



AQA
A-level

Biology

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Go online for answers and extended glossaries:
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Get the most from this book

Welcome to the **AQA A-level Biology Student's Book**. This book covers all content for the AQA AS Biology specification and the AQA A-level Biology specification.

The following features have been included to help you get the most from this book.

Prior knowledge

This is a short list of topics that you should be familiar with before starting a chapter. The questions will help to test your understanding.

1 Biological molecules

Prior knowledge
Before you start, make sure that you are confident in your knowledge and understanding of the following points:

- Carbohydrates, fats and proteins are used by the body as fuels and to build cells.
- Many small molecules (monomers) can join together to form very large molecules (polymers).
- Protein molecules are made up of long chains of amino acids.
- They are folded to produce a specific shape that enables other molecules to fit into the protein.

Test yourself on prior knowledge

- Name the process in which molecules such as carbohydrates are used by the body as fuels.
- Proteins are polymers. Name the monomer from which they are made.
- Explain the difference between an atom and a molecule.

Molecules make up living organisms

You may think that living things – all very different from each other, and in some ways they are. But when you study them in detail, you find that all living things are fundamentally alike. They are all made of cells, and the molecules they are made from are the same, so at this level living things are remarkably similar to each other. These fundamental similarities are explained by evolutionary theory: it is thought that all living things share a common ancestor.

Figure 1.3 All living things are fundamentally alike when you look at the molecules they are made from.

TIP
Water is the most common molecule in cells and its properties are extremely important for life on Earth. You will find out about the properties of water in Chapter 10 on mass transport in plants.

Large and small molecules

The food we buy in a supermarket may be processed but, whether it is a pizza or peanut butter, it has been derived from living organisms. It contains substances that once made up those organisms, although maybe not in the same proportions. Three groups of these substances are very important in our diet. They are carbohydrates, proteins and lipids, and they all contain carbon. We describe the molecules of substances in these groups as being organic molecules. All other carbon-containing substances that were once in living organisms are also organic molecules.

Carbon atoms are unusual because they can form four chemical bonds. They can bond with other carbon atoms and with atoms of other elements. The carbon atoms can join in long, straight chains or in branched chains. Many of the organic molecules found in living organisms are very large in size and are known as macromolecules. Macromolecules are built up from much smaller molecules. In many macromolecules these small building blocks are called monomers and they may be identical or similar to each other. Several monomers join together to form a polymer.

Look at Figure 1.2. It shows how two monomers join together by a chemical reaction called **condensation**, in which a molecule of water is formed. This water molecule is made up of a hydrogen atom (H) that is removed from one of the two monomers, and a hydroxyl (OH) group from the other. Because parts of the molecules have been removed (to form water), we refer to the larger parts that remain as **residues**. Joining a lot of monomer residues in this way produces a polymer.

Polymers may be broken down to the monomers that formed them by **hydrolysis**. This reaction is the opposite of condensation, because it adds H and OH from a molecule of water (see Figure 1.2).

TIP
There are numerous examples of molecules joining together by condensation in biology. Many of them are polymers, but many more are not.

Carbohydrates

A carbohydrate molecule contains carbon, hydrogen and oxygen. It has twice as many hydrogen atoms as oxygen atoms – the same proportion as in water. Carbohydrates are divided into three main types:

- Monosaccharides are single sugars. Different monosaccharides contain different numbers of carbon atoms. Most of those that are important in our food, such as glucose, fructose and galactose, contain six carbon atoms.
- Disaccharides are carbohydrates that contain two monosaccharides joined together. Sucrose, maltose and lactose are disaccharides.
- Polysaccharides are very large molecules and contain many monosaccharides. Starch is a polysaccharide.

Key terms and formulae

These are highlighted in the text and definitions are given in the margin to help you pick out and learn these important concepts.

Tips

These highlight important facts, common misconceptions and signpost you towards other relevant topics.

Test yourself questions

These short questions, found throughout each chapter, are useful for checking your understanding as you progress through a topic.

TIP
Get Chapter 14 to find out how to calculate magnification. See Chapter 15 to find out how to use measuring instruments such as a micrometer and a microscope.

TEST YOURSELF
1. Explain the similarities and differences between a prokaryotic cell and a eukaryotic cell.
2. A bacterial cell is 2 μm long. Its length in a diagram is 40 mm. What is the magnification of the diagram?

Practice questions

1 The figure shows a bacterial cell.

a) Name structures A, B and C.
b) The following descriptions apply to structures found in a human cell. Give the name of each structure:

| Name of structure | Description |
|-------------------|--|
| | Contains proteins and lipids that surround the cell. |
| | Contains enzymes that digest substances within the cell. |
| | Contains genetic material in the form of a chromosome. |
| | Increases the surface area of the cell. |

2 a) Copy and complete the table with a tick if the statement applies or a cross if the statement does not apply.

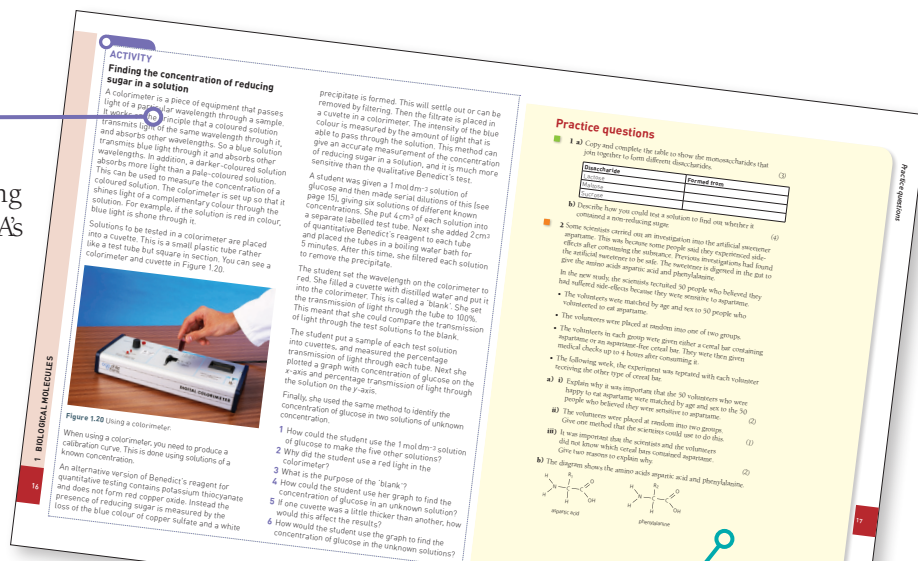
| Feature | Uses membrane proteins | Requires energy from ATP |
|------------------|------------------------|--------------------------|
| Active transport | | |
| Channel proteins | | |

b) A student cut a potato tuber in half. She placed the cut part of the potato in a beaker of distilled water. She then scooped out a hollow in the top of the potato and placed 10% sucrose solution into this hollow. She left the potato for 3 hours. The figure shows the results of her investigation.

c) The level of the solution in the hollow at the top of the potato rose. Use your knowledge of water potential to explain why.

Activities and Required practicals

These practical-based activities will help consolidate your learning and test your practical skills. AQA's required practicals are clearly highlighted.



Practice questions

You will find Practice questions at the end of every chapter. These follow the style of the different types of questions you might see in your examination, including multiple-choice questions, and are colour coded to highlight the level of difficulty. Test your understanding even further, with Maths questions and Stretch and challenge questions.

- Green – Basic questions that everyone should be able to answer without difficulty.
- Orange – Questions that are a regular feature of exams and that all competent candidates should be able to handle.
- Purple – More demanding questions which the best candidates should be able to do.
- Stretch and challenge – Questions for the most able candidates to test their full understanding and sometimes their ability to use ideas in a novel situation.

Extension

Throughout the book you will also find Extension boxes, which contain extra material to deepen your understanding of a topic.

Figure 2.6 In the induced-fit model, the substrate does not fit perfectly with the active site of the enzyme. The active site then changes shape to better fit the substrate, allowing a reaction to occur.

