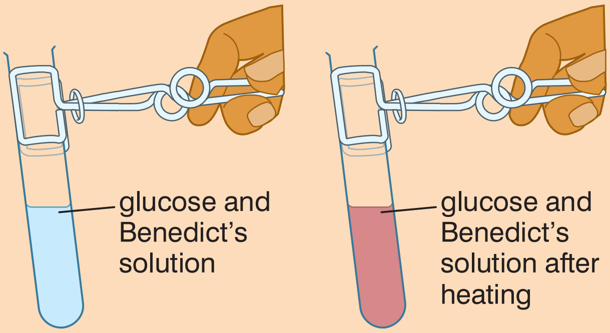


***Figure 2.42** Result of the Benedict's test*

It is important to note that the Benedict's test does not distinguish between different reducing sugars. It is *not* a test for glucose – or galactose or any individual sugar. To distinguish between individual sugars, enzyme-based tests are used.

Activity 2.10: The Benedict's test for non-reducing sugars

1. First, we must establish that no reducing sugars are present. The test is carried out as described above. If the solution remains blue, there can be no reducing sugars present.
2. Then, boil 5 cm^3 of the test sample with 5 cm^3 of hydrochloric acid to hydrolyse any molecules of non-reducing sugar.
3. Neutralise the solution by adding sodium carbonate (remember, the reducing sugars will not reduce Benedict's solution in acidic conditions).
4. Retest the mixture with Benedict's solution. A red precipitate indicates that reducing sugars are now present. As they weren't present at the start, they must have been formed by the acid hydrolysis. So, at the start, a *non-reducing* sugar must have been present.

DID YOU KNOW?

Reducing sugars

They are called reducing sugars because they will act as reducing agents in an alkaline solution. This is the basis of the Benedict's test. In this test, reducing sugars reduce copper (II) ions (blue) to copper (I) ions (brick red).

Activity 2.11: The emulsion test for lipids

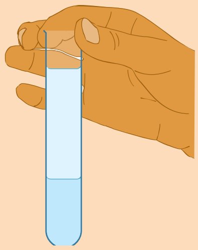


Figure 2.43 Result of the emulsion test

This test is based on the fact that lipids are soluble in organic solvents such as ethanol, but insoluble in water. This test is carried out as follows.

1. Shake the test sample with 5 cm^3 ethanol, in a clean, dry test tube.
2. Filter the mixture (if necessary).
3. Pour the filtrate into water.

Any lipid in the filtrate will not dissolve in the water. It will form an emulsion that makes the liquid appear milky white.

Activity 2.12: The Biuret test for proteins

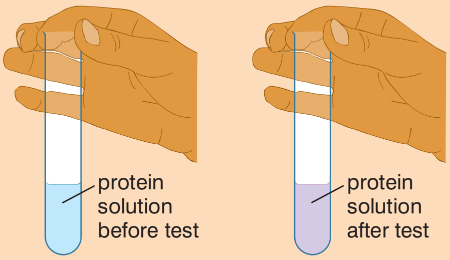


Figure 2.44 Result of the Biuret test

In this test, a protein in an alkaline solution reacts with copper ions to produce a mauve/purple colour. There are two ways of carrying out the test:

Method 1

1. Mix the food or 2 cm^3 of the test solution with sodium hydroxide solution in a test tube.
2. Add a few drops of 1% copper (II) sulphate solution.
3. Allow the mixture to stand for a few minutes (to allow the colour to develop fully).

Method 2

1. Mix the food or 2 cm^3 of the test solution with Biuret solution (which contains copper ions in an alkaline solution).
2. Allow the mixture to stand for a few minutes to allow the colour to develop fully.

Activity 2.13: Library search

Clinistix is an example of a biosensor-based test for glucose. Try to find out how it works.

Review questions

Choose the correct answer from A to D.

1. Hexoses are:
   - A disaccharides with molecules that contain six carbon atoms
   - B monosaccharides with molecules that contain six oxygen atoms
   - C monosaccharides with molecules that contain six carbon atoms
   - D disaccharides with molecules that contain six oxygen atoms
2. The main advantage of the high level of branching in a molecule of amylopectin is that:
   - A the many 'ends' allow rapid hydrolysis
   - B much can be stored in a small space
   - C there are no osmotic effects
   - D it is insoluble
3. The secondary structure of a protein can be:
   - A a globular or a fibrous structure
   - B a specific sequence of amino acids
   - C a dipeptide
   - D an α-helix or a β-pleated sheet
4. Condensation involves:
   - A the creation of new bonds with the addition of a molecule of water
   - B the creation of new bonds with the loss of a molecule of water
   - C the breaking of existing bonds with the addition of a molecule of water
   - D the breaking of existing bonds with the loss of a molecule of water
5. A food gives a positive result when tested with the Biuret test, and an initial negative result when tested with Bendict's solution. Following acid hydrolysis and neutralisation, the food gave a negative test with Benedict's solution. The food contains:
   - A protein and a non-reducing sugar
   - B protein and a reducing sugar
   - C protein, a reducing sugar and a non-reducing sugar
   - D protein only

