Unit two

Biochemical molecules

2.1 Inorganic molecules

- **Biological molecules** can be classified into **two** main types:i.e

  i/ inorganic molecules

  ii/ organic molecules

- **Organic molecules** always contain both **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**.

- **Inorganic molecules** may contain **one or** the **other** (or **neither**), but **not both**.

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

Activity: Classify the following substances as organic and in organic molecule

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

- In the periodic table below, **Highlighted elements** are the ones that are used to **build nearly all biological molecules**.
- **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.**

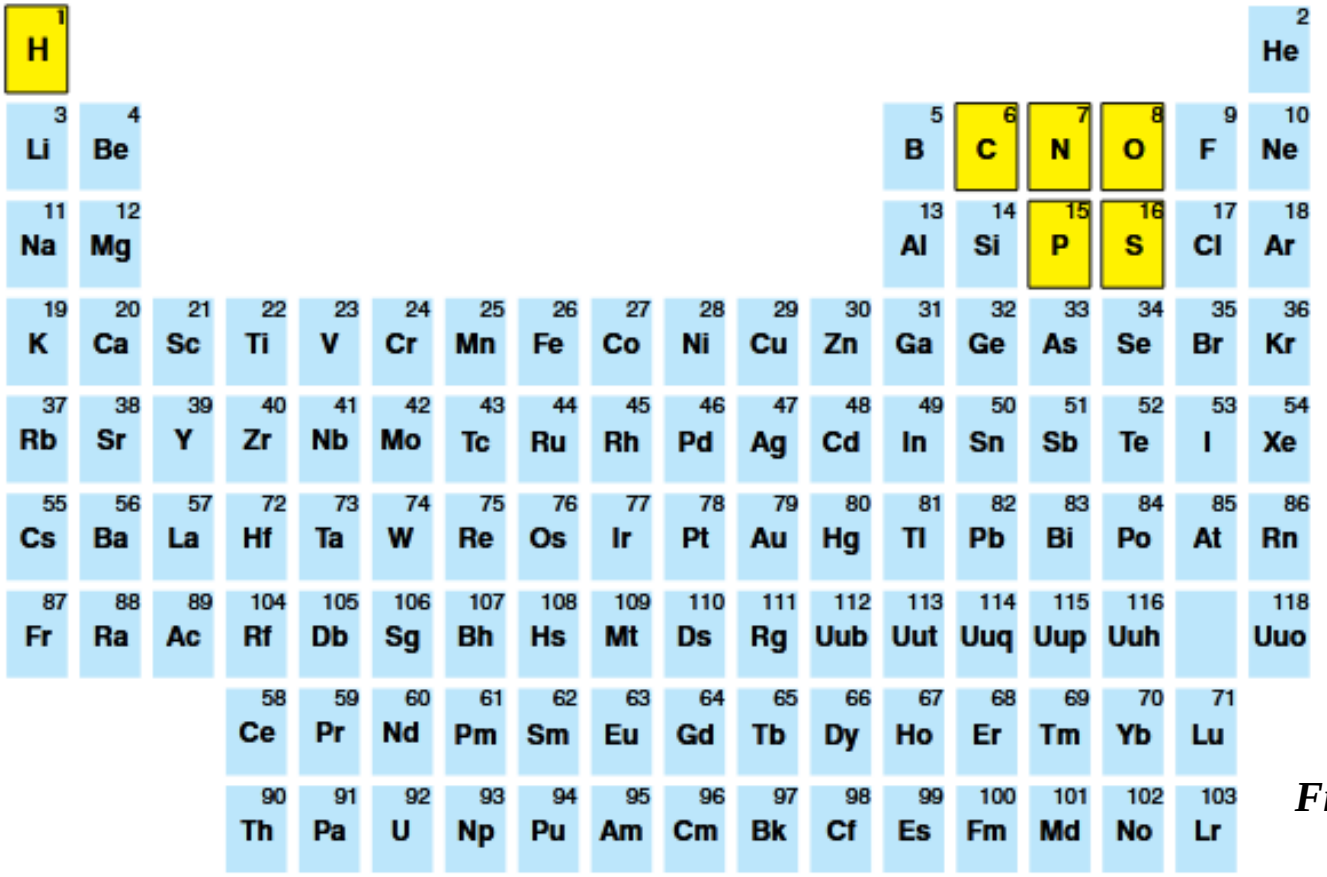


Fig. 2.1 *Periodic table.*

Element refers a substance that is made of only one kind of atom

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*

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.)

- **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**
- 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.**

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

- **Carbon atom** can bond with **four hydrogen atoms,** each hydrogen atom can only bond with one carbon.
- Because carbon 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.**

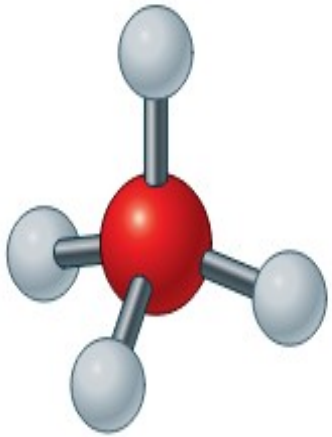


Figure 2.2 The structure of methane. In a molecule of methane, a carbon atom bonds with four hydrogen atoms. Each hydrogen atom only bonds with one carbon atom.

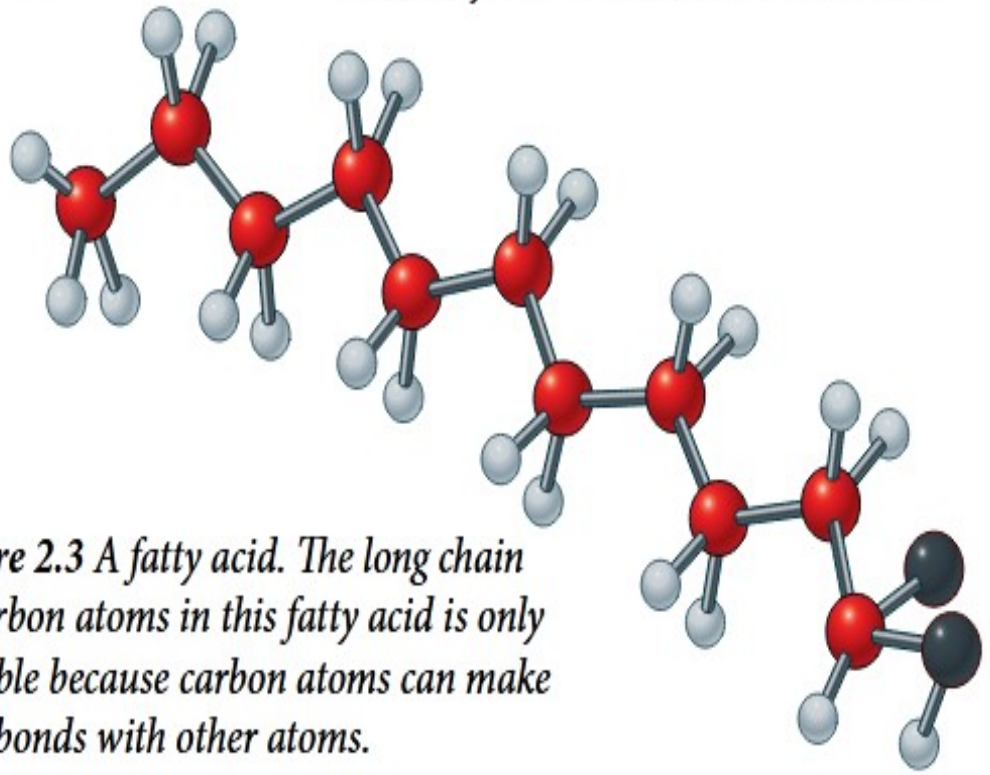


Figure 2.3 A fatty acid. The long chain of carbon atoms in this fatty acid is only possible because carbon atoms can make four bonds with other atoms.

Water

- It 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%.**
- 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.

- **Water molecule** is **not 'straight'** it is bent into a **'v' shape.**
- The **molecule forms** '**dipole**'. i.e Part of the molecule has a slight **negative charge** (δ–) and other parts have a slight **positive charge** (δ+).

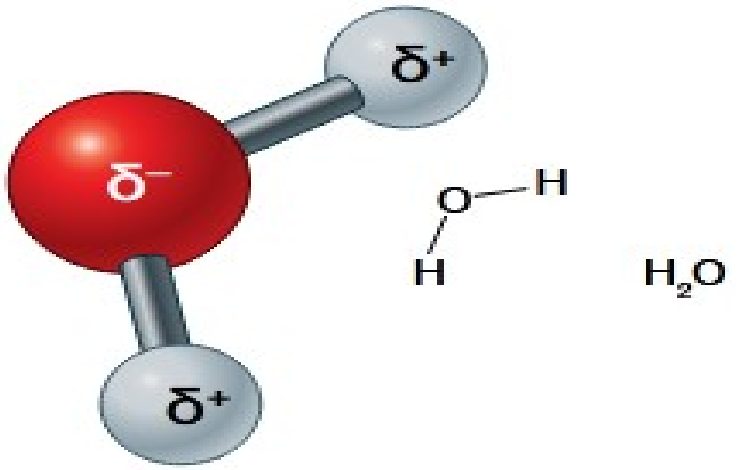


Figure 2.4 *Water molecule.*

- 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**).

