6 The chemistry of living organisms

Living organisms are composed of about 22 different **chemical elements**. These are combined to form a great variety of **compounds**. Six major elements make up almost 99% of the mass of the human body, as shown in Figure 6.1.

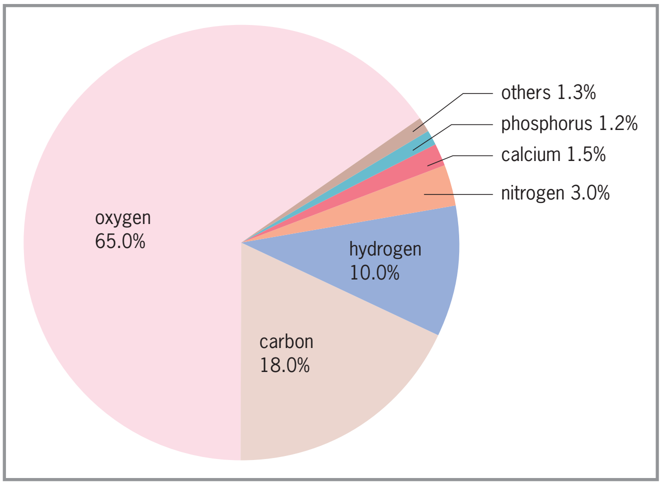


Figure 6.1 *The percentage, by mass, of the major elements that make up the human body*

The main **compounds** formed from these elements include water, an **inorganic compound** that makes up about 65% of the body, and carbohydrates, proteins and lipids which are all **organic compounds**.

Carbohydrates

Carbohydrates include sugars and starches. They are **molecules** composed of carbon, hydrogen and oxygen atoms. The ratio of hydrogen atoms to oxygen atoms is always 2:1. The simplest carbohydrate molecule has the formula $\mathbf{C_6H_{12}O_6}$. Carbohydrates can be classified into **three** groups: **monosaccharides**, **disaccharides** and **polysaccharides**.

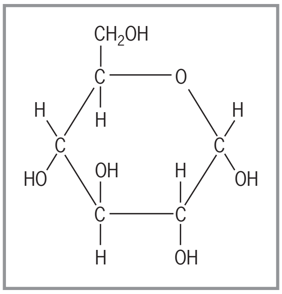


Figure 6.2 *A glucose molecule*

Table 6.1 *The three groups of carbohydrates*

Group	Properties	Formula	Examples
Monosaccharides (single sugars)	Have a sweet taste. Soluble in water.	$C_6H_{12}O_6$	Glucose Fructose Galactose
Disaccharides (double sugars)	Have a sweet taste. Soluble in water.	$C_{12}H_{22}O_{11}$	Maltose Sucrose Lactose
Polysaccharides (complex carbohydrates)	Do not have a sweet taste. Insoluble in water.	$(C_6H_{10}O_5)_n$	Starch Cellulose Glycogen (animal starch)

Disaccharides are formed by chemically joining two monosaccharide molecules together with the loss of a water molecule from between, a process called **condensation** or **dehydration synthesis**:

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

glucose + glucose ⟶ maltose

glucose + fructose ⟶ sucrose

glucose + galactose ⟶ lactose

Polysaccharides are formed by the **condensation** of many monosaccharides into straight or branched chains.

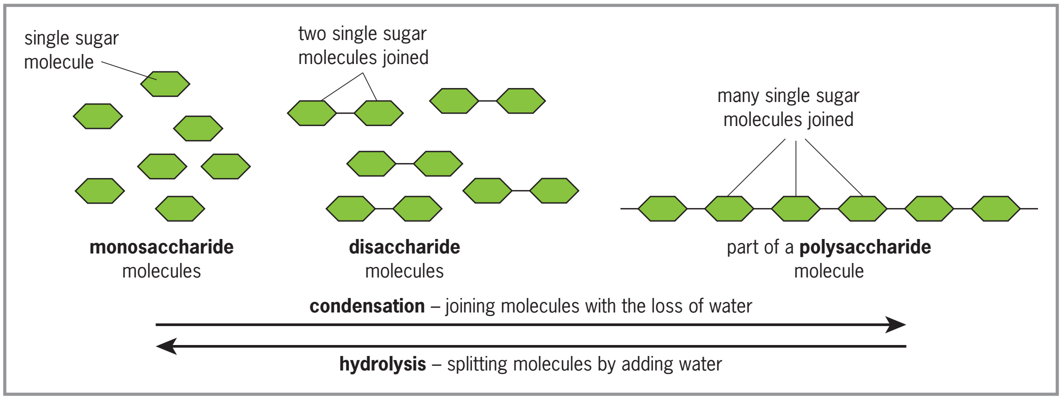


Figure 6.3 *The three types of carbohydrates*

Lipids

Lipids are fats and oils. They feel greasy and are insoluble in water. Lipids are **molecules** composed of carbon, hydrogen and oxygen atoms. Their molecules have fewer oxygen atoms than carbohydrate molecules, e.g. beef fat has the formula $\mathbf{C_{57}H_{110}O_6}$. Each lipid molecule is composed of **four** smaller molecules joined together; three **fatty acid** molecules and one **glycerol** molecule.