Activity 2.14

Work in groups of four. You are going to debate the importance of the four groups of biological molecules highlighted in this chapter – carbohydrates, lipids, proteins and nucleic acids. Each of you takes one of these types of molecules and spends about 5 minutes planning a short speech explaining why it is the most important type of biological molecule. Then listen to each other's speeches and take a vote on the most important. Record the results of your vote – how many votes each type of molecule gets.

Set up a tally chart of the board and add together the results from all the different groups. Which type of molecule won – or was it a draw? Discuss the outcome of the class voting.

6. In a saturated fatty acid:
   A there are only single bonds between carbon atoms
   B there is one double bond between carbon atoms
   C there is one triple bond between carbon atoms
   D there is more than one double bond between carbon atoms
7. Phospholipids form bilayers in water because:
   A the hydrophilic head is repelled by the water and the hydrophobic tail is attracted by it
   B the hydrophilic head is attracted by the water and the hydrophobic tail is repelled by it
   C both the hydrophilic head and the hydrophobic tail are attracted by the water
   D both the hydrophilic head and the hydrophobic tail are repelled by the water
8. When heated with Benedict's solution, sucrose does not cause a colour change because it is:
   A a reducing sugar
   B a disaccharide
   C a non-reducing sugar
   D a compound sugar
9. A triglyceride molecule is an ester of:
   A three fatty acids and ethanol
   B two fatty acids and glycerol
   C two fatty acids and ethanol
   D three fatty acids and glycerol
10. DNA is made from:
   A a single polynucleotide chain
   B a single chain of amino acids
   C two chains of amino acids
   D two polynucleotide chains
11. The functional group of a fatty acid is:
   A a ketone group
   B an aldehyde group
   C a carboxyl group
   D an amino group

12. DNA differs from RNA in that it (DNA) is:
    - A larger and double stranded
    - B smaller and double stranded
    - C smaller and single stranded
    - D larger and single stranded
13. Maltose is a:
    - A reducing monosaccharide sugar
    - B reducing disaccharide sugar
    - C non-reducing disaccharide sugar
    - D non-reducing monosaccharide sugar
14. The cellulose molecule is ideal for making cell walls because:
    - A it is an unbranched molecule
    - B molecules can hydrogen-bond with other cellulose molecules
    - C the molecules are relatively unreactive
    - D all of the above
15. A student carried out four biochemical tests to investigate the composition of onion, biscuit, potato and banana. The results are shown in the table. A ✓ indicates a positive result and a ✗ indicates a negative result.

Test	Onion	Biscuit	Potato	Banana
Add iodine solution	✗	✓	✓	✓
Boil with Benedict's solution	✓	✗	✗	✓
Ethanol emulsion test	✗	✓	✗	✗
Add Biuret reagent	✗	✓	✓	✗

Which food contained starch, lipid and protein?
- A onion
- B biscuit
- C potato
- D banana

Activity 2.15

Drawings of biological molecules in your text book are two dimensional but they are actually 3-D structures. Using any materials you have available – clay, beads, paper, straws – make simple 3-D models of the following: water, glucose, a general amino acid (see p62).

Summary

In this unit you have learnt that:

- Organic molecules always contain carbon and hydrogen.
- The most common elements in living tissue are carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorus.
- Atoms are the simplest particles of elements; they can join together to form molecules.
- Elements only contain one kind of atom.
- Compounds are made from molecules containing atoms joined together in a fixed ratio.
- Water is the most abundant substance on Earth; it covers three-quarters of the Earth's surface.
- Water has the chemical formula H_2O; the molecules can hydrogen-bond with each other.
- Water has several properties that are important to living things:
  - transparency allows light to penetrate, which allows water plants to photosynthesise
  - a high surface tension allows organisms to live on and just below the surface
  - a high specific heat capacity means that water does not heat up or cool down too quickly
  - a high latent heat of vaporisation means that water takes in a lot of energy when it is turned to a vapour
  - ice is less dense than liquid water, so ponds freeze from the top down allowing life to continue under the ice
  - it is a good solvent, allowing reactions to occur and making it ideal as a transport medium
  - it is a reactant in many reactions, including photosynthesis and all hydrolysis reactions (for example, those of digestion)
  - it has a low (but not too low) viscosity, again making it ideal as a transport medium.
- Carbohydrate molecules contain the elements carbon, hydrogen and oxygen only. The ratio of hydrogen atoms to oxygen atoms is 2:1.
- Monosaccharides are carbohydrates with atoms that are arranged in a single ring-like structure.
- The formula of α-glucose and all other hexose monosaccharides is $C_6H_{12}O_6$.
- Two monosaccharides can be joined by condensation to form a disaccharide. In the formation of maltose, two α-glucose molecules are joined with the loss of a molecule of water (H_2O). The formula of maltose is $C_{12}H_{22}O_{11}$.