- 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.**

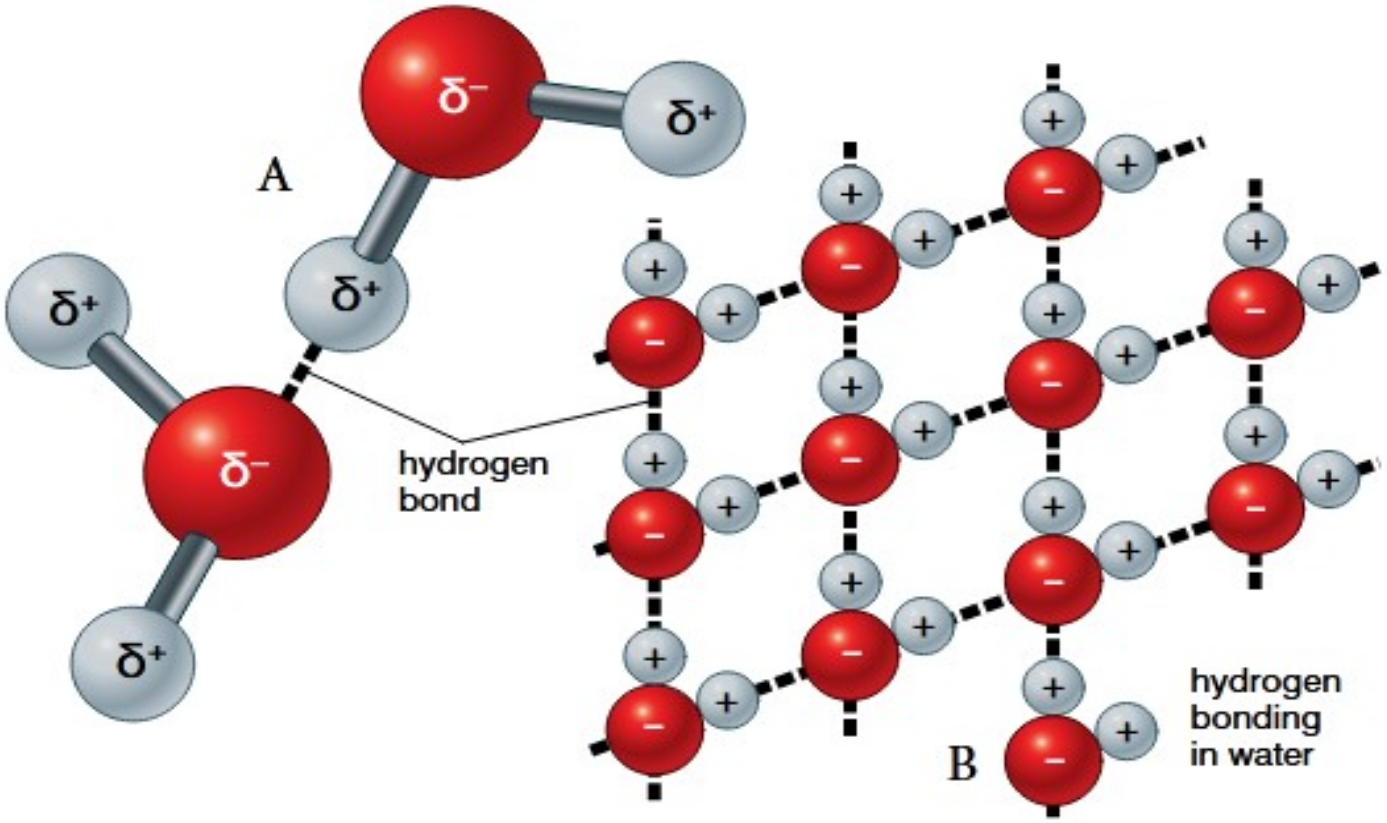


Figure 2.5 *Hydrogen bonding in water.* ***A)*** *Two water molecules hydrogen-bonded together* ***B)*** *Many water molecules hydrogen-bonded together.*

- **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**.

Importance of water in 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 transparent:

- This means that **light can pass** through the **water** and **allow the plants** and **algae** to **photosynthesis.**
- 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.

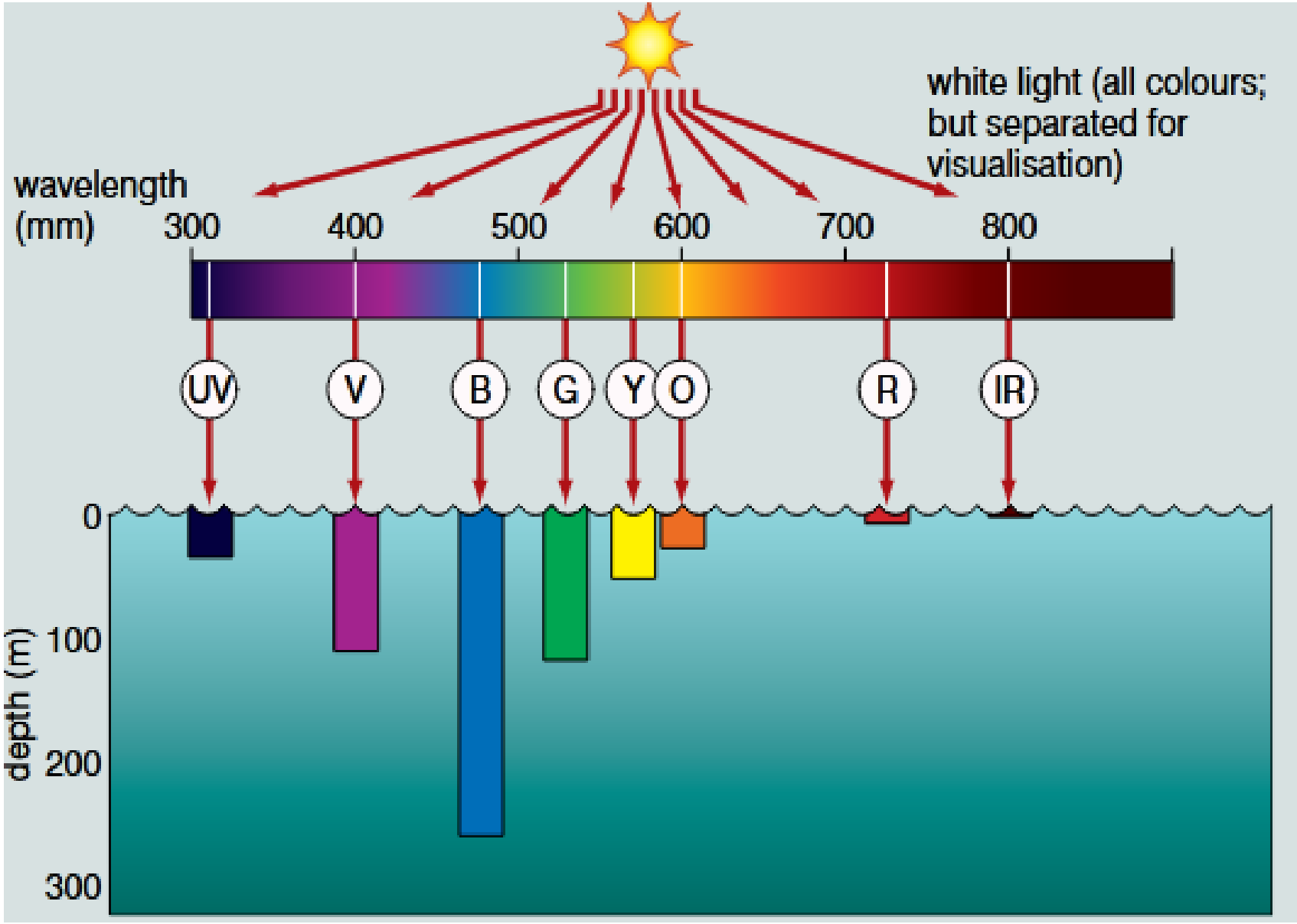


Figure.2.6 *Penetration of different wavelengths of light.*

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.**

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*

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 vaporization:

- This **means** that **it takes** a **lot of energy** to **turn liquid water** into **water vapour /steam.**
- In turn this means that **water doesn't vaporize 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 vaporize** the **sweat comes from our bodies.** This **heat is then lost** from **our bodies** and so **we cool down**. If **water vaporized easily, sweating wouldn't** be as **effective** in **controlling our body temperature.**
- **Water** has *the **highest** latent heat of **vaporization** of all substances.*

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**.

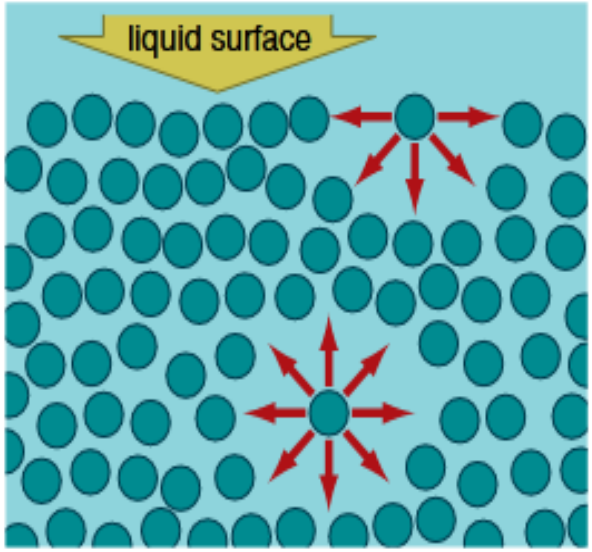


Figure 2.7 *The surface tension of water.*

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

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



Figure 2.8 *A water strider walking on water.* The water strider in this figure 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 2.9 *Mosquito larvae.* The mosquito larvae in this figure hang from the surface of the water by their breathing tubes. The surface tension is sufficiently strong to hold their weight.

- **Water** is a **good solvent** for of many **organic** and **inorganic** substances **important to life**
- 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**.
- 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 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

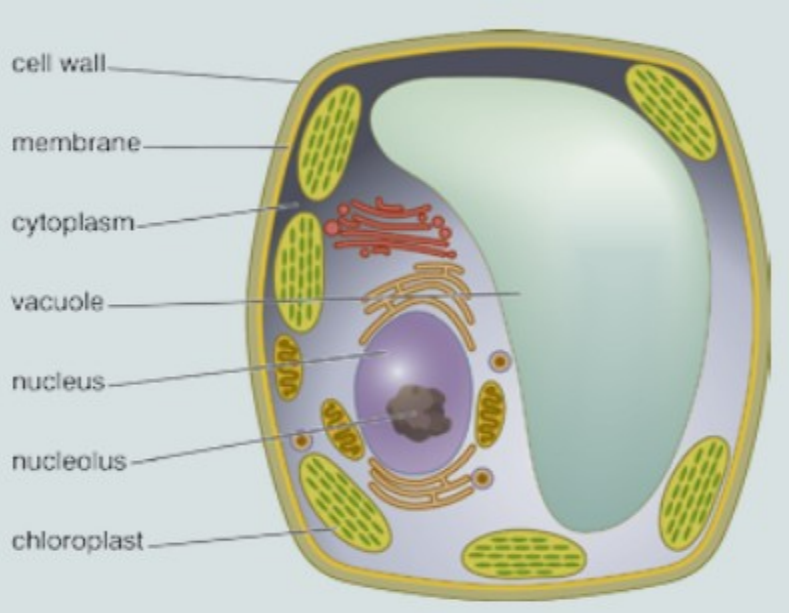


Figure 2.10 *A turgid plant cell.*



Figure 2.11 *A well-watered coleus plant*



Figure 2.12 *A coleus plant that has not been well-watered.*

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.

Water as a reactant:

- **Reactant** a **substance** that **takes part** in a **chemical reaction**
- **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. i.e **hydrolysis** refers using water to split large molecules.
- **Water molecules** are **used** to **split large food molecules** into **smaller ones** that can be **absorbed into the bloodstream**.
- Water 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.