Extension

Evidence for the induced-fit model

It is one thing to come up with a model to explain how enzymes work, but in order to make that scientific progress we need to find evidence to support it. Is there any evidence for the induced-fit model? We'll look at one piece of evidence.

Hexokinase is an enzyme that phosphorylates glucose. The reaction is shown below:

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

Hexokinase transfers a phosphate group from a substance called ATP to a glucose molecule. This produces glucose-6-phosphate and ADP. Scientists used a technique called X-ray diffraction, which could then be used to form three-dimensional pictures of molecules. They investigated what happened to the shape of hexokinase when it binds to glucose.

Look at Figure 2.7. It shows you that the active site has changed in shape and has moulded round the glucose molecule.

Figure 2.7 The diagram shows the shape of a hexokinase molecule before and after it has bound with the glucose substrate. Look at how the shape of the active site has changed.

TEST YOURSELF

- 1 Name the substrate and product in the following reaction. Lactase catalyses the hydrolysis of lactose to glucose and galactose.
- 2 Use a diagram to explain why enzymes can hydrolyse starch but cannot hydrolyse cellulose.
- 3 A student wrote: 'Maltase forms an enzyme-substrate complex with maltose because maltose is the same shape as the enzyme's active site.' What is wrong with this statement?
- 4 In the Haber process, nitrogen and hydrogen react together to form ammonia, using a catalyst as well as an 18–20 megapascal (MPa) pressure and 350–500°C. Nitrogen-fixing bacteria have an enzyme called nitrogenase that enables them to carry out the same reaction at atmospheric pressures and normal soil temperatures. How does the enzyme do this?

The properties of enzymes: active sites and enzyme action

Enzyme-controlled reactions depend on substrate molecules fitting into the active site of the enzyme. Environmental factors alter the shape of the active site and therefore alter the rate of a reaction. Such factors include high temperatures, variations in pH and the presence of inhibitors.

High temperatures

Each enzyme has an optimum temperature. At this temperature, its rate of reaction is at its maximum. If the temperature is increased above this optimum, we increase the kinetic energy of the enzyme molecules. As a result, they vibrate more vigorously and this breaks the hydrogen bonds and ionic bonds that maintain the tertiary structure of the enzyme molecules. Once these bonds have broken, the enzyme changes its shape. This is called **denaturation**. Its active site also changes shape and, as a result, substrate molecules will no longer fit and form an enzyme-substrate complex. For example, the saliva of many people contains amylase. This enzyme most actively digests starch at body temperature. When your food is eaten, very little will be digested in the mouth as the temperature is too high.

EXAMPLE

Temperature and enzymes

Acetylcholinesterase is an enzyme that exists in several different forms in different animal species. It is found in the nerve endings of many animals including fish.

Table 2.1 shows the temperature at which the rate of reaction catalysed by acetylcholinesterase is at its maximum in three different species of fish.

| Species | Habitat | Temperature at which the rate of reaction is at a maximum/°C |
|-------------|--|--|
| Trout | Coldwater lakes and streams in Britain | Between 2 and 18 |
| Grey mullet | Mediterranean Sea | 25 |

1 Describe the relationship between the temperature of the fish's habitat and the temperature at which the rate of reaction of acetylcholinesterase is at a maximum.

The temperature at which the enzyme's rate of reaction is at its maximum is about the same temperature that the fish's habitat will be for most of the time.

2 Trout have two forms of acetylcholinesterase, which are active under different environmental conditions. One has a maximum rate of reaction at 18°C. Suggest the advantage of this.

The form of acetylcholinesterase will be more active in the summer months when the environmental temperature is higher.

3 Acetylcholinesterase is found in codfish and grey mullet, but it has slightly different properties in three different species of fish.

The enzyme has an active site that is the right shape for acetylcholine to fit into.

4 Use your knowledge of protein structure to explain why the acetylcholinesterase found in these two fish has slightly different properties. Each enzyme has a slightly different amino acid sequence so that hydrogen bonds and disulfide bridges form in slightly different places, giving a slightly different tertiary structure.

Examples

Examples of questions and calculations feature full workings and sample answers.

Dedicated chapters for developing your **Maths** and **Practical skills** and **Preparing for your exam** can be found at the back of this book.

1

Biological molecules

PRIOR KNOWLEDGE

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TEST YOURSELF ON PRIOR KNOWLEDGE

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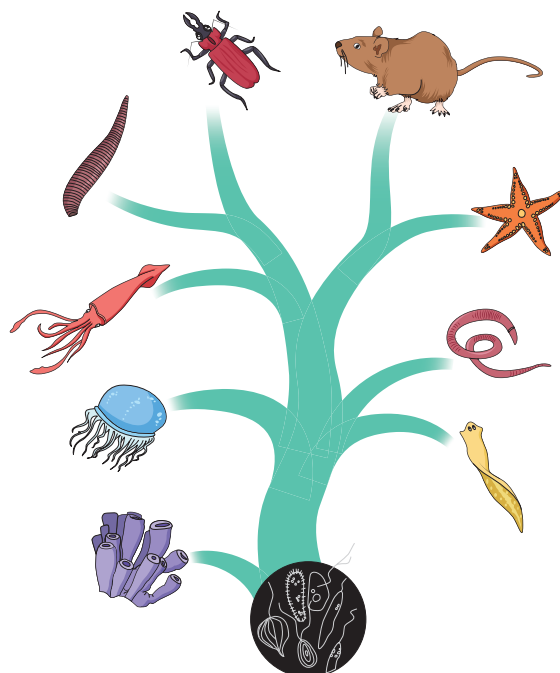


Figure 1.1 All living things are fundamentally alike when you look at the molecules they are made from.

TIP

Water is the most common molecule in cells and its properties are extremely important for life on Earth. You will find out about the properties of water in Chapter 10 on mass transport in plants.

Large and small molecules

The food we buy in a supermarket may be processed but, whether it is a pizza or peanut butter, it has been derived from living organisms. It contains substances that once made up those organisms, although maybe not in the same proportions. Three groups of these substances are very important in our diet. They are carbohydrates, proteins and lipids, and they all contain carbon. We describe the molecules of substances in these groups as being organic molecules. All other carbon-containing substances that were once in living organisms are also organic molecules.

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Polymers may be broken down to the monomers that formed them by **hydrolysis**. This reaction is the opposite of condensation, because it adds $-H$ and $-OH$ from a molecule of water (see Figure 1.2).

TIP

There are numerous examples of molecules joining together by condensation in biology. Many of them are polymers, but many more are not.

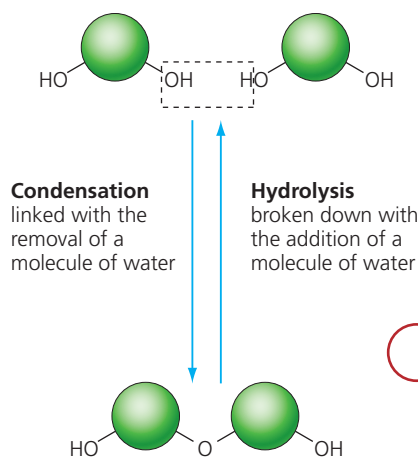


Figure 1.2 Monomers join together by condensation to form a polymer. This diagram shows two monomers joining together. When a large number of monomers are joined like this, we get a polymer. A polymer can be broken down into its monomers by hydrolysis.

Carbohydrates

A carbohydrate molecule contains carbon, hydrogen and oxygen. It has twice as many hydrogen atoms as oxygen atoms – the same proportion as in water. Carbohydrates are divided into three main types:

- Monosaccharides are single sugars. Different monosaccharides contain different numbers of carbon atoms. Most of those that are important in our food, such as glucose, fructose and galactose, contain six carbon atoms.
- Disaccharides are carbohydrates that contain two monosaccharides joined together. Sucrose, maltose and lactose are disaccharides.
- Polysaccharides are very large molecules and contain many monosaccharides. Starch is a polysaccharide.



Figure 1.3 Most of the carbohydrate that we eat comes from plants. This crop is sugar cane, a plant that stores sucrose in its stem. The carbohydrate stored by other food plants such as potatoes and cereals is starch.