- The bond joining the two molecules of α-glucose is an α-1,4-glycosidic bond.
- Polysaccharides are formed when many monosaccharide molecules join by condensation.
- Starch contains two polymers of α-glucose – amylose and amylopectin.
- Starch and glycogen are storage carbohydrates. They have compact molecules that enable much glucose to be stored in a small place. They are insoluble, which means that they have no osmotic effects within the cell and do not move from the cell.
- Amino acids contain carbon, hydrogen, oxygen and nitrogen. They have the general structure shown on the right.
- Amino acids can be joined by condensation. The bond between two amino acids is a peptide bond. A large number of amino acids joined in this way form a polypeptide.
- Proteins are polymers of amino acids. They have several levels of structure:
  - the primary structure is the sequence of amino acids in a polypeptide chain
  - the secondary structure is determined by the folding of the primary structure into either an α-helix or a β-pleated sheet; these structures are held in shape by hydrogen bonds
  - the tertiary structure is determined by the further folding of the secondary structure into either a fibrous or a globular shape; these structures are held in place by further hydrogen bonds, disulphide bridges and ionic bonds
  - some have a quaternary structure in which two or more polypeptide chains, each with a tertiary structure, are bonded together; a haemoglobin molecule consists of four polypeptide chains bonded together
- A triglyceride molecule is an ester of three fatty acid molecules and one glycerol molecule; the ester bonds are formed by condensation.
- Fatty acid molecules can be either saturated (all carbon–carbon bonds are single), monounsaturated (one carbon–carbon double bond) or polyunsaturated (more than one carbon–carbon double bond).
- A phospholipid molecule consists of two fatty acids and a phosphate group bonded to a molecule of glycerol. The phosphate group gives the molecule a hydrophilic ‘head’ and the fatty acids give the molecule hydrophobic ‘tails’.
- Phospholipid bilayers are the basis of biological membranes.
- Nucleic acids are made from nucleotides.

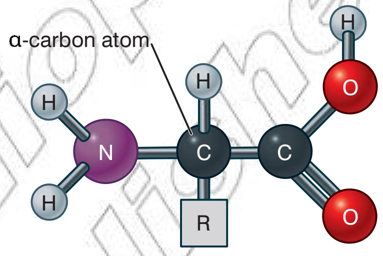
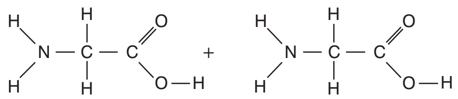


Figure 2.45 *General structure of amino acids*

- DNA is a double-stranded nucleic acid; RNA is a single-stranded nucleic acid.
- Reducing sugars react with Benedict's solution when heated to give a yellow/orange/red precipitate.
- Non-reducing sugars must first be hydrolysed by boiling with HCl and then neutralised before they will react with Benedict's solution; they then give the same yellow/orange/red precipitate as reducing sugars.
- Proteins react with Biuret reagent to give a mauve/purple colour.
- The emulsion test for lipids produces a milky-white colour in water.

End of unit questions



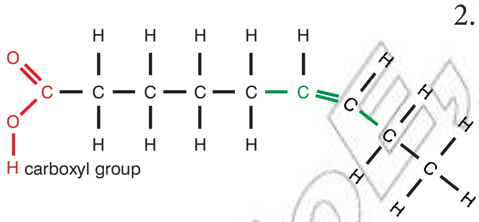
1. The diagram shows two amino acids.

   a) (i) Copy the diagram and indicate the amino group on one amino acid and the carboxyl group on the other.

   (ii) Draw another diagram to show how these amino acids could form a dipeptide.

   (iii) Name both the process involved in forming the dipeptide and the bond formed.

   b) Explain what is meant by the quaternary structure of a protein.



2. The diagram shows the arrangement of the atoms in a fatty acid.

   a) Is the fatty acid a saturated fatty acid, monounsaturated or polyunsaturated? Give a reason for your answer.

   b) A molecule of this fatty acid contains more carbon atoms than a glucose molecule. Give three other differences between the two molecules.

   c) Explain how fatty acids are used to form:

   (i) triglycerides

   (ii) phospholipids

3. a) Copy and complete the table.