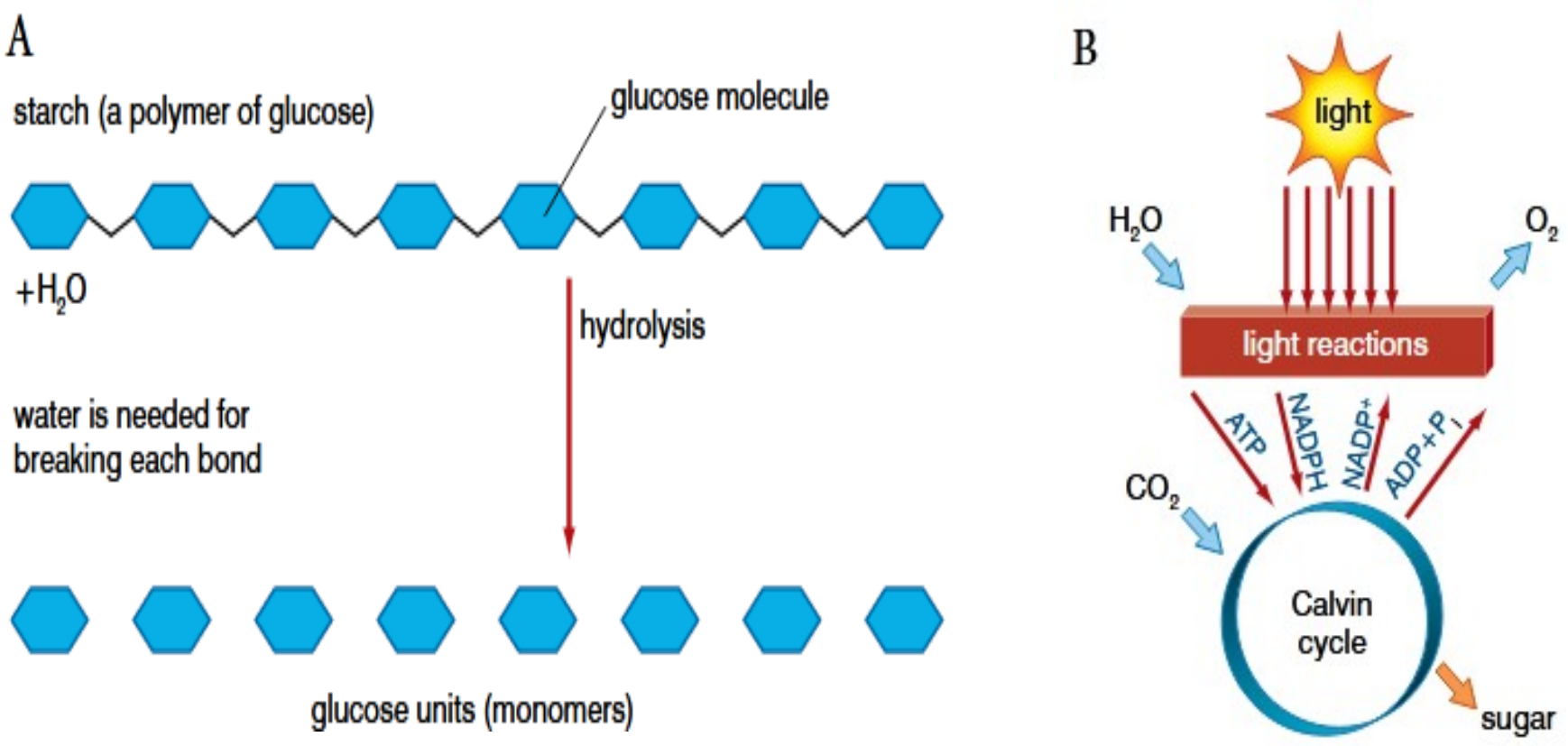


Figure 2.13 *The hydrolysis of starch (A)*
Summary of photosynthesis (B)

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.

2.2 Organic molecules

Carbohydrates:

- **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, $C_6 H_{12}O_6$, 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.**

Functions of Carbohydrates :

- 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**

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*

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.

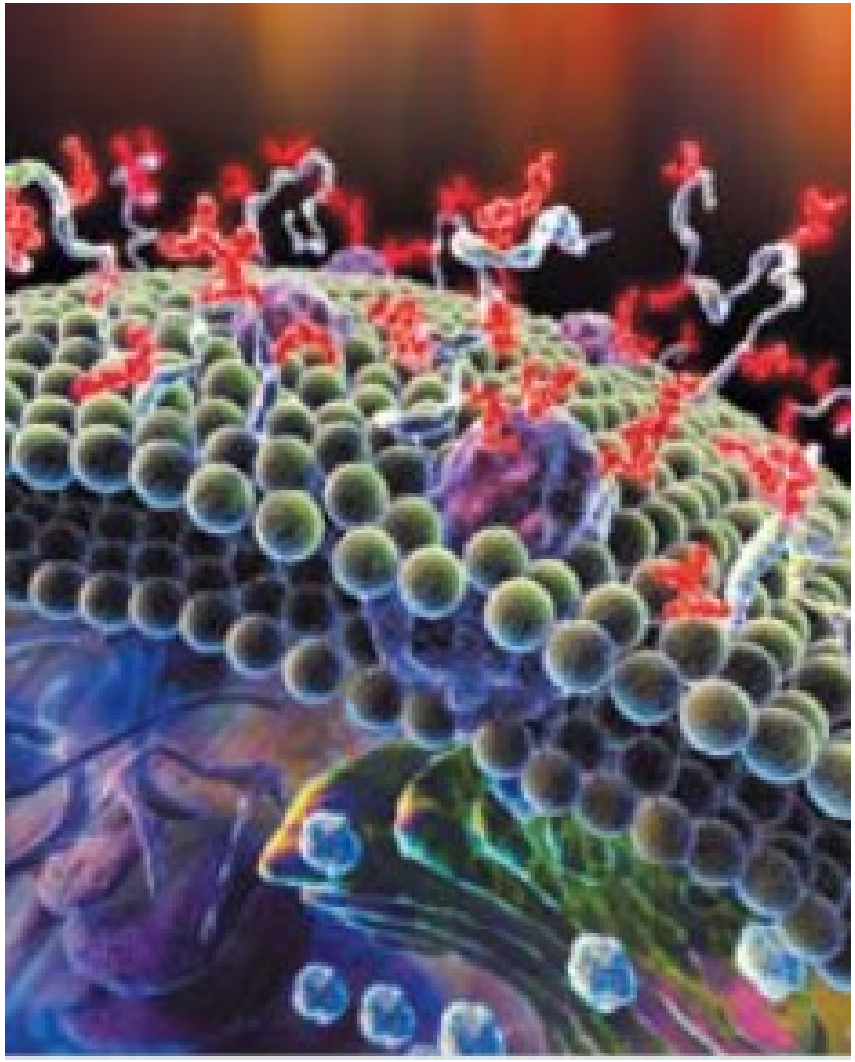


Figure 2.14 *A glycoprotein in a membrane.*

Types of carbohydrates

- **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. i.e
  ***A **triose** monosaccharide has **three carbon atoms –** formula **C $_3$H$_6$O$_3$. Glycerate phosphate** is a **triose** important in **photosynthesis.**

  *A **pentose** monosaccharide has **five carbon atoms –** formula **C $_5$ H$_{10}$O$_5$.** Ribose is found in RNA nucleotides.

  *A **hexose** monosaccharide has **six carbon atoms –** formula **C$_6$ H$_{12}$O$_6$. Glucose is the hexos**e 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.**

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*

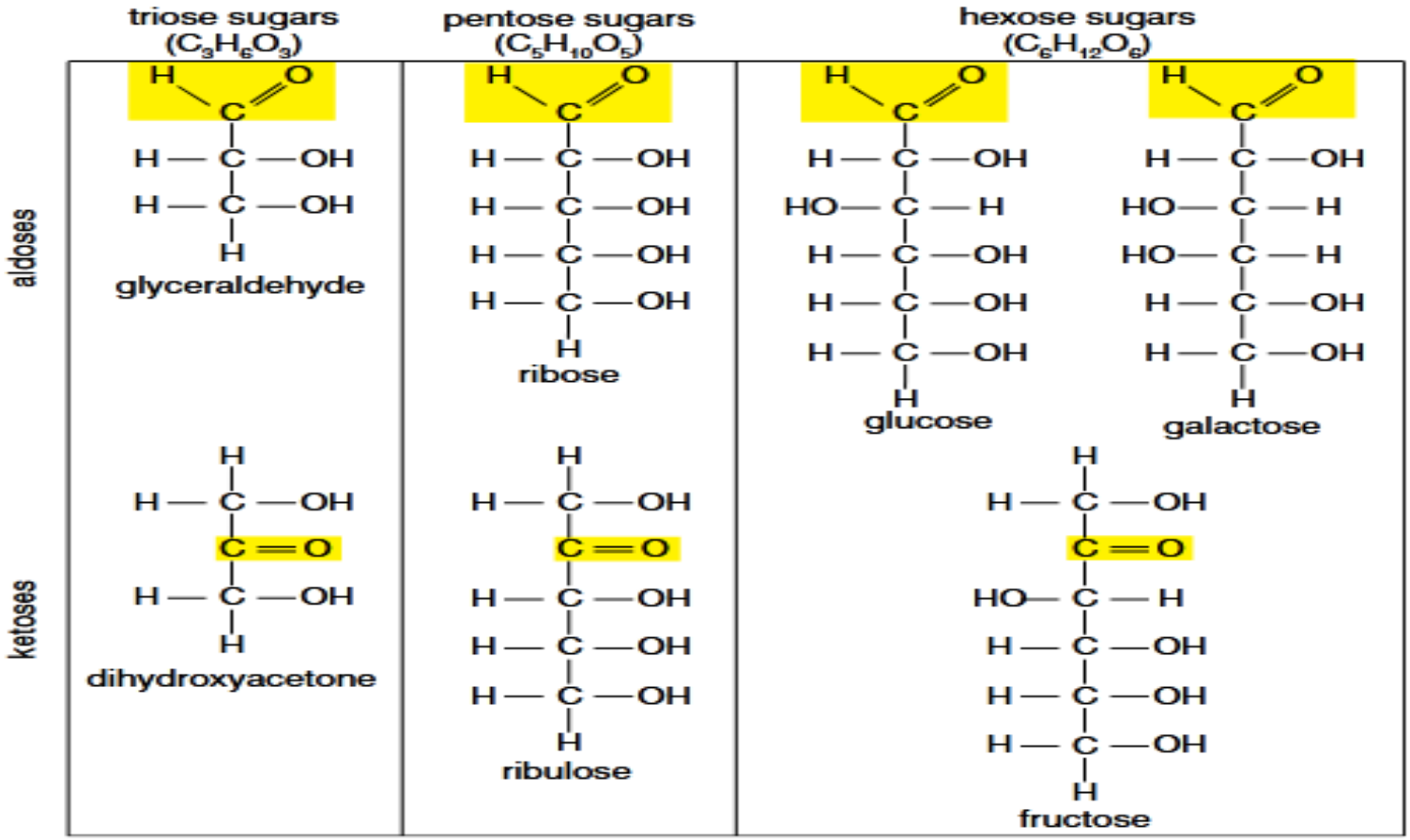


Figure 2.15 *Aldose and ketose monosaccharides. It shows examples of each type of sugar according to both classifications.*