Glucose and other sugars

Glucose is a monosaccharide, so it is a single sugar. Its molecular formula is $C_6H_{12}O_6$. This formula simply tells us how many atoms of each element there are in each glucose molecule.

Now look at the structural formulae shown in Figure 1.4. They show a molecule of α -glucose and a molecule of β -glucose. Count each type of atom in diagram (a). There are 6 carbon atoms, 12 hydrogen atoms and 6 oxygen atoms, equal to the numbers of different atoms shown by the molecular formula, $C_6H_{12}O_6$. This diagram also shows you how the atoms are arranged.

All glucose molecules have the same formula, $C_6H_{12}O_6$. However, there are two different kinds of glucose. This is because the atoms in the glucose molecule can be arranged in different ways, called isomers. Figure 1.4 shows the arrangement of the atoms in the two different kinds of glucose.

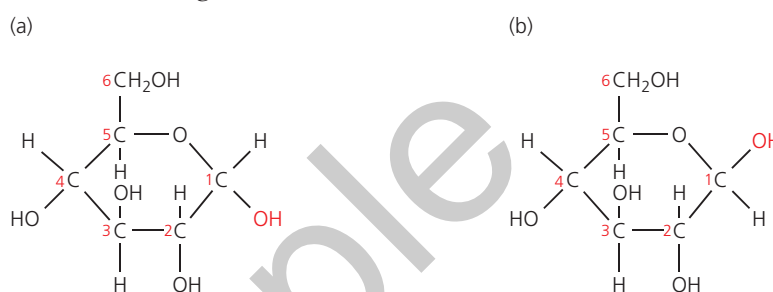


Figure 1.4 (a) An α -glucose molecule; and (b) a β -glucose molecule.

Look at the way that the $-H$ and $-OH$ groups are bonded to the carbon atom on the right-hand side (1C) in β -glucose. Now look at the $-H$ and $-OH$ groups bonded to the carbon atom on the left-hand side (C4). Notice that they are bonded the opposite way round. Compare this with the diagram of α -glucose. Here, both $-H$ groups are above the carbon atoms, and both $-OH$ groups are below the carbon atoms.

Galactose and fructose are also monosaccharides and have exactly the same molecular formula as α -glucose. However, the atoms that make up these molecules are arranged in different ways. This means that, although all three substances are sugars, they have slightly different structures. This gives them slightly different properties.

Monosaccharides such as α -glucose are the monomers that join together to make many other carbohydrates. Two α -glucose molecules join by condensation to form a molecule of the disaccharide maltose. The bond forms between carbon 1 of one α -glucose molecule and carbon 4 of the other; such a bond is called a **glycosidic bond** (see Figure 1.5).

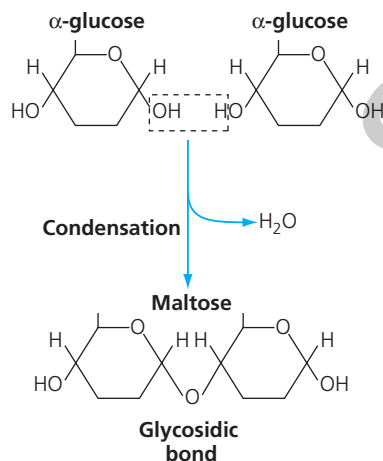


Figure 1.5 Two α -glucose molecules join together by condensation to give a molecule of the disaccharide maltose.

Glycosidic bond A chemical bond formed as the result of condensation between two monosaccharides.

Reduction is gain of electrons or hydrogen.

Other disaccharides form in a similar way. Lactose, for example, is the sugar found in milk. It is formed in a condensation reaction between a molecule of α -glucose and a molecule of another monosaccharide, galactose. Sucrose is formed from α -glucose and fructose.

When sugars such as α -glucose are boiled with Benedict's solution, an orange precipitate is formed because $Cu(II)$ ions in the Benedict's solution are **reduced** to orange $Cu(I)$ ions. This reaction occurs because of the way the chemical groups are arranged in such sugars. These sugars are therefore called reducing sugars. Fructose, maltose and galactose are also reducing sugars.

Extension

Structure of amylose and amylopectin

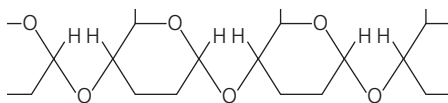
Figure 1.6 shows the structure of starch. You can see that amylose is a long chain of α -glucose molecules. They are linked by 1,4-glycosidic bonds. This chain is coiled into a spiral and its coils are held in place by chemical bonds called hydrogen bonds. Amylopectin is also a polymer of α -glucose but its molecules are branched due to 1,6-glycosidic bonds.

In amylose, the α -glucose molecules are linked by 1,4-glycosidic bonds. Notice that the $-\text{CH}_2\text{OH}$

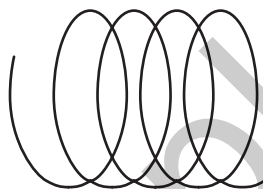
side-chains all stick out on the same side. This arrangement causes the chains of α -glucose molecules to coil into spirals as shown in Figure 1.6. Amylopectin molecules have branches because some of the α -glucose molecules form bonds between carbon atoms 1 and 6 instead of 1 and 4. This enables starch molecules to fold up compactly.

Amylose

consists of a long chain of α -glucose residues



The chain is coiled into a spiral. Hydrogen bonds hold this spiral in shape.



Amylopectin

consists of branched chains of α -glucose residues

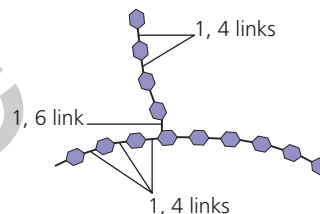


Figure 1.6 Starch consists of amylose and amylopectin. Starch from different plants contains different amounts of these two substances.

TIP

You can remember that oxidation is loss of electrons or hydrogen and reduction is gain of electrons or hydrogen by using the mnemonic OILRIG: Oxidation Is Loss, Reduction Is Gain.

Sucrose does not give an orange precipitate with Benedict's solution; it is a non-reducing sugar. However, when boiled with dilute acid, sucrose is hydrolysed to monosaccharides. The sucrose molecules are hydrolysed into α -glucose and fructose, both reducing sugars. Then it will give a positive test with Benedict's solution. (See page 14 for details of qualitative tests.)

Starch

Starch, a substance found in plants, is one of the most important fuels in the human diet. It makes up about 30% of what we eat. Starch is a mixture of two substances, amylose and amylopectin. Both these substances are polymers made from a large number of α -glucose molecules joined together by condensation reactions. In the biochemical test for starch, you add a drop of iodine solution. A blue-black colour indicates the presence of starch.

Storage molecules

Starch for storage

We use the starch from plants as a fuel. For many plants, starch is a storage compound, both for short-term storage overnight when photosynthesis cannot occur, and for long-term storage, for example in seeds and in the

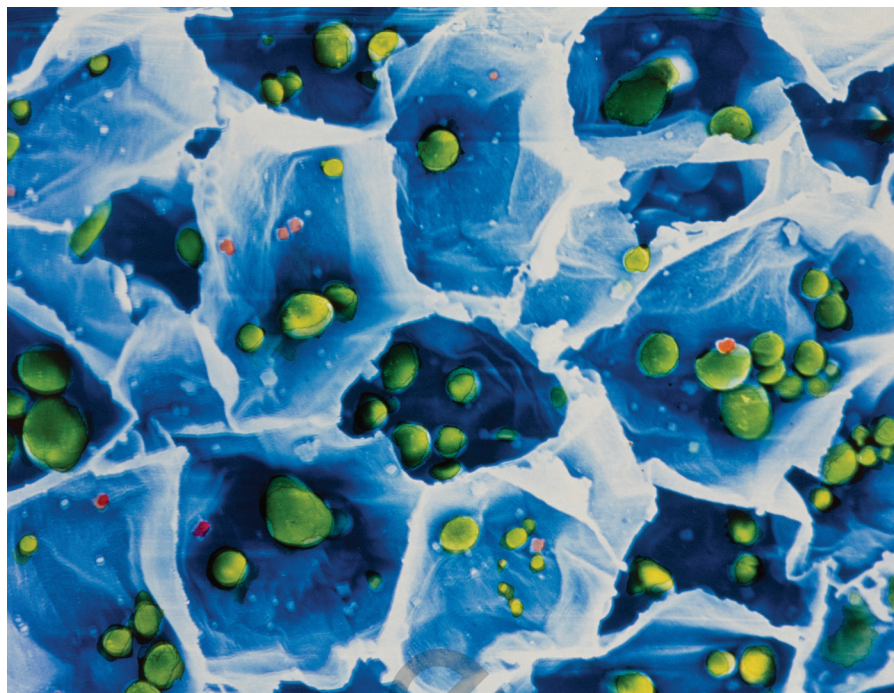


Figure 1.7 Starch molecules can fold up compactly and can therefore fit into small storage organelles, such as the starch grains in potato tuber cells, shown here. The starch grains are shown in green.