Organic substance	Solubility in water	Sub-units	Elements present
Glucose		(None)	
Starch			C, H, O
Triglyceride			
Protein	Variable	Amino acids	

b) Describe how you would test a sample of powdered milk to see if it contained:

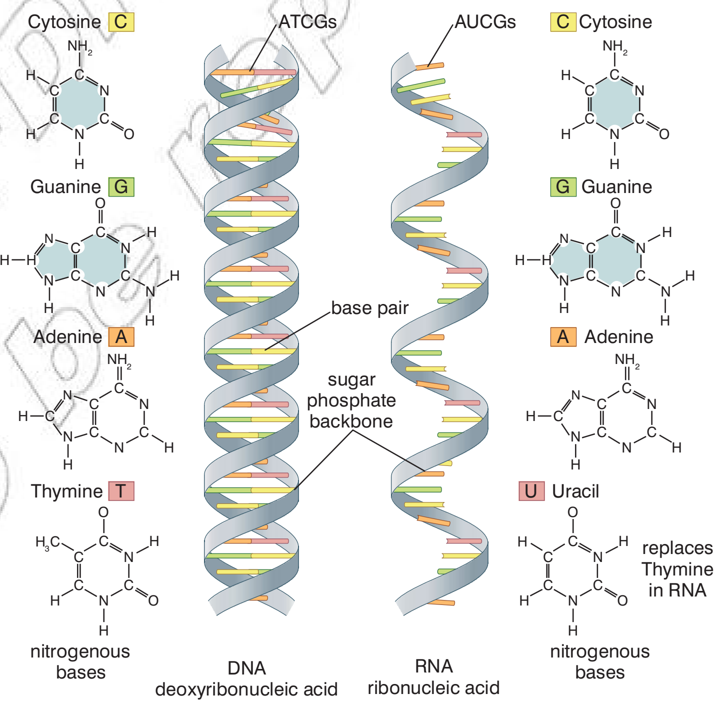
(i) reducing sugar

(ii) protein

4. Copy and complete the table, which describes the importance of some properties of water to living things.

Property	Importance to living things
High specific heat capacity	
Transparency	
	Takes a lot of energy to turn it to a vapour – allows temperature regulation by sweating
	Allows organisms to live at and just below the surface
Ice is less dense than liquid water	
	Allows many substances to dissolve and allows many reactions to take place

5. The diagram shows the molecules of DNA and RNA.



a) Describe three differences between the two molecules that you can see in the diagram.

b) Where is DNA found in a cell?

c) How is the structure of DNA adapted to its function?

6. a) Describe the structure of starch and explain how its structure makes it ideal for its function as a storage carbohydrate.

b) (i) Describe three ways in which the structure of cellulose differs from the structure of starch.

(ii) Describe two ways in which the structure of glycogen differs from the structure of starch.

7. a) Explain, with the aid of diagrams, how it is possible for glucose and fructose both to have the formula $C_6H_{12}O_6$ and yet be different substances.

b) What is meant by the term 'functional group'? Use two examples to illustrate your answer.

c) Explain what is meant by the term α-1,4-glycosidic link.

8. a) Four solutions were made up; one containing glucose, one containing starch, one containing amylase (a starch digesting enzyme) and one containing sucrose. Unfortunately, they were not labelled, except as solutions A, B, C and D. The following tests were carried out to identify the solutions.

All solutions were tested with Biuret reagent

- Solution C turns purple
- Solutions A, B and D remain blue

Solutions A, B and D tested with Benedict's solution

- Solutions A and B remain blue
- Solution D turns red

Solutions A and B incubated with Solution C and then retested with Benedict's solution