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

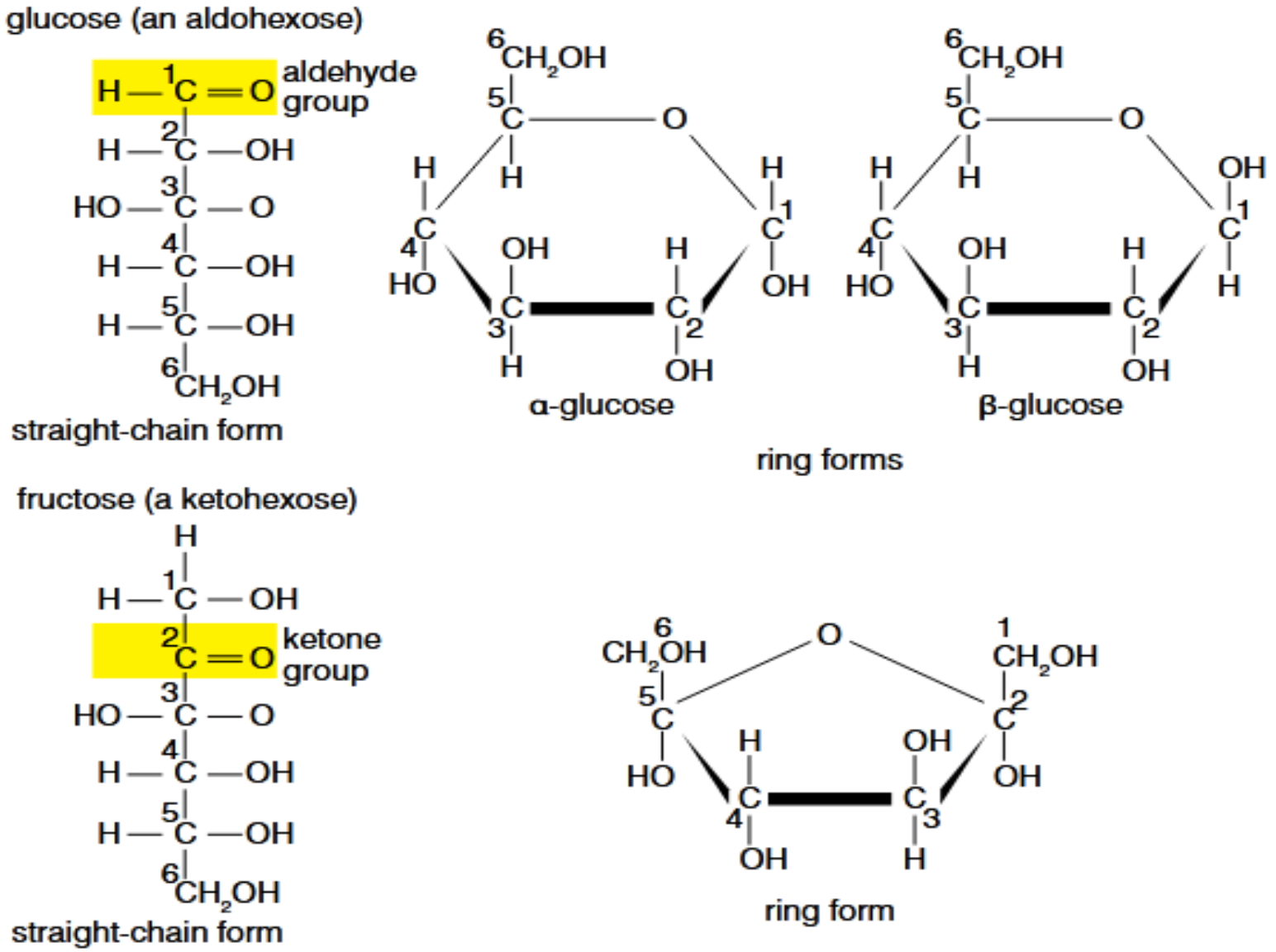


Figure 2.16 *Straight chain forms and ring forms of glucose and fructose.*

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

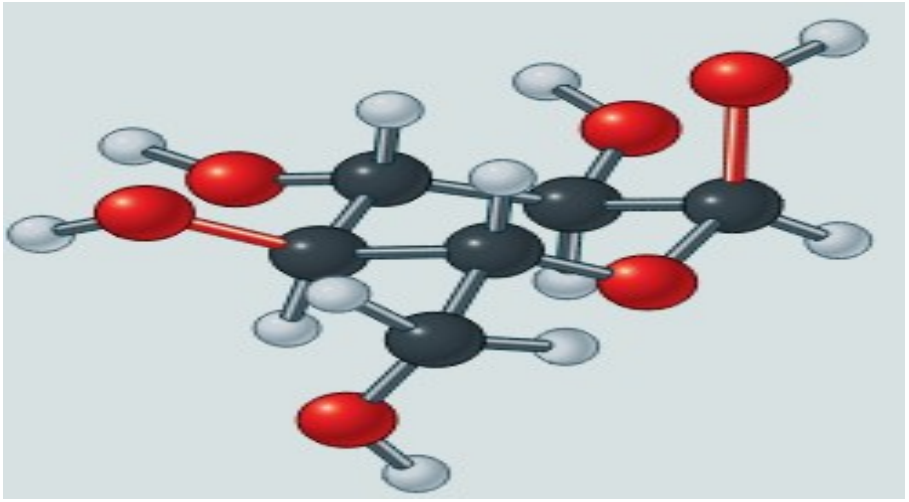


Figure 2.17 *A 3-D representation of the α-glucose molecule.*

➢The **straight chain** form of **glucose** can produce **two different ring forms – α-glucose and β glucose**

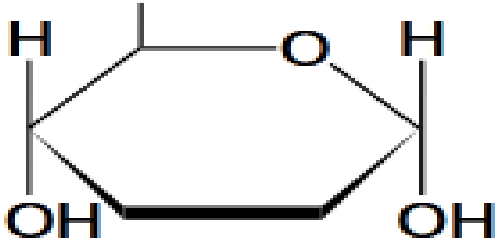


Figure 2.18 A simplified representation of the structure of α-glucose.

- **Disaccharide**: carbohydrate molecules are **made by two monosaccharide molecule**s **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** is $C_6 H_{12} O_6$, 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. This allows a bond to be formed between the two monosaccharide units to make a disaccharide.

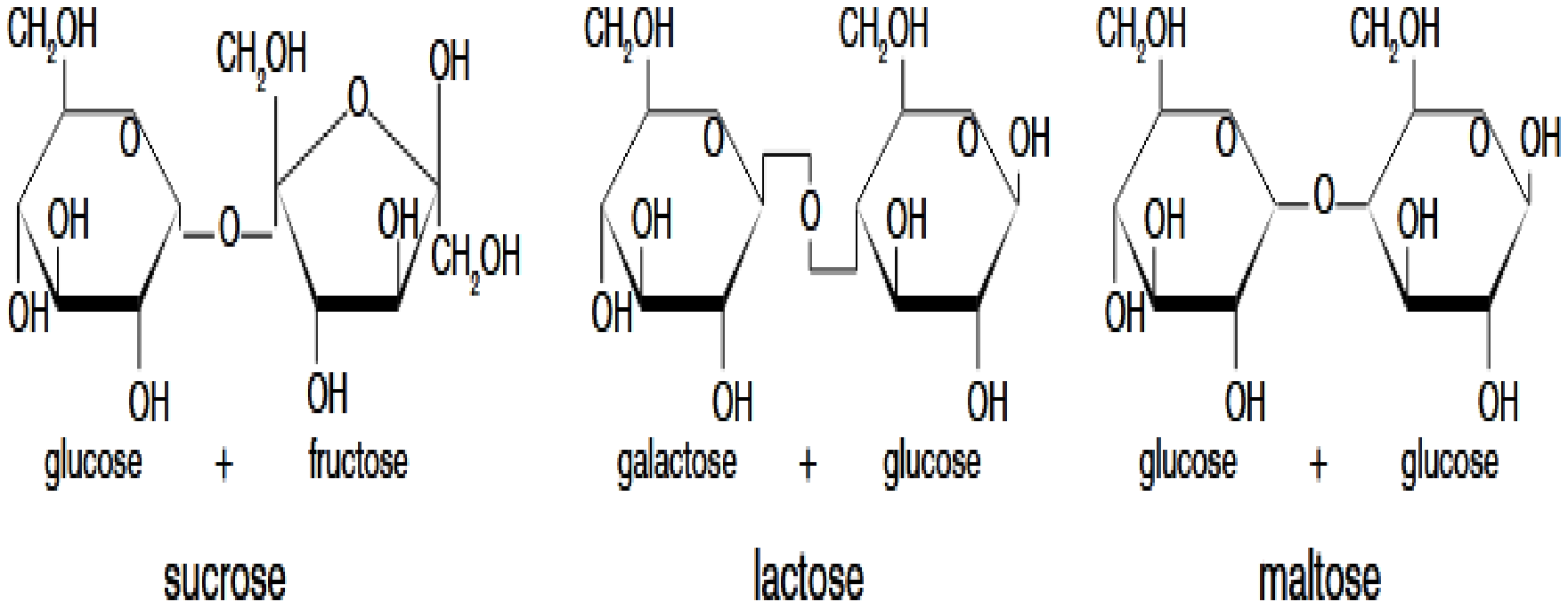


Figure 2.19 *The structures of three disaccharides.*

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

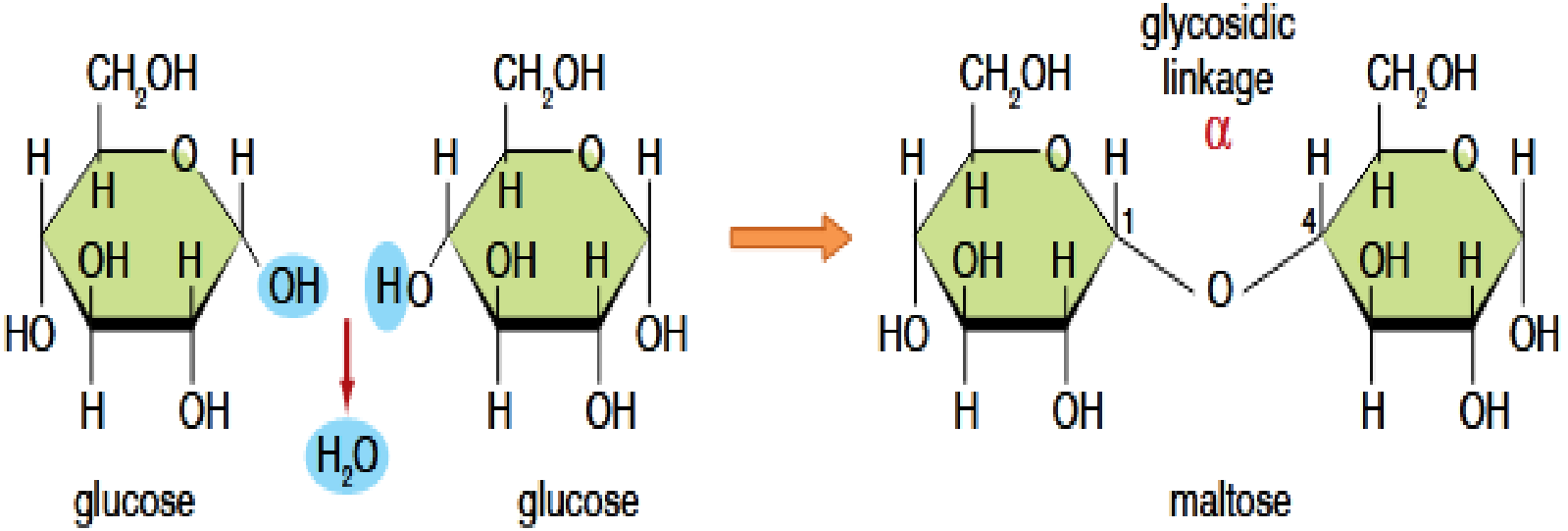


Figure 2.20 *Two molecules of α-glucose are joined to form a molecule of maltose (a disaccharide).*

- **Polysaccharides**: a carbohydrate whose **molecules consist** of a number of **monosaccharide molecules** bonded together. A are **complex carbohydrates**.
- **Condensation does not just occur** in the formation of **disaccharides**, but also in the **formation of polysaccharides** and other **large molecules.**

- **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.**

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

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

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**.