organs such as bulbs and tubers that survive through the winter. It is particularly suited for storage because it is insoluble and so does not diffuse out of cells easily or have any effects on water potential and thus osmosis.

As a storage compound it is important that starch can be easily synthesised and broken down. Plants have enzymes that can rapidly carry out these processes.

We have a digestive enzyme called amylase that hydrolyses the starch in our diet to maltose. This can then be hydrolysed into glucose, which is needed to provide a source of fuel for respiration.

Glycogen for storage

Animals such as humans do not rebuild excess glucose into starch for storage. Instead, we make it into a polysaccharide similar to starch called glycogen.

Like amylopectin, glycogen also consists of α -glucose chains with both 1,4- and 1,6-glycosidic bonds, but the 1,6 bonds are much more frequent, so the molecules are much more branched (see Figure 1.8, overleaf). This makes glycogen molecules even more compact than starch molecules. In humans, some glycogen is stored in the muscles as a readily accessible store of glucose close to the site where the rate of respiration is regularly raised very rapidly. The liver stores larger reserves of glycogen and continually breaks it down to maintain a stable blood glucose concentration.

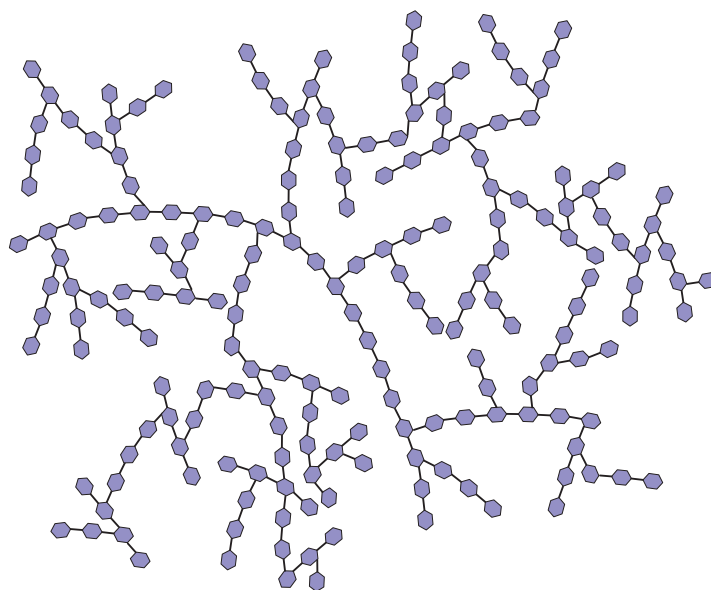


Figure 1.8 A glycogen molecule.

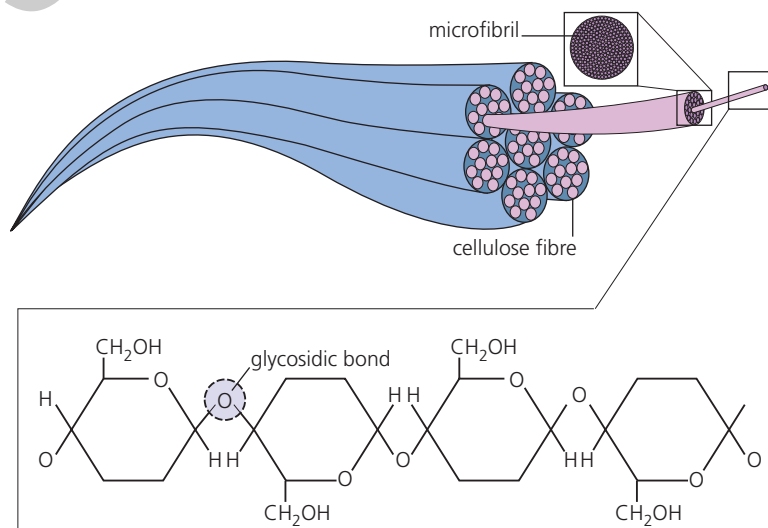
Cellulose for strength

The main substance in a plant cell wall is the carbohydrate cellulose. Like starch, cellulose is a polysaccharide and is a polymer of glucose. The monomer in cellulose is β -glucose.

Hydrogen bond A chemical bond important in the three-dimensional structure of biological molecules. Hydrogen bonds require relatively little energy to break.

In cellulose, the β -glucose molecules join together in chains by condensation. As when starch chains are made from α -glucose molecules, glycosidic bonds are formed. But in the cellulose chains, every other β -glucose is 'upside-down', so the $-\text{CH}_2\text{OH}$ side-chains stick out alternately on opposite sides, as you can see in Figure 1.9. This 'alternate' bonding makes the cellulose molecules very straight. They are also very long. They line up parallel with each other and become linked together by many **hydrogen bonds**. Although each hydrogen bond is weak, many together lead to strong binding between the molecules.

Figure 1.9 Cellulose is a polymer of β -glucose molecules joined by glycosidic bonds. Its molecules are long and straight and form fibres that are very strong. Cellulose gives cell walls their strength and resistance to being stretched.



Long chain of 1,4 linked β -glucose residues. Hydrogen bonds link these chains together to form microfibrils.

Small bundles of cellulose molecules make very thin fibres, called microfibrils. These microfibrils are remarkably strong. They have the ability to withstand stretching as steel fibres of the same diameter. Groups of microfibrils are joined together to make thicker, stronger fibres, just as a piece of string is made from many thinner strands. In cell walls, these fibres are criss-crossed, making the walls resistant to stretching in any direction.

Cellulose is structurally so well suited to its functions of supporting cells and limiting water intake that it is found throughout the plant kingdom. It is probably the most abundant carbohydrate. Surprisingly, neither humans nor any other mammal are able to make an enzyme that can digest cellulose. There are bacteria and fungi that do make such an enzyme, and these play an important role in recycling the constituents of cellulose. This is fortunate, since otherwise the world would have disappeared under cellulose long ago. Mammals such as cattle and rabbits, whose diet consists largely of plants, carry bacteria in their guts that hydrolyse cellulose, so they can make use of the energy in the large quantities of cellulose in their food. Humans, however, have no means of extracting the energy stored in cellulose.

TEST YOURSELF

- 1 Explain, using a diagram, how α -glucose molecules join together by condensation.
- 2 List the differences between the structures of cellulose molecules and starch molecules.
- 3 Starch is insoluble and does not affect osmosis in cells in which it is stored. Explain how these properties make starch a good storage compound.
- 4 What features of glycogen make it useful as a storage molecule in muscle tissue?
- 5 The molecular formula of galactose is $C_6H_{12}O_6$. What is the molecular formula of a molecule of lactose?
- 6 Starch molecules from different plants may differ from each other. Give two ways in which they might be different.

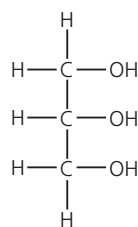
Lipids

The term 'lipids' covers a group of substances that includes fats and oils (triglycerides), steroids and sterols, and waxes. Two groups of lipids are especially significant. These are triglycerides and phospholipids. You will learn in Chapter 3 that the cell-surface membrane is made up of lipids and proteins.