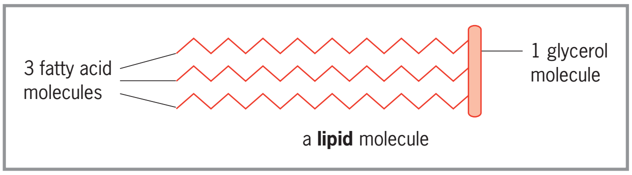


Figure 6.4 *A lipid molecule*

Proteins

Proteins are **molecules** composed of carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur and phosphorus atoms. These atoms form small molecules known as **amino acids**. There are 20 different common amino acids. Protein molecules are formed by the **condensation** of hundreds or thousands of amino acid molecules in long chains. The links between adjacent amino acid molecules are called **peptide links**. The chains then fold to give each type of protein molecule a specific shape.

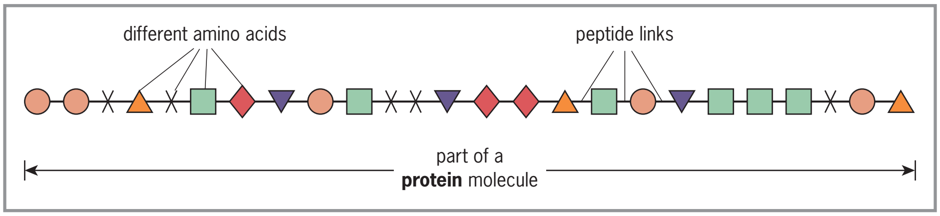


Figure 6.5 *Part of a protein molecule*

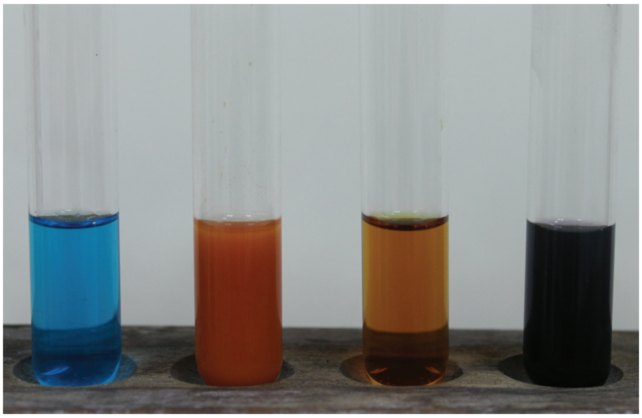
Some proteins are soluble in water, e.g. haemoglobin; others are insoluble, e.g. collagen.

Recognising carbohydrates, proteins and lipids

Tests can be performed in the laboratory to identify carbohydrates, proteins and lipids. Apart from the tests for lipids, the tests are usually carried out on about 2 cm^3 of a solution of the test substance in a test tube.

Table 6.2 *Laboratory tests to identify carbohydrates, proteins and lipids*

Food substance	Test	Positive result
Reducing sugars – monosaccharides and some disaccharides, e.g. glucose, maltose	Add an equal volume of **Benedict's solution** and shake. Heat the mixture.	An **orange-red** precipitate forms.
Non-reducing sugars – some disaccharides, e.g. sucrose	Add a few drops of dilute **hydrochloric acid** and heat for 1 minute. Add **sodium hydrogencarbonate** until effervescence stops. Add an equal volume of **Benedict's solution** and shake. Heat the mixture.	An **orange-red** precipitate forms. The acid **hydrolyses** the disaccharide molecules to monosaccharide molecules. The sodium hydrogencarbonate neutralises the acid allowing the Benedict's solution to react with the monosaccharides.
Starch	Add a few drops of **iodine solution** and shake.	Solution turns **blue-black**.
Protein – the biuret test	Add an equal volume of **sodium hydroxide solution** and shake. Add drops of dilute **copper sulfate solution** and shake. Or add an equal volume of **biuret reagent** and shake.	Solution turns **purple**.
Lipid – the emulsion test	Place 4 cm^3 of **ethanol** in a dry test tube. Add one drop of test substance and shake. Add an equal volume of **water** and shake.	A **milky-white** emulsion forms.
Lipid – the grease spot test	Rub a drop of test substance onto **absorbent paper**. Leave for 10 minutes.	A **translucent mark** remains.



Benedict's solution forms an orange-red precipitate with reducing sugars

Iodine solution turns starch blue-black

Enzymes

***Enzymes** are biological catalysts produced by all living cells. They speed up chemical reactions occurring in living organisms without being changed themselves.*

Enzymes are **proteins** that living cells produce from amino acids obtained from the diet in animals, or manufactured in plants. Without enzymes, chemical reactions would occur too slowly to maintain life.