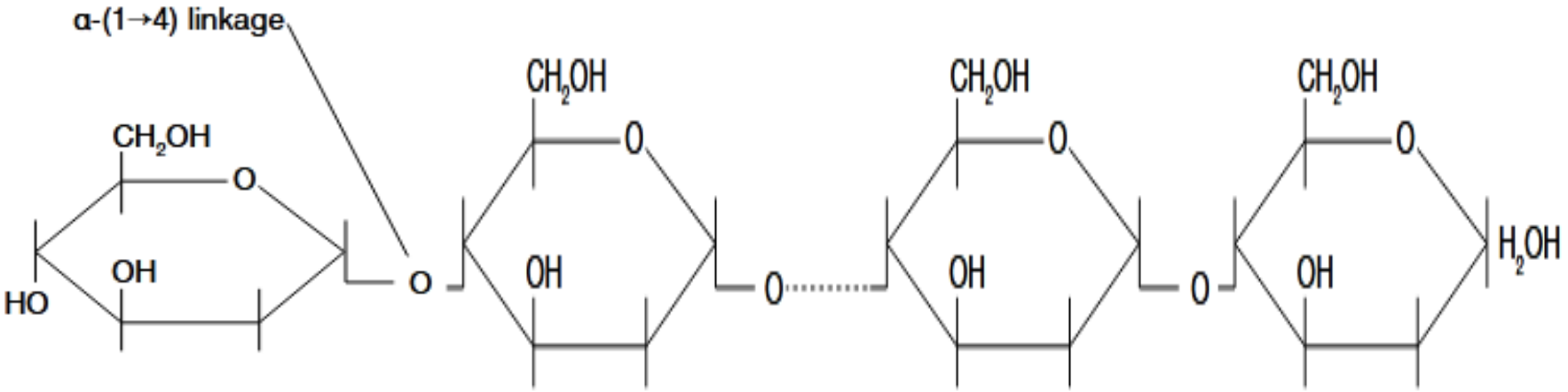


Figure 2.21 *Linkages in amylose.*

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.

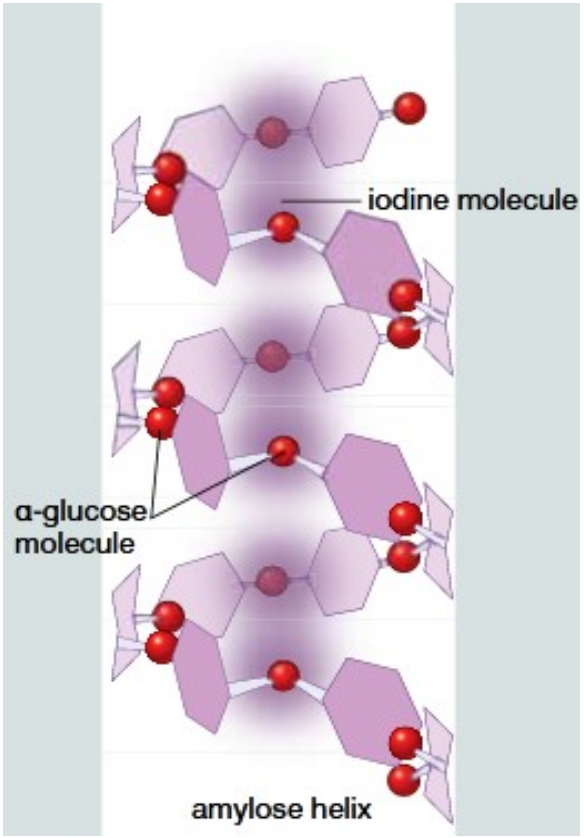


Figure 2.22 *Iodine stains starch blue-black.*

- **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**
- 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**.

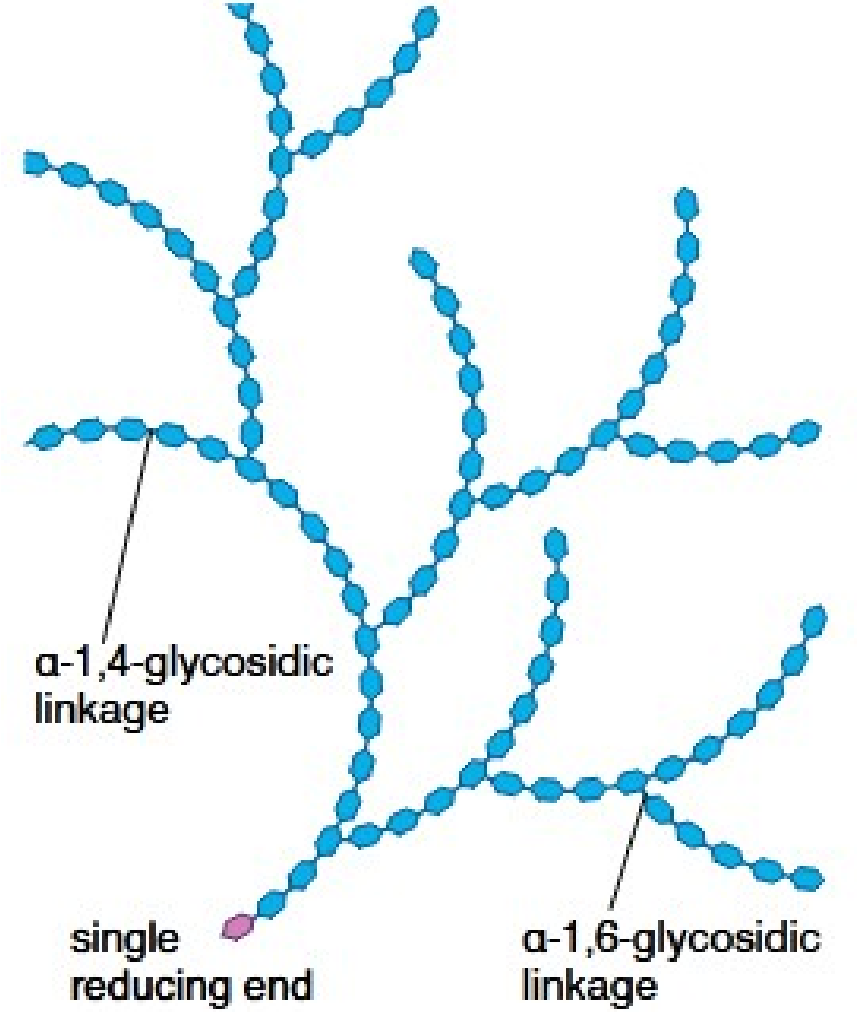


Figure 2.23 *The structure of amylopectin.*

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.

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**.
- Also, the chain is **unbranched**.

- **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 fibers or fibrils**, which make up the **structure of cell walls.**

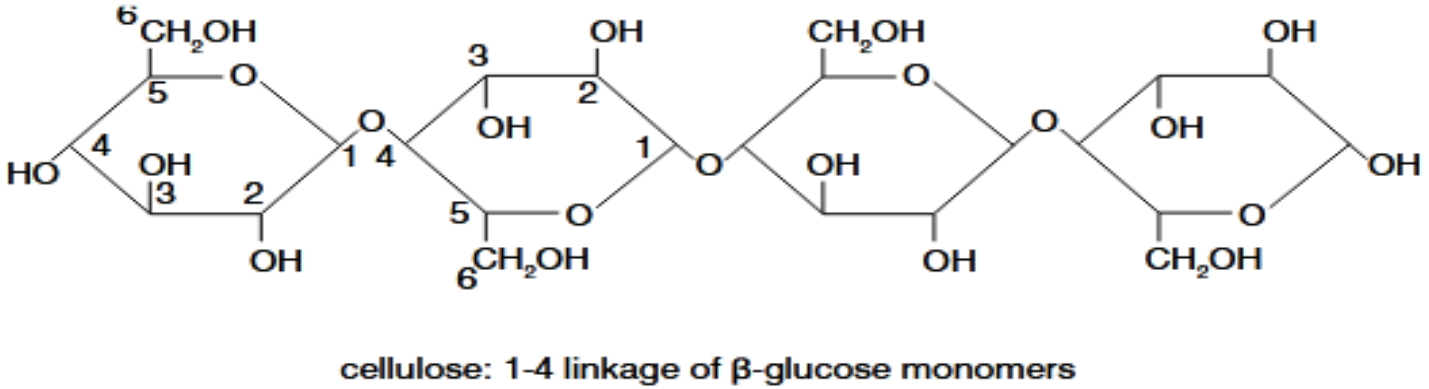


Figure 2.24 *The structure of cellulose.*

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.