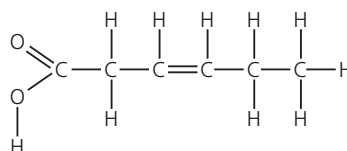
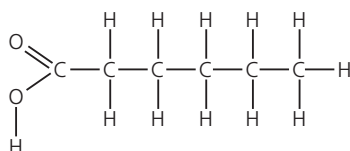
Triglycerides

The commonest lipids found in living organisms are triglycerides. Most of the triglycerides found in animals are known as fats. They are solid at a temperature of about 20°C . A triglyceride is made up of a molecule of glycerol and three fatty acid molecules. The basic structures of these molecules are shown in Figure 1.10, overleaf.

As Figure 1.10 shows, there are two kinds of fatty acids. Saturated fatty acids have only single bonds between the carbon atoms. Unsaturated fatty acids have at least one double bond between carbon atoms. In general,



- (a) Glycerol is a type of alcohol. It has three –OH groups, each of which can undergo a condensation reaction with a fatty acid.
- (b) This is the simplest formula for a fatty acid molecule. The letter R represents a hydrocarbon chain consisting of carbon and hydrogen atoms.



- (c) In saturated fatty acids, each of the carbon atoms in this chain, with the exception of the last, has two hydrogen atoms joined to it. The bonds between the carbon atoms are single bonds.
- (d) In unsaturated fatty acids, there are one or more double bonds between the carbon atoms in the chain. Because of this, some carbon atoms will be joined only to a single hydrogen atom.

Figure 1.10 The basic structure of a molecule of (a) glycerol and (b) fatty acid; (c) shows the structure of a saturated fatty acid and (d) shows the structure of an unsaturated fatty acid.

saturated fatty acids have higher melting points than unsaturated fatty acids. Fats that are solid at room temperature, such as lard or butter, tend to have more saturated fatty acids in them, while oils that are liquid at room temperature, such as sunflower or olive oil, have more unsaturated fatty acids.

Glycerol is a type of alcohol. Look at Figure 1.10 (a). You will see that there are three –OH groups in glycerol. These groups allow the molecule to join with three fatty acids to produce a triglyceride. Figure 1.10 (b) is the simplest possible way of showing the structure of a fatty acid molecule. The letter R represents a chain of hydrogen and carbon atoms. In the fatty acids found in animal cells there are often 14 to 16 carbon atoms in this chain.

When a triglyceride is formed, a molecule of water is removed as each of the three fatty acids joins to the glycerol. You may remember that this type of chemical reaction is called condensation (see page 2). The formation of a triglyceride from glycerol and fatty acids is shown in Figure 1.11. The bond formed between the glycerol and the fatty acid is called an ester bond.

You can use the emulsion test to test for lipids such as triglycerides. Crush a little of the test material and mix it thoroughly with ethanol. Pour the resulting solution into water in a test tube. A white emulsion shows that a lipid is present.

- Draw a diagram to show a glycerol molecule.
- Draw three fatty acid molecules 'the wrong way round' next to it.

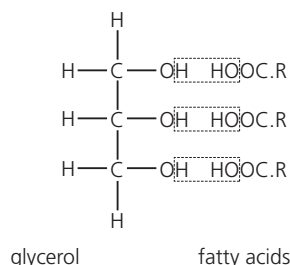
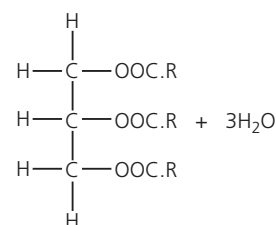


Figure 1.11 This diagram is a simple way of showing how a molecule of glycerol joins with three fatty acid molecules to form a triglyceride.

- Remove three molecules of water, taking the H from the glycerol and the -OH from the fatty acids.

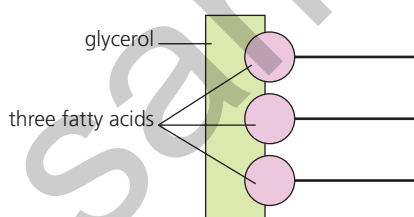


- Close everything up to show the completed triglyceride.

Phospholipids

A phospholipid has a very similar structure to a triglyceride, but as you can see from Figure 1.12, it contains a phosphate group instead of one of the fatty acids. It is quite a good idea to think of a phospholipid as having a 'head' consisting of glycerol and phosphate and a 'tail' containing the long chains of hydrogen and carbon atoms in the two fatty acids. The presence of the phosphate group means that the 'head' is attracted to water. It is therefore described as being **hydrophilic** or 'water loving'. The hydrocarbon tails do not mix with water, so this end of the molecule is described as **hydrophobic** or 'water hating'.

Triglyceride



Phospholipid

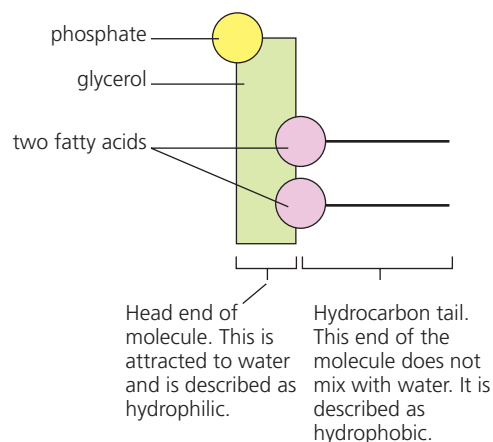


Figure 1.12 A phospholipid has a structure very similar to a triglyceride, but it contains a phosphate group instead of one of the fatty acids.

When phospholipids are mixed with water, they arrange themselves in a double layer with their hydrophobic tails pointing inwards and their hydrophilic heads pointing outwards. This double layer is called a phospholipid bilayer and forms the basis of membranes in and around cells.

TEST YOURSELF

- 7 Triglycerides are not polymers. Explain why.
- 8 Carbohydrates and triglycerides are both made of carbon, hydrogen and oxygen atoms. Explain how the proportions of these atoms are different in carbohydrates and triglycerides.
- 9 How is a triglyceride different from a phospholipid?

ACTIVITY

Fatty acids in milk

Milk contains triglycerides. Scientists investigated whether the fatty acids in human breast milk depend on the food that the mother eats. The scientists collected samples of breast milk from two groups of women. The women in one group were vegans and only ate food obtained from plants. Those in the other group, the control group, ate food obtained from both animals and plants. Table 1.1 shows the concentrations of different fatty acids in the milk samples.

Table 1.1 The concentrations of different fatty acids in vegan and control group milk samples.

| Fatty acid | Number of double bonds in hydrocarbon chain | Number of carbon atoms in hydrocarbon chain | Concentration of fatty acid in breast milk sample/mg g ⁻¹ | |
|-------------|---|---|--|---------------|
| | | | Vegan group | Control group |
| Lauric | 0 | 12 | 39 | 33 |
| Myristic | 0 | 14 | 68 | 80 |
| Palmitic | 0 | 16 | 166 | 276 |
| Stearic | 0 | 18 | 52 | 108 |
| Palmitoleic | 1 | 16 | 12 | 36 |
| Oleic | 1 | 18 | 313 | 353 |
| Linoleic | 2 | 18 | 317 | 69 |
| Linolenic | 3 | 18 | 15 | 8 |

- 1 The first four fatty acids in the table are saturated fatty acids. Explain why they are described as saturated.
- 2 Construct a table to show all of the following:
 - the total concentration of saturated fatty acids in milk from the vegan group
 - the total concentration of unsaturated fatty acids in milk from the vegan group
 - the total concentration of saturated fatty acids in milk from the control group
 - the total concentration of unsaturated fatty acids in milk from the control group.
- 3 Use an example from the table to explain what is meant by a polyunsaturated fatty acid.
- 4 Describe the difference between the total concentration of polyunsaturated fatty acids in milk produced by the vegan group and by the control group. Suggest an explanation for this difference.