Examples:

- **Amylase** catalyses the breakdown of **starch** into sugars, mainly **maltose**. It is present in saliva, pancreatic juice and germinating seeds.

$$\text{starch} \xrightarrow{\text{amylase}} \text{maltose}$$

- **Catalase** catalyses the breakdown of hydrogen peroxide into water and oxygen:

$$\text{hydrogen peroxide} \xrightarrow{\text{catalase}} \text{water} + \text{oxygen}$$

or

$$2H_2O \xrightarrow{\text{catalase}} 2H_2O + O_2$$

Catalase is found in most cells. It prevents the build-up of harmful hydrogen peroxide which is produced as a by-product of many chemical reactions occurring in cells.

Properties of enzymes

All enzymes have similar **properties**:

- Enzymes are **specific**, i.e. each type of enzyme catalyses only one type of reaction.
- Enzymes work best at a particular temperature known as the **optimum temperature**. This is about 37 °C for human enzymes.

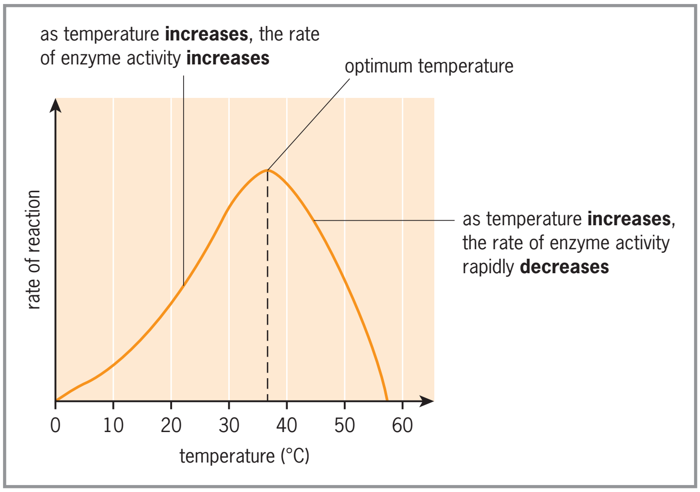


Figure 6.6 *The effect of temperature on the rate of a reaction catalysed by enzymes*

- High temperatures **denature** enzymes, i.e. the shape of the enzyme molecules changes so that they are inactivated. Enzymes start to be denatured at about 40 °C to 45 °C.

- Enzymes work best at a particular pH known as the **optimum pH**. This is about pH 7 for most enzymes.

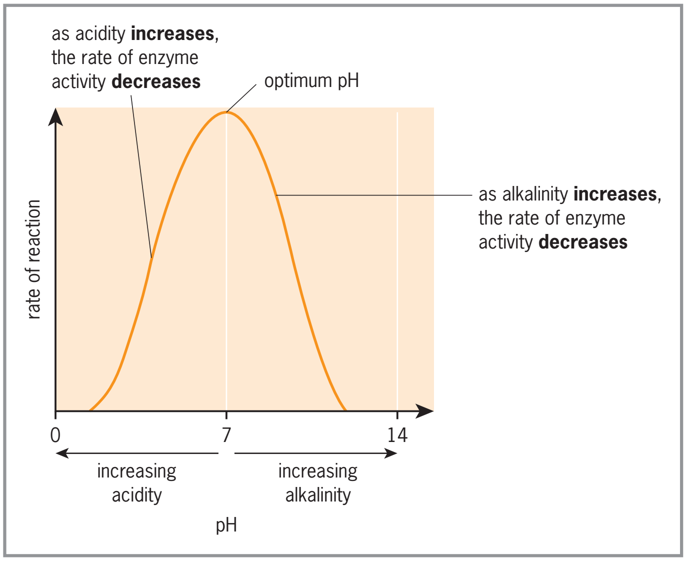


Figure 6.7 *The effect of pH on the rate of a reaction catalysed by enzymes*

- Extremes of acidity or alkalinity **denature** most enzymes.
- The action of enzymes is **helped** by certain vitamins and minerals, e.g. vitamin B_1 helps the action of respiratory enzymes.
- The action of enzymes is **inhibited** by certain poisons, e.g. arsenic and cyanide.

Revision questions

1. Describe the simple molecular structure of EACH of the following:
   a polysaccharides **b** proteins **c** lipids.
2. Distinguish between condensation and hydrolysis.
3. You are given three solutions labelled X, Y and Z and told that they contain starch, glucose and gelatin (a protein), respectively. Describe THREE laboratory tests you could perform to confirm what you are told about X, Y and Z.
4. What are enzymes?
5. Name the enzyme responsible for the breakdown of starch.
6. Explain the effect that temperature has on enzyme activity.
7. Other than the effect of temperature on enzyme activity, give THREE other properties of enzymes.