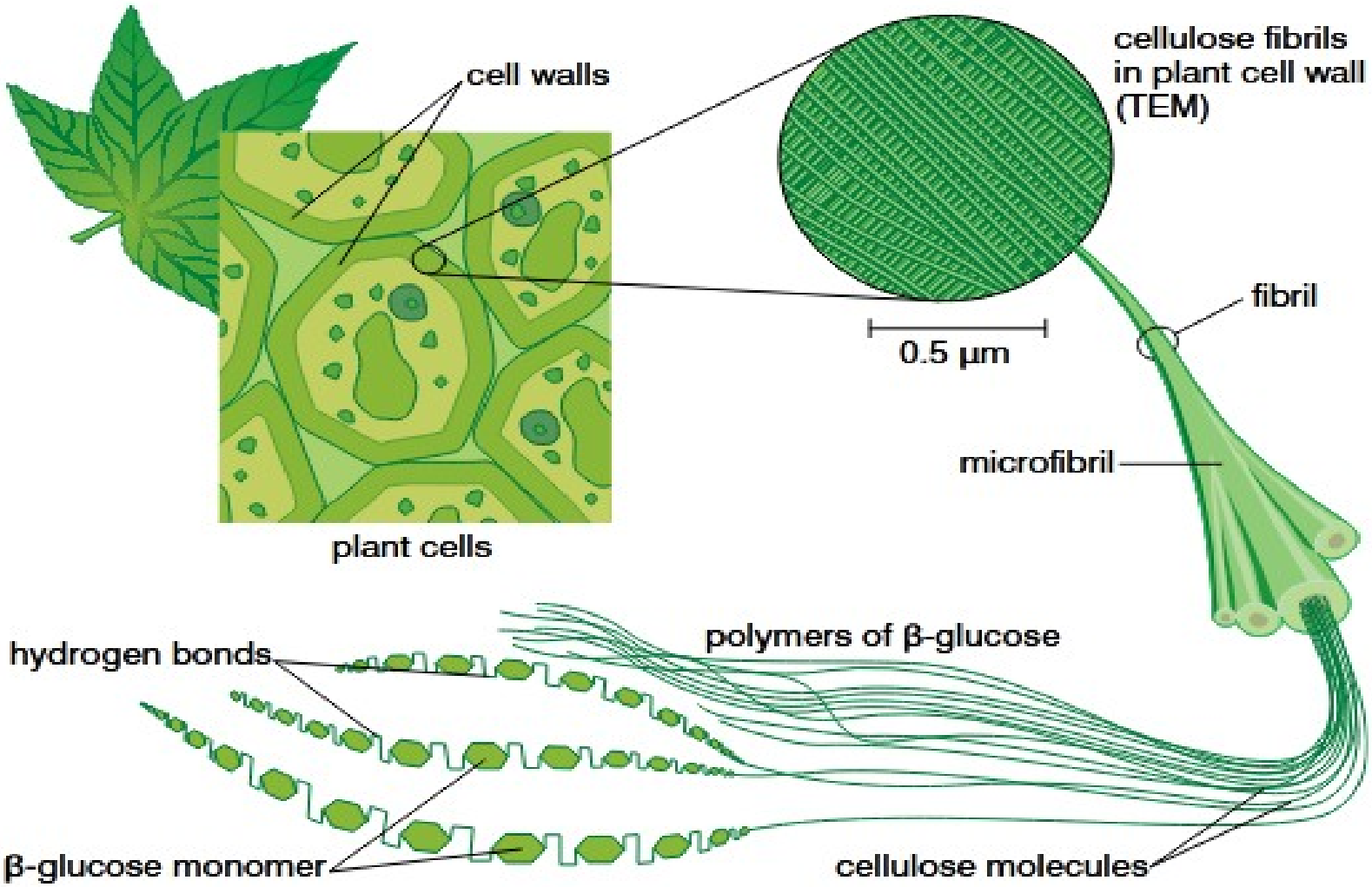


Figure 2.25 *How cellulose molecules are organized in plant cell walls.*

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.**

- 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 **oxyge**n.

- **covalently bonded hydro-carbon** 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.**

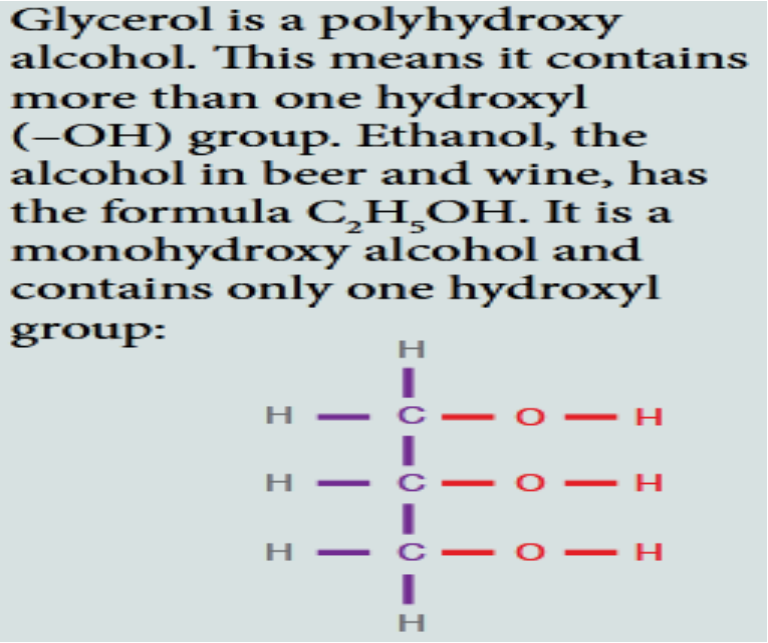


Figure 2.26 *The structure of glycerol.*



Figure 2.27 *The structure of a triglyceride.*

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*

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 poly-unsaturated 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.

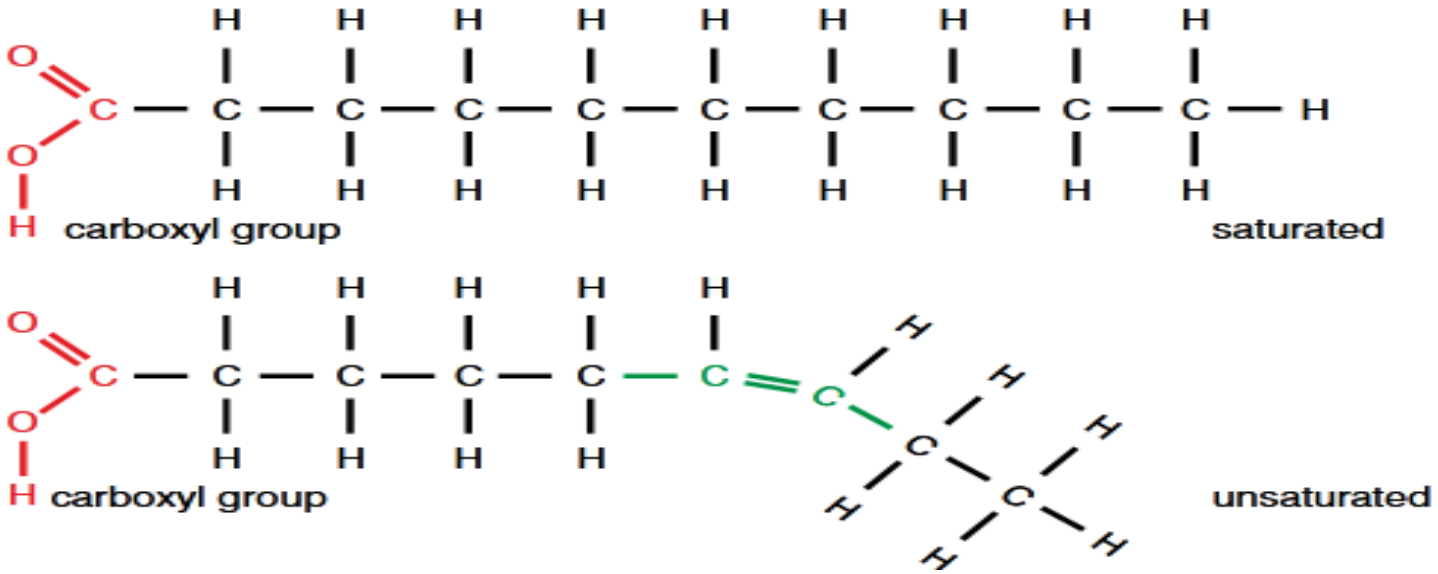


Figure 2.28 *The structure of fatty acids.*

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 '**generalized 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**.

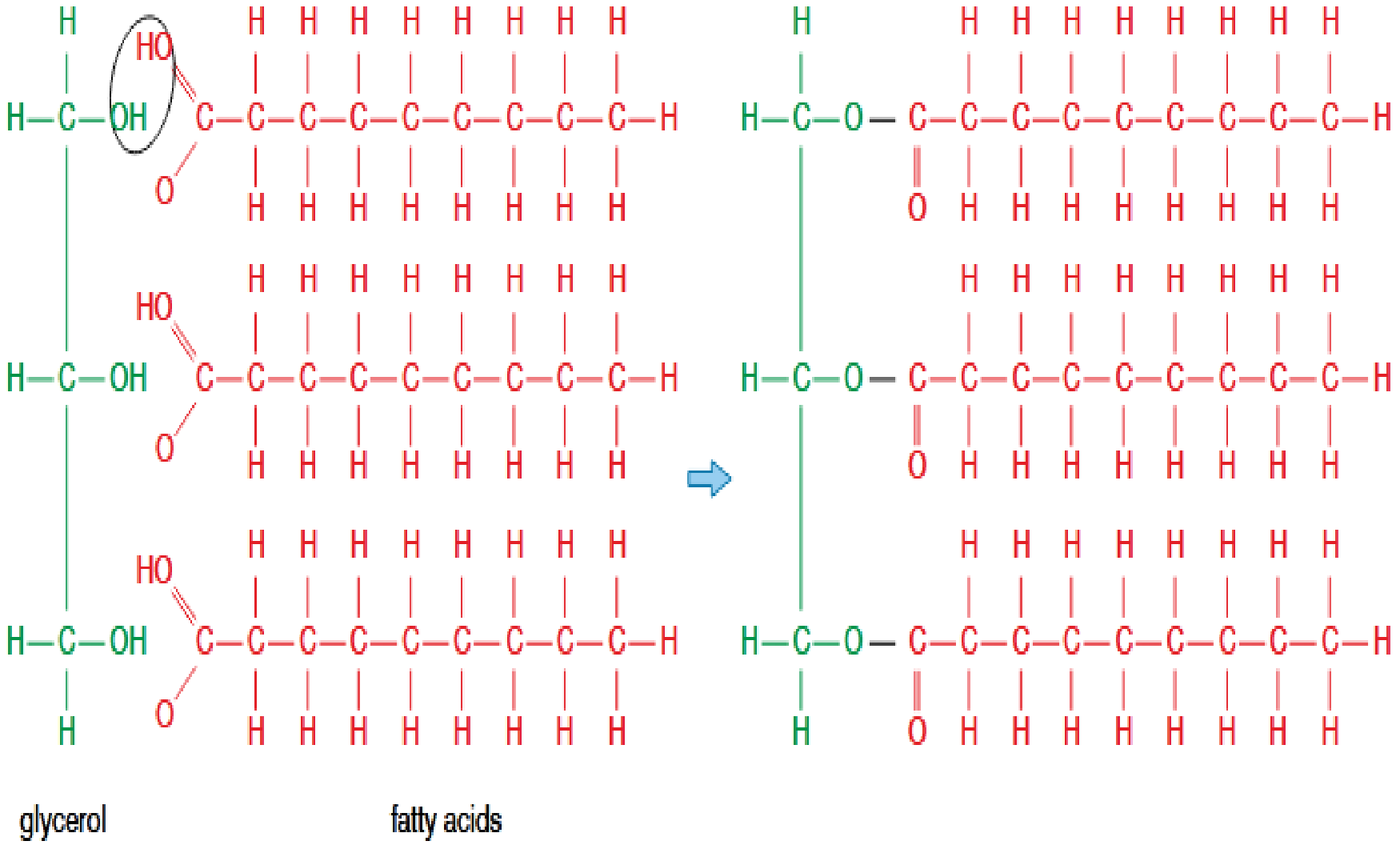


Figure 2.29 *The formation of a triglyceride.*

Phospholipids

- 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’