Proteins

Earlier in this chapter, we saw that starch is a polymer made up of a single type of monomer, α -glucose. Whether these α -glucose monomers are joined to form straight chains or branched chains, they still form starch. Different types of starch are very similar.

Proteins are different. The basic building blocks of proteins are amino acids. There are 20 different amino acids found in almost all living organisms, which is indirect evidence for evolution. These amino acids can be joined in a range of different orders. In any living organism, there are a huge number of different proteins and they have many different functions.

If we take a single tissue, such as blood, we can get some idea of just how varied and important are the roles of proteins. Human blood is red because it contains haemoglobin. This is an iron-containing protein that plays an extremely important part in transporting oxygen from the lungs to respiring cells. When you cut yourself, blood soon clots. This is because another protein, fibrin, forms a mesh of threads over the surface of the wound, trapping red blood cells and forming a scab. Blood also contains enzymes, which are proteins. The antibodies produced by white blood cells are also proteins, and are important in protecting the body against disease.

The biuret reaction enables us to test for a protein. Sodium hydroxide solution is added to a test sample, and then a few drops of dilute copper sulfate solution. If there is a protein present, the solution will turn mauve.

Amino acids: the building blocks of proteins

All 20 amino acids have the same general structure. Look at Figure 1.13. Notice that there is a central carbon atom called the α -carbon and that it is attached to four groups of atoms. There is an amine group ($-\text{NH}_2$). This is the group that gives the molecule its name. Then we have a carboxyl group (the acid; $-\text{COOH}$) and a hydrogen atom ($-\text{H}$). These three features are exactly the same in all 20 amino acids. The fourth group, called the R-group, differs from one amino acid to another. As well as showing the general structure of an amino acid, Figure 1.13 also shows the structures of three particular amino acids found in proteins. In each of these three amino acids (and in the other 17), it is only the R-group that is different.

Peptide bond A chemical bond formed between two amino acids as a result of condensation.

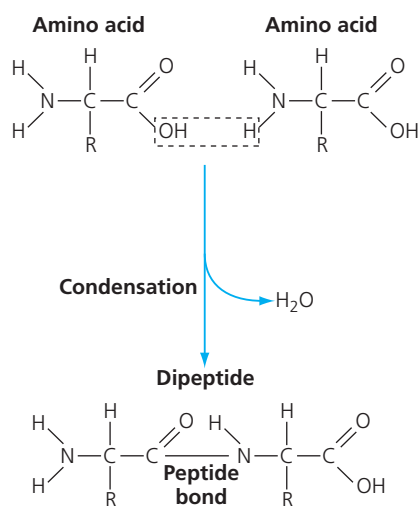


Figure 1.14 Joining amino acids.

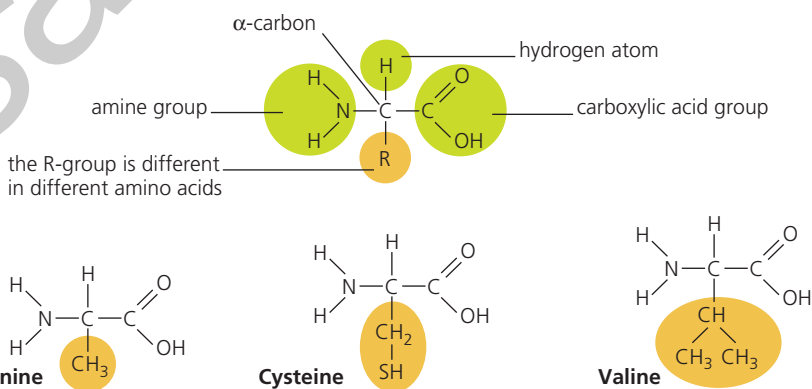


Figure 1.13 The structure of amino acids.

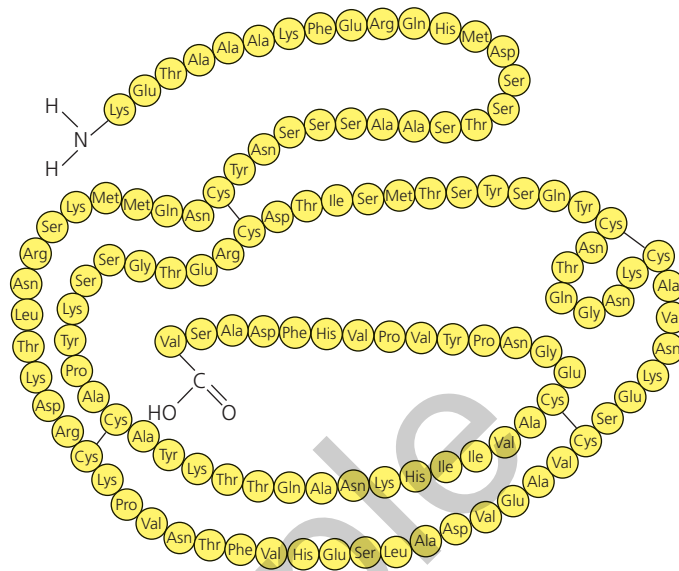
Amino acids join together by condensation reactions. Look at Figure 1.14. You can see that a hydrogen atom is removed from the amino group of one amino acid. This combines with an $-\text{OH}$ group removed from the carboxylic acid of the other amino acid, forming a molecule of water. The bond formed between the two amino acid residues is called a **peptide bond**. Joining two amino acids together produces a dipeptide. When many amino acids are joined in this way, they form an unbranched chain called a polypeptide. Polypeptides can be broken down again by hydrolysis into the amino acids from which they are made.

Primary structure The sequence of amino acids in a polypeptide.

Figure 1.15 This diagram shows the primary structure of an enzyme called ribonuclease. The names of the amino acids that make up this protein have been abbreviated. Ribonuclease has 124 amino acids. Some proteins, such as antibodies, are much larger and contain many more amino acids.

Polypeptides and proteins

A protein consists of one or more polypeptide chains folded into a complex three-dimensional shape. Different proteins have different shapes, determined by the order in which the amino acids are arranged in the polypeptide chains. The sequence of amino acids in a polypeptide chain is the **primary structure** of a protein (see Figure 1.15).



We shall see in Chapter 4 that genes carry the genetic information that enables cells to make polypeptides and ensures that the sequence of amino acids is the same in all molecules of a particular polypeptide. Changing a single one of these amino acids may be enough to cause a change in the shape of the protein and prevent it from carrying out its normal function.

Secondary structure The shape the polypeptide chain folds into, such as an alpha helix or a beta pleated sheet.

Parts of a polypeptide chain are twisted and folded. This is the **secondary structure** of a protein.

Extension

Secondary structure: α -helix and β -pleated sheet

Sometimes the chain, or part of it, coils to produce a spiral or α -helix. Other parts of the polypeptide may form a β -pleated sheet; this occurs where two or more parts of the chain run parallel to each other and are linked to each other by hydrogen bonds.

The sequence of amino acids in the polypeptide decides whether an α -helix or a β -pleated sheet is formed. Some sequences are more likely to form an α -helix, while others form a β -pleated sheet, as in Figure 1.16.

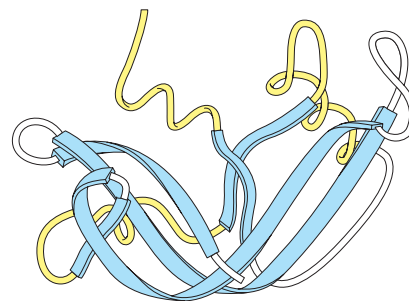


Figure 1.16 Here is another diagram of a ribonuclease molecule, this time showing its secondary structure. The three spiral yellow parts of the polypeptide chain are where it is coiled into an α -helix. The flat blue sections show where the chain is folded to form a β -pleated sheet.

Tertiary structure Gives a protein the characteristic complex, three-dimensional shape that is closely related to its function.