- Solution B turns red
- Solution A remains blue

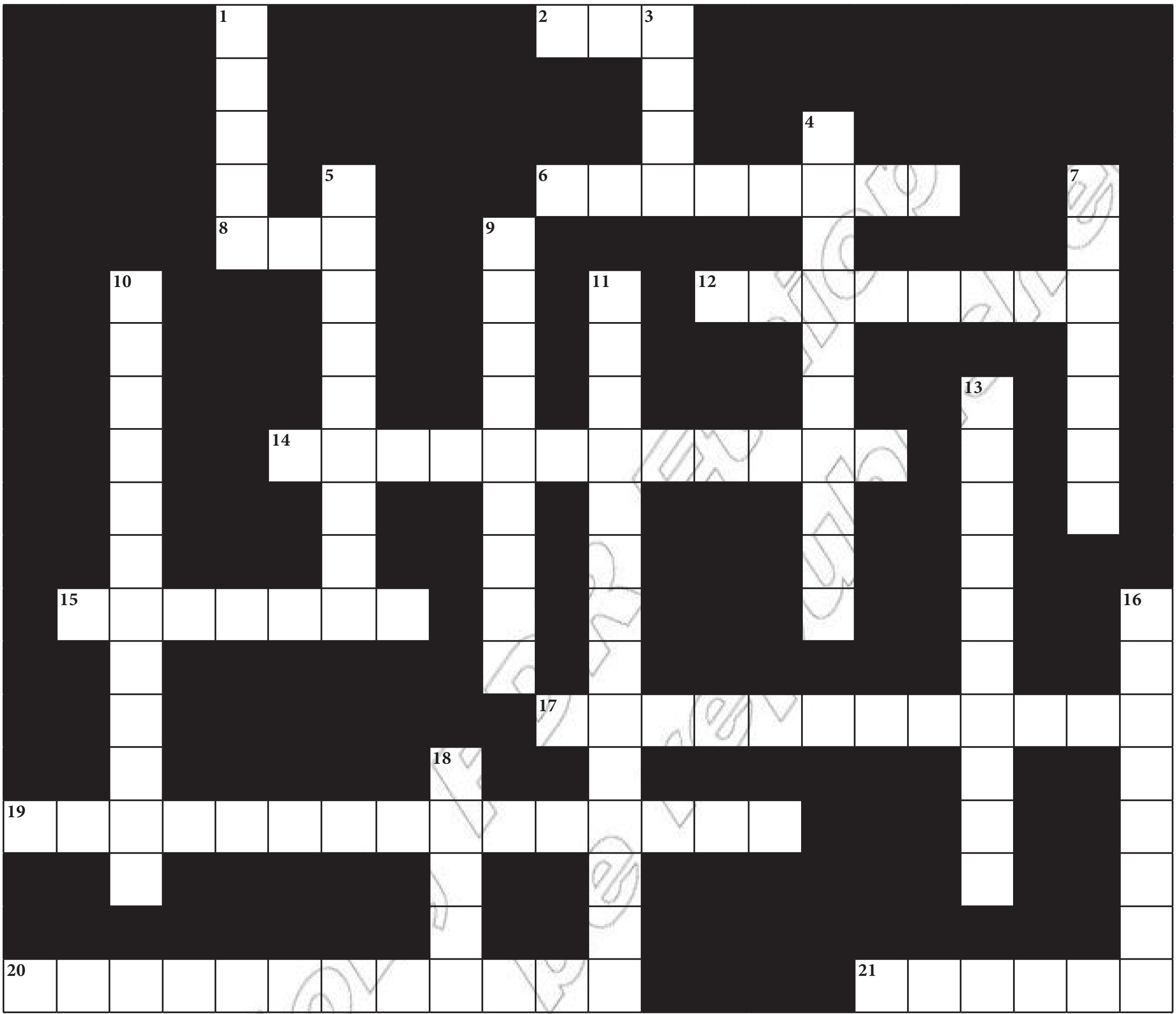
Identify, with reasons, the four solutions.

b) (i) Describe the structure of a saturated triglyceride.

(ii) Describe three ways in which a phospholipid differs from a triglyceride.

c) Describe three uses of lipids in living organisms.

Copy the crossword puzzle below into your exercise book (or your teacher may give you a photocopy) and solve the numbered clues to complete it.



Across

2. Nucleic acid found both in the nucleus and in the cytoplasm (3)
6. A substance containing two or more chemical elements in a fixed ratio (8)
8. Nucleic acid that is the hereditary material (3)
12. A particle containing at least two atoms joined together (8)
14. Type of organic molecule often used for energy release (12)
15. The type of bond that holds amino acids together (7)
17. Type of lipid that forms the bilayer in cell membranes (12)
19. The aldehyde group in glucose is an example of this (10, 5)
20. Two monosaccharides joined together (12)
21. Element found in carbohydrates with a valency of four (6)

Down

1. Organic substance used in mammals for insulation (5)
3. Smallest particle that retains the properties of an element (4)
4. Building block of nucleic acids (10)
5. Found in lipids, these can be saturated or unsaturated (5, 4)
7. Substance containing only one type of atom (7)
9. Building block of proteins (5, 4)
10. Type of bond that holds water molecules together (8, 4)
11. Starch and cellulose are examples of this type of carbohydrate (14)
13. Bond holding glucose molecules together (10)
16. Most common element in cells (8)
18. Liquid that freezes from the top down (5)