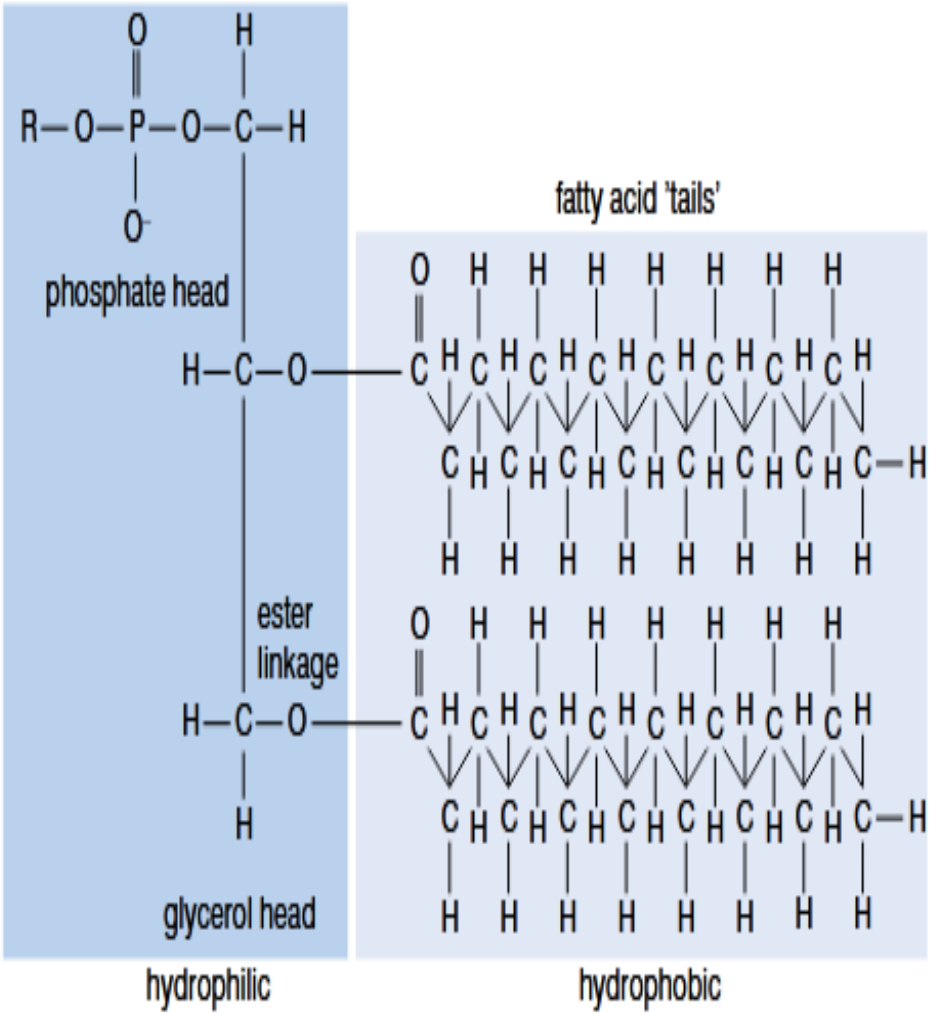


Figure 2.30 *The structure of a phospholipid.*

- In **water, phospholipids** become **organized** 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.**
- It is the **dual hydrophilic**–hydrophobic nature of **phospholipids** that makes them **organize** into **bilayers**. **Without this property**, **cell membranes would not be formed.**

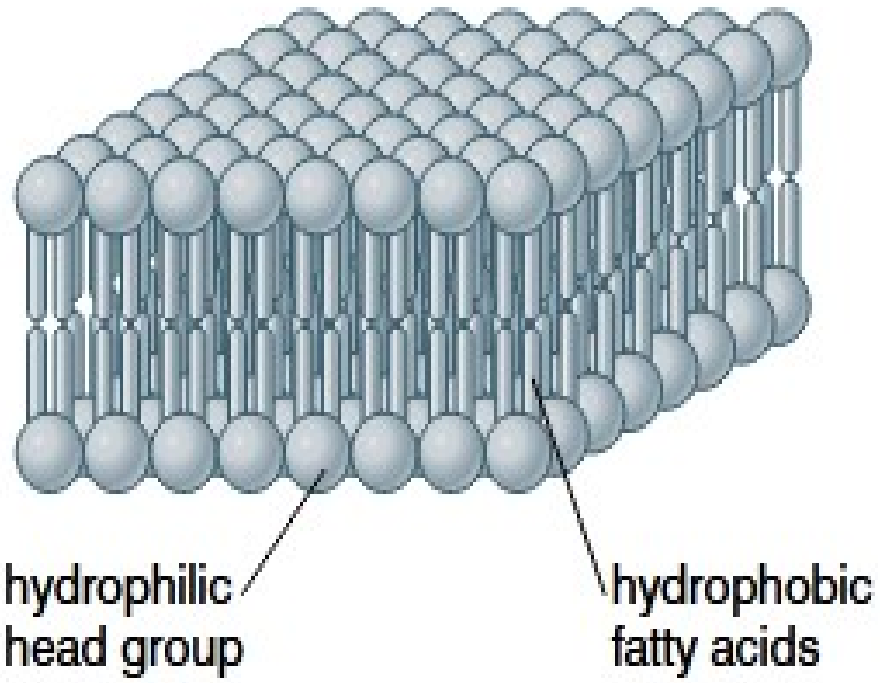


Figure 2.31 *The structure of a phospholipid bilayer.*

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
- **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

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.

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*

- **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

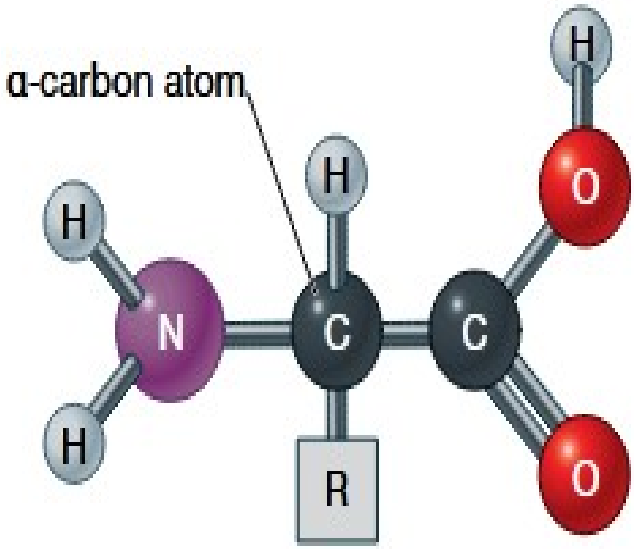


Figure 2.32 *The general structure of an amino acid.*

- **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.

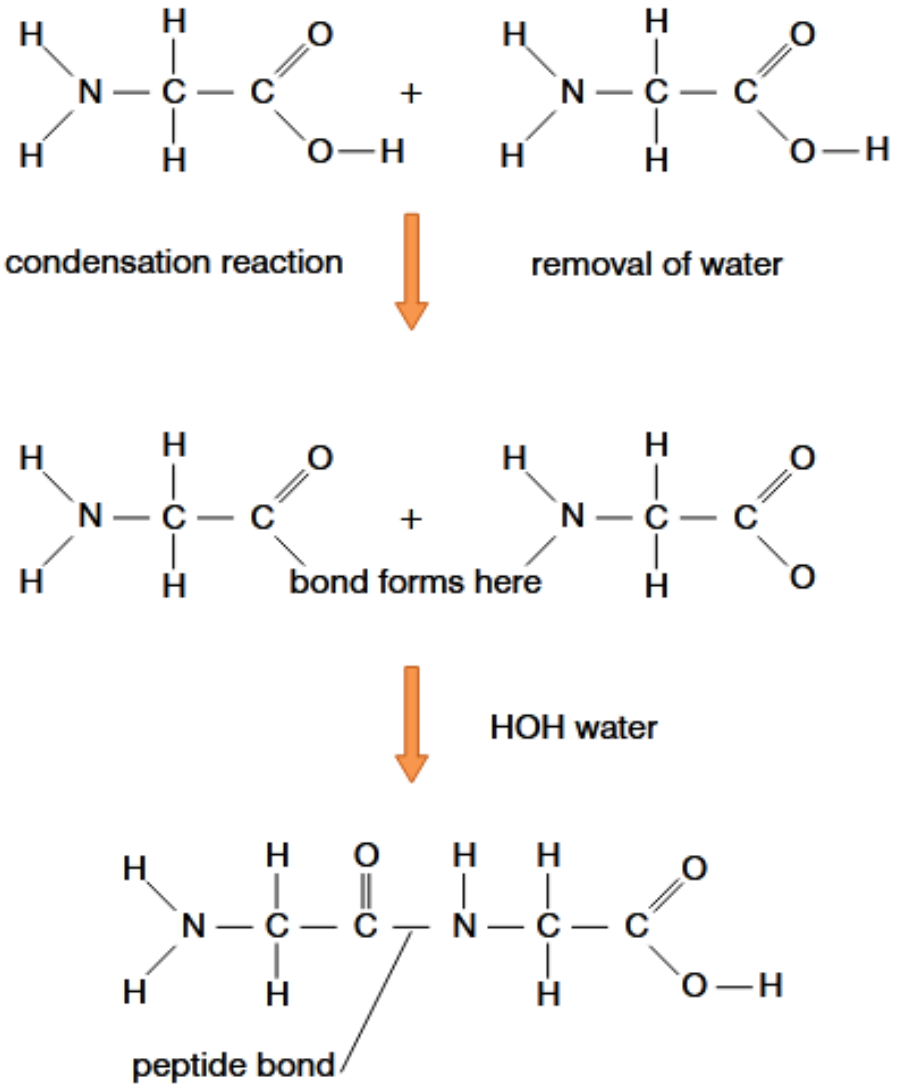


Figure 2.33 *How a dipeptide is formed.*

- 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**.
- 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-group