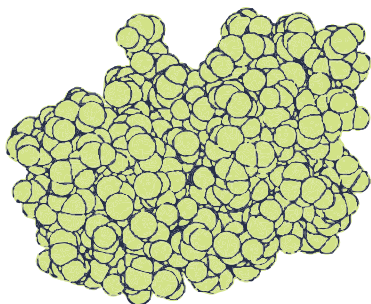


Figure 1.17 The model in this diagram shows the tertiary structure of a ribonuclease molecule. (The shapes represent atoms.) This is the way the whole polypeptide is folded.

TIP

Enzymes are proteins. You will learn more about them in Chapter 2.

The twisted and folded chain may fold up further to give the whole polypeptide molecule a globular shape. The complex folding of the whole molecule is the **tertiary structure** of the protein (Figure 1.17).

As with the secondary structure, the tertiary structure is also determined by the sequence of amino acids in the polypeptide chain. All molecules of a particular protein have the same sequence of amino acids, so under the same conditions they will all fold in the same way to produce molecules with the same tertiary structure.

Tertiary structure is extremely important and is very closely related to the function of the protein. Different types of bond form between different amino acids within the protein and the types of bond help to maintain the shape of the protein. These bonds include the following:

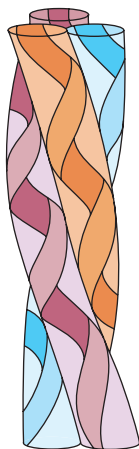
- Hydrogen bonds (see page 6), which form between the R-groups of a variety of amino acids. These bonds are not strong. They are easily broken, but there are many of them.
- Ionic bonds, which form between an amino acid with a positive charge and an amino acid with a negative charge, if they are close enough to each other. These are not strong bonds and are easily broken.
- Disulfide bridges, which form between amino acids that contain sulfur in their R-groups. These are quite strong covalent bonds, less easily broken than hydrogen bonds or ionic bonds.

There are two categories of proteins, differing in their tertiary structure. Fibrous proteins are typically long and thin, and they are insoluble.

They often have structural functions, such as keratin in hair or collagen that makes up a lot of connective tissue in our bodies. Globular proteins are more spherical in shape. They are soluble and have biochemical functions, such as enzymes or myoglobin, a pigment that stores oxygen in muscle tissue.

Some proteins have more than one polypeptide chain. We describe a protein that is made up from two or more polypeptide chains as having a quaternary structure. The polypeptide chains are held together by the same sorts of chemical bond that maintain the tertiary structure. The ribonuclease molecule shown in Figure 1.17 does not have a quaternary structure because it consists of only one polypeptide chain. The red pigment in our blood, haemoglobin, is a protein that does have a quaternary structure. A molecule of human haemoglobin has four polypeptide chains.

(a)



(b)

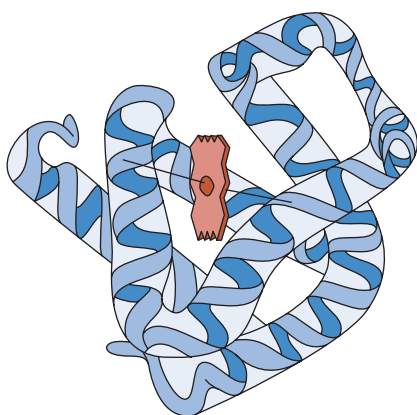


Figure 1.18 (a) Fibrous and (b) globular proteins.

TEST YOURSELF

- 10 Polypeptides can be made up from 20 different amino acids. A tripeptide is a polypeptide consisting of three amino acids. How many different tripeptides is it possible to make?
- 11 Give one way in which the formation of a peptide bond is similar to the formation of a glycosidic bond.
- 12 Egg white contains a protein. Which one (or more) of the following occurs when egg white is heated in a water bath containing water at 100 °C?
 - A Glycosidic bonds are broken.
 - B The protein is killed by the heat.
 - C The bonds holding the tertiary structure are broken.
 - D The protein is hydrolysed.

TIP

Qualitative tests detect the presence of a substance but do not show exactly how much is present.

Qualitative tests for substances in food

There are some tests that can be carried out to find out which substances are present in samples of food and other substances. These tests are summarised in Table 1.2.

Table 1.2 Tests for food substances.

| Substance | Test | Brief details of test | Positive result |
|---------------------|-----------------|--|----------------------------------|
| Protein | Biuret test | <ul style="list-style-type: none"> Add sodium hydroxide to the test sample. Add a few drops of dilute copper sulfate solution. | Solution turns mauve |
| Carbohydrates | Benedict's test | <ul style="list-style-type: none"> Heat test sample with Benedict's reagent. | Orange-red precipitate is formed |
| Reducing sugars | | <ul style="list-style-type: none"> Check that there is no reducing sugar present by heating part of the sample with Benedict's solution. Hydrolyse rest of sample by heating with dilute hydrochloric acid. Neutralise by adding sodium hydrogencarbonate. Test sample with Benedict's solution. | Orange-red precipitate is formed |
| Non-reducing sugars | | | |
| Starch | Iodine test | <ul style="list-style-type: none"> Add iodine solution. | Turns blue-black |
| Lipid | Emulsion test | <ul style="list-style-type: none"> Dissolve the test sample by shaking with ethanol. Pour the resulting solution into water in a test tube. | A white emulsion is formed |

Care should be taken with the chemicals and methods described above. Consult the CLEAPSS Hazcards for each chemical, and ensure sufficient safety precautions are taken with chemicals and hot water.

ACTIVITY

A student was given three tubes. The table shows the contents of each tube.

| Tube | Contents of tube |
|------|---|
| A | Protein and protease (an enzyme that digests protein) that have been left together at room temperature for an hour. |
| B | Sucrose, starch, lipid |
| C | Glucose, protein |

The student carried out tests for food substances on all three tubes. The table below shows the results she obtained.

- Copy the table and complete the left-hand column to indicate which tube gave which results.

| Tube | Benedict's test for reducing sugars | Benedict's test for non-reducing sugars | Iodine test for starch | Emulsion test for lipids | Biuret test for protein |
|------|-------------------------------------|---|------------------------|-----------------------------|-------------------------|
| | Orange-red precipitate formed | Test not carried out | Stayed yellowy-brown | Stayed clear | Mauve |
| | Stayed blue | Stayed blue | Stayed yellowy-brown | Stayed clear | Mauve |
| | Stayed blue | Orange-red precipitate formed | Blue-black colour | Milky-white emulsion formed | Stayed blue |

- Why did the student decide not to carry out the non-reducing sugar test on one of the tubes?
- Explain why two tubes gave a positive result for the biuret test.
- Suggest how the student could use qualitative tests to distinguish between three solutions containing different concentrations of glucose.

ACTIVITY

A student decided to investigate the sensitivity of the iodine test for starch. She was given a 1% starch solution. She used this to make serial dilutions as shown in Figure 1.19.

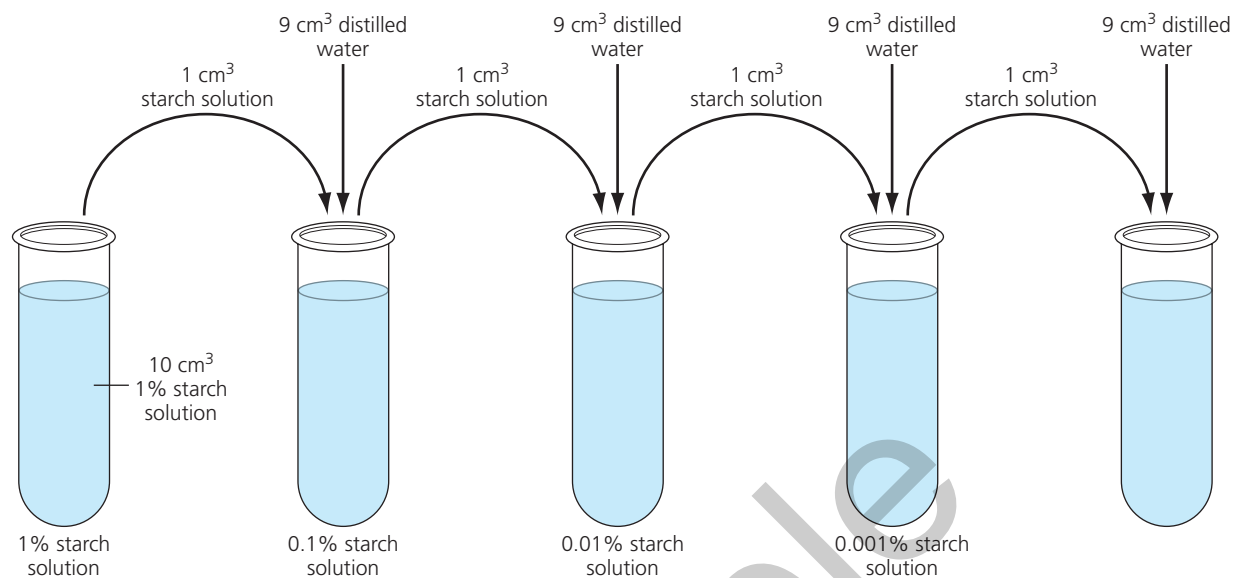


Figure 1.19 Making serial dilutions of starch.

After this she added 0.5 cm³ of iodine solution to each starch solution and looked for a blue-black colouration.

- 1 How would a technician make up a 1% solution of starch?
- 2 Give the concentration of the final solution in the diagram.
- 3 The blue-black colouration that occurs when iodine interacts with starch is caused by the iodine molecules becoming trapped in the amylose helix. Use this information to explain why the sensitivity of the iodine test can be different depending on the type of starch present.

TIP

You do not need to be able to recall the details of this practical activity.

ACTIVITY

Finding the concentration of reducing sugar in a solution

A colorimeter is a piece of equipment that passes light of a particular wavelength through a sample. It works on the principle that a coloured solution transmits light of the same wavelength through it, and absorbs other wavelengths. So a blue solution transmits blue light through it and absorbs other wavelengths. In addition, a darker-coloured solution absorbs more light than a pale-coloured solution. This can be used to measure the concentration of a coloured solution. The colorimeter is set up so that it shines light of a complementary colour through the solution. For example, if the solution is red in colour, blue light is shone through it.

Solutions to be tested in a colorimeter are placed into a cuvette. This is a small plastic tube rather like a test tube but square in section. You can see a colorimeter and cuvette in Figure 1.20.



Figure 1.20 Using a colorimeter.

When using a colorimeter, you need to produce a calibration curve. This is done using solutions of a known concentration.

An alternative version of Benedict's reagent for quantitative testing contains potassium thiocyanate and does not form red copper oxide. Instead the presence of reducing sugar is measured by the loss of the blue colour of copper sulfate and a white precipitate is formed. This will settle out or can be

removed by filtering. Then the filtrate is placed in a cuvette in a colorimeter. The intensity of the blue colour is measured by the amount of light that is able to pass through the solution. This method can give an accurate measurement of the concentration of reducing sugar in a solution, and it is much more sensitive than the qualitative Benedict's test.

A student was given a 1 mol dm^{-3} solution of glucose and then made serial dilutions of this (see page 15), giving six solutions of different known concentrations. She put 4 cm^3 of each solution into a separate labelled test tube. Next she added 2 cm^3 of quantitative Benedict's reagent to each tube and placed the tubes in a boiling water bath for 5 minutes. After this time, she filtered each solution to remove the precipitate.

The student set the wavelength on the colorimeter to red. She filled a cuvette with distilled water and put it into the colorimeter. This is called a 'blank'. She set the transmission of light through the tube to 100%. This meant that she could compare the transmission of light through the test solutions to the blank.

The student put a sample of each test solution into cuvettes, and measured the percentage transmission of light through each tube. Next she plotted a graph with concentration of glucose on the x-axis and percentage transmission of light through the solution on the y-axis.

Finally, she used the same method to identify the concentration of glucose in two solutions of unknown concentration.

- 1 How could the student use the 1 mol dm^{-3} solution of glucose to make the five other solutions?
- 2 Why did the student use a red light in the colorimeter?
- 3 What is the purpose of the 'blank'?
- 4 How could the student use her graph to find the concentration of glucose in an unknown solution?
- 5 If one cuvette was a little thicker than another, how would this affect the results?
- 6 How would the student use the graph to find the concentration of glucose in the unknown solutions?

Practice questions

- 1 a) Copy and complete the table to show the monosaccharides that join together to form different disaccharides. (3)

| Disaccharide | Formed from |
|--------------|-------------|
| Lactose | |
| Maltose | |
| Sucrose | |

- b) Describe how you could test a solution to find out whether it contained a non-reducing sugar. (4)

- 2 Some scientists carried out an investigation into the artificial sweetener aspartame. This was because some people said they experienced side-effects after consuming the substance. Previous investigations had found the artificial sweetener to be safe. The sweetener is digested in the gut to give the amino acids aspartic acid and phenylalanine.

In the new study, the scientists recruited 50 people who believed they had suffered side-effects because they were sensitive to aspartame.

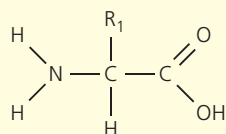
- The volunteers were matched by age and sex to 50 people who volunteered to eat aspartame.
- The volunteers were placed at random into one of two groups.
- The volunteers in each group were given either a cereal bar containing aspartame or an aspartame-free cereal bar. They were then given medical checks up to 4 hours after consuming it.
- The following week, the experiment was repeated with each volunteer receiving the other type of cereal bar.

- a) i) Explain why it was important that the 50 volunteers who were happy to eat aspartame were matched by age and sex to the 50 people who believed they were sensitive to aspartame. (2)

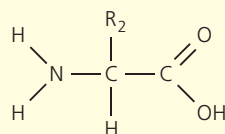
- ii) The volunteers were placed at random into two groups. Give one method that the scientists could use to do this. (1)

- iii) It was important that the scientists and the volunteers did not know which cereal bars contained aspartame. Give two reasons to explain why. (2)

- b) The diagram shows the amino acids aspartic acid and phenylalanine.



aspartic acid



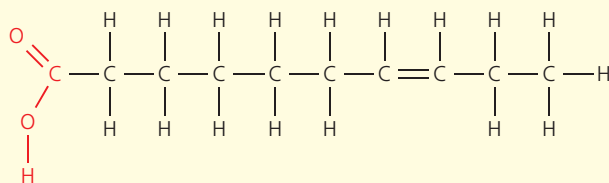
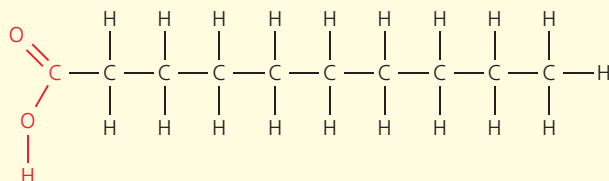
phenylalanine

Aspartame is made by joining these two amino acids together.

i) Draw a molecule of aspartame. (2)

ii) Name the reaction that occurs when these two amino acids are joined together. (1)

3 The diagram shows two fatty acids.



a) i) Which of these fatty acids is saturated? Explain your answer. (1)

ii) Name the reaction involved when three fatty acids combine with a glycerol molecule to form a triglyceride. (1)

b) Describe a test you could perform to show that a mixture contains lipids. (2)

c) Give one similarity and one difference between the structure of a phospholipid and the structure of a triglyceride. (2)

4 a) Copy and complete the table below with a tick if the statement is true and a cross if it is not true. (3)

| Statement | Proteins | Polysaccharides | Lipids |
|-------------------------|----------|-----------------|--------|
| Molecule is a polymer | | | |
| Contains amino acids | | | |
| Contains nitrogen atoms | | | |

b) i) A protein has a tertiary structure but not a quaternary structure. How many polypeptides does it contain? (1)

ii) Name two kinds of bond that hold a protein in its tertiary structure. (2)

Stretch and challenge

5 Research the differences between D- and L-isomers of molecules. You should find that the **amino acids** in most living organisms are the **L-isomers**, and the **monosaccharides** in most living organisms are the **D-isomers**. Suggest why this is indirect evidence for evolution.