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*

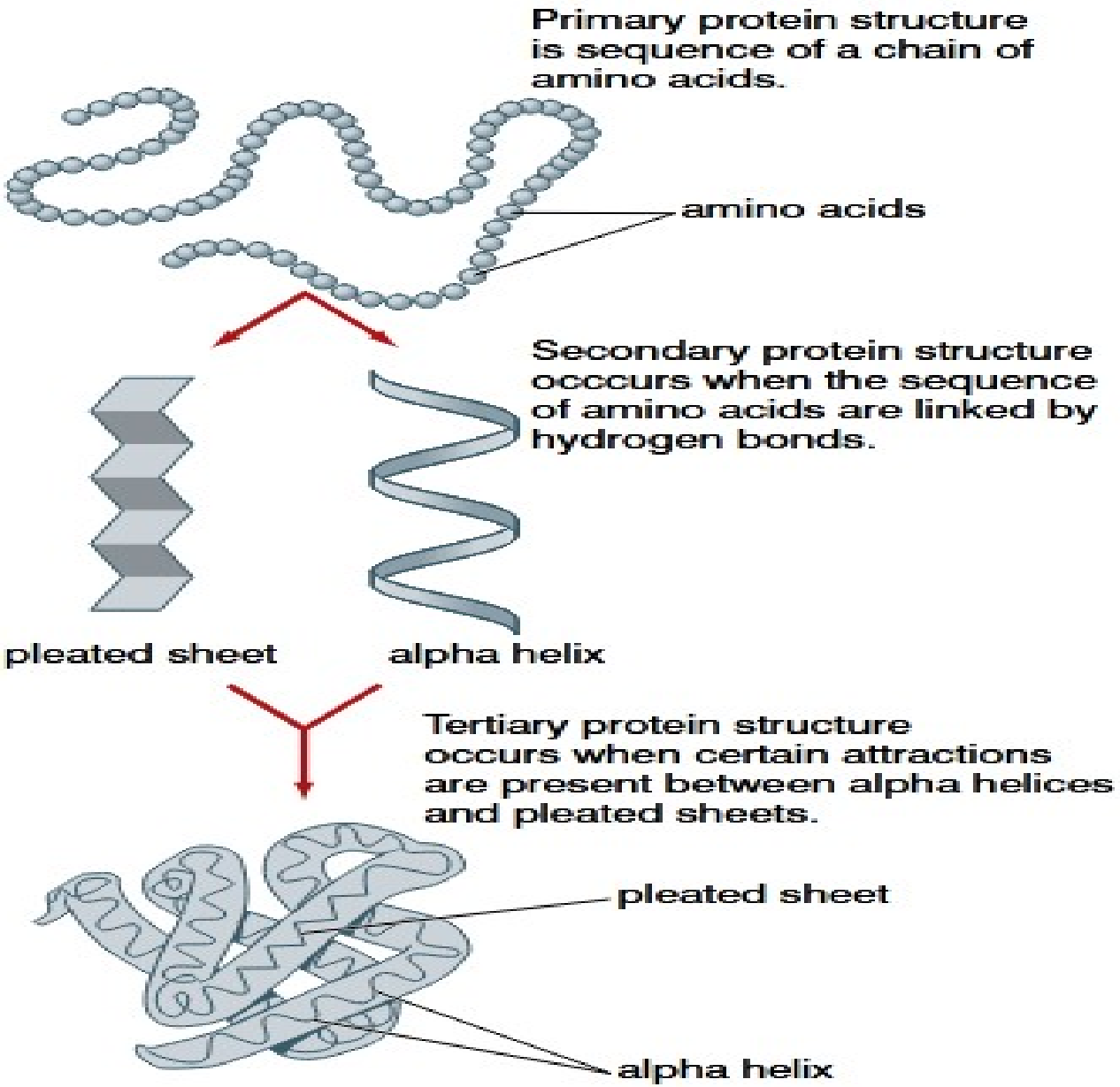


Figure 2.34 *The levels of structure of a protein.*

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

- 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 catalyze 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 organization 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).

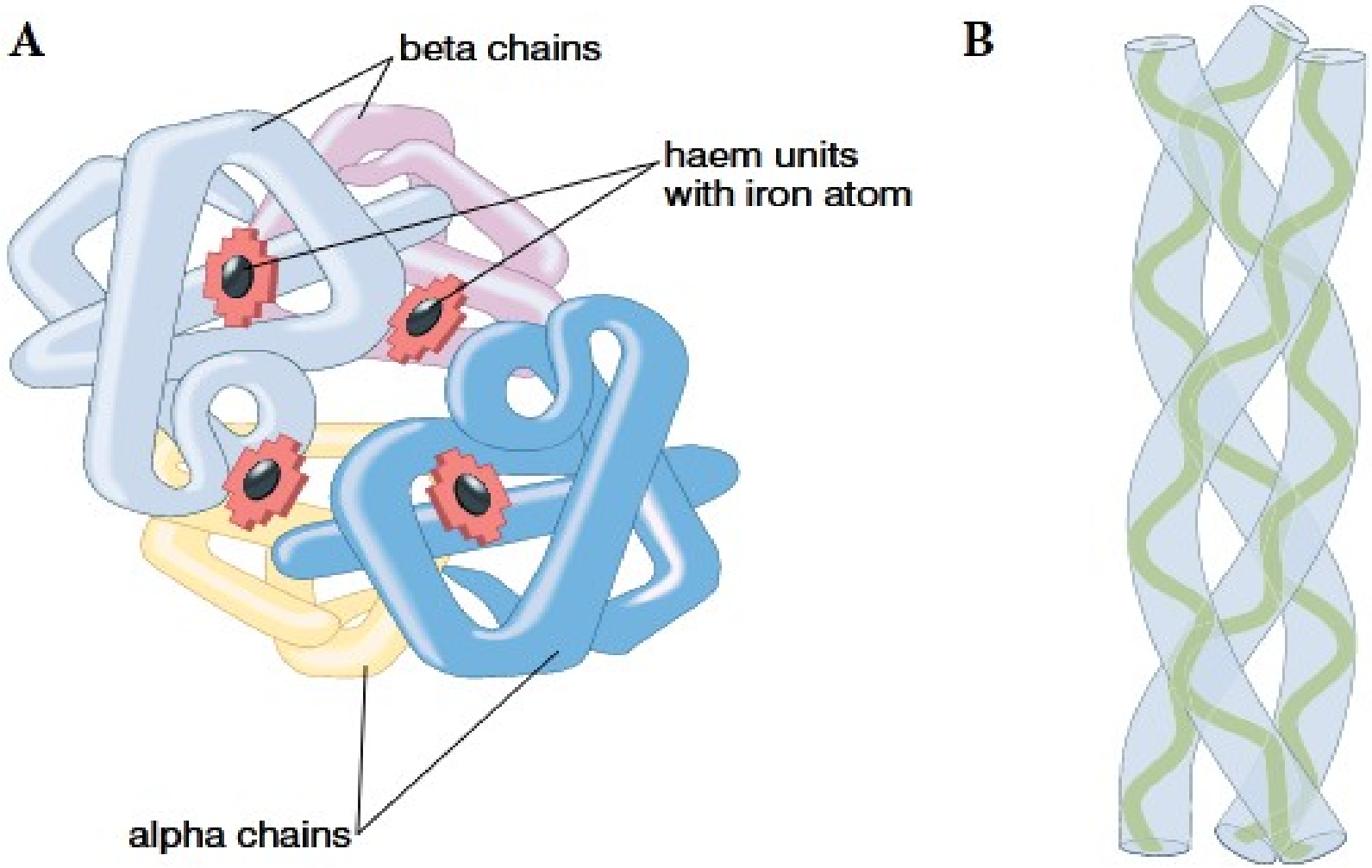


Figure 2.35 ***A*** *The four polypeptides in haemoglobin's quaternary structure;* ***B*** *The three polypeptides in collagen's quaternary structure.*

- **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**

➢ **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 fiber (for example, collagen and keratin)

✓ **globular proteins** that have a **tertiary structure** that resembles a **globule or ball** (for example, enzymes and receptor proteins).

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** realized that **both** types are **present in all living cells.**
- **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.**

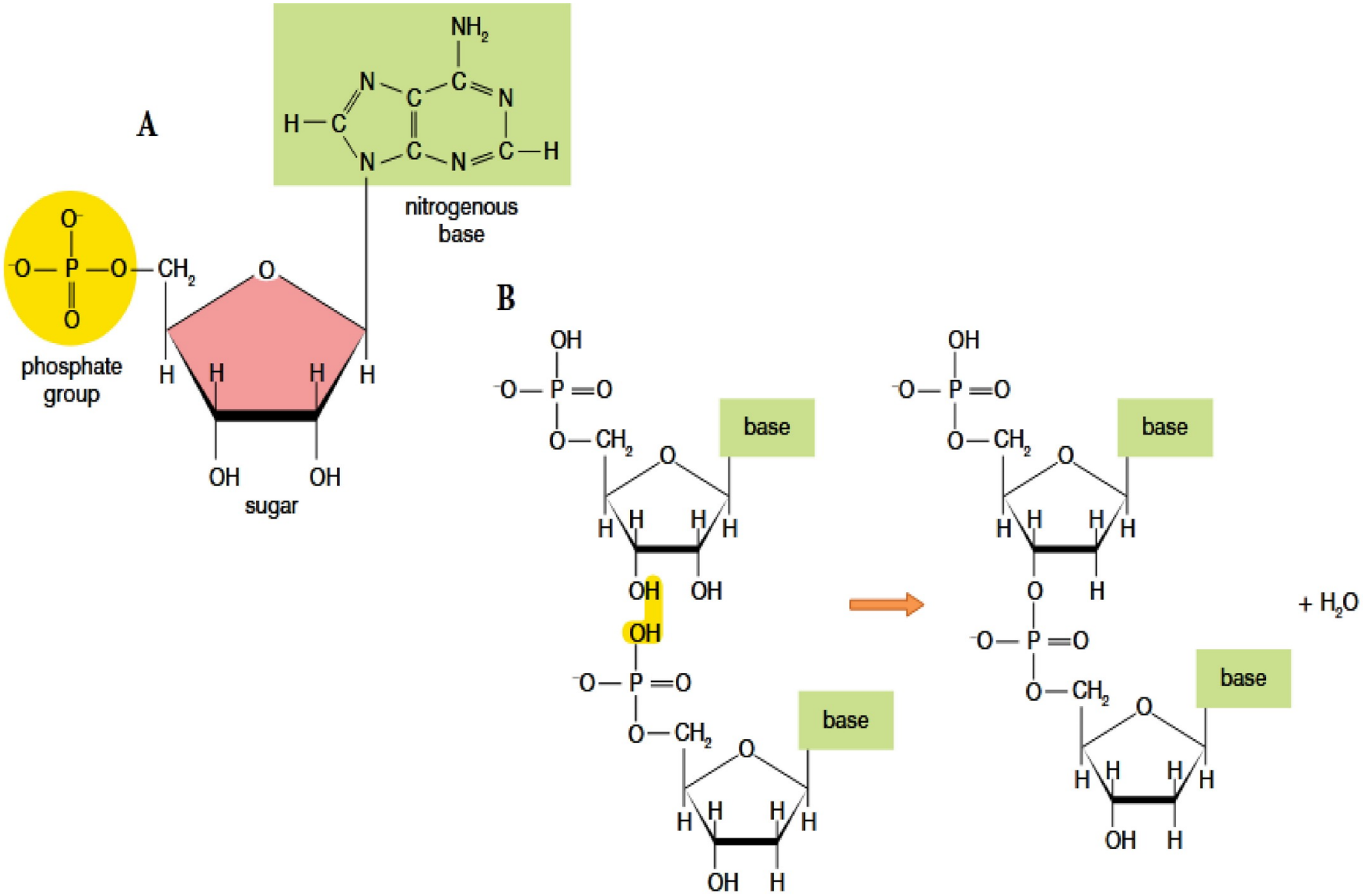


Figure 2.36 *The structure of a nucleotide* ***(A)*** *Nucleotide, form a strand by condensation reaction* ***(B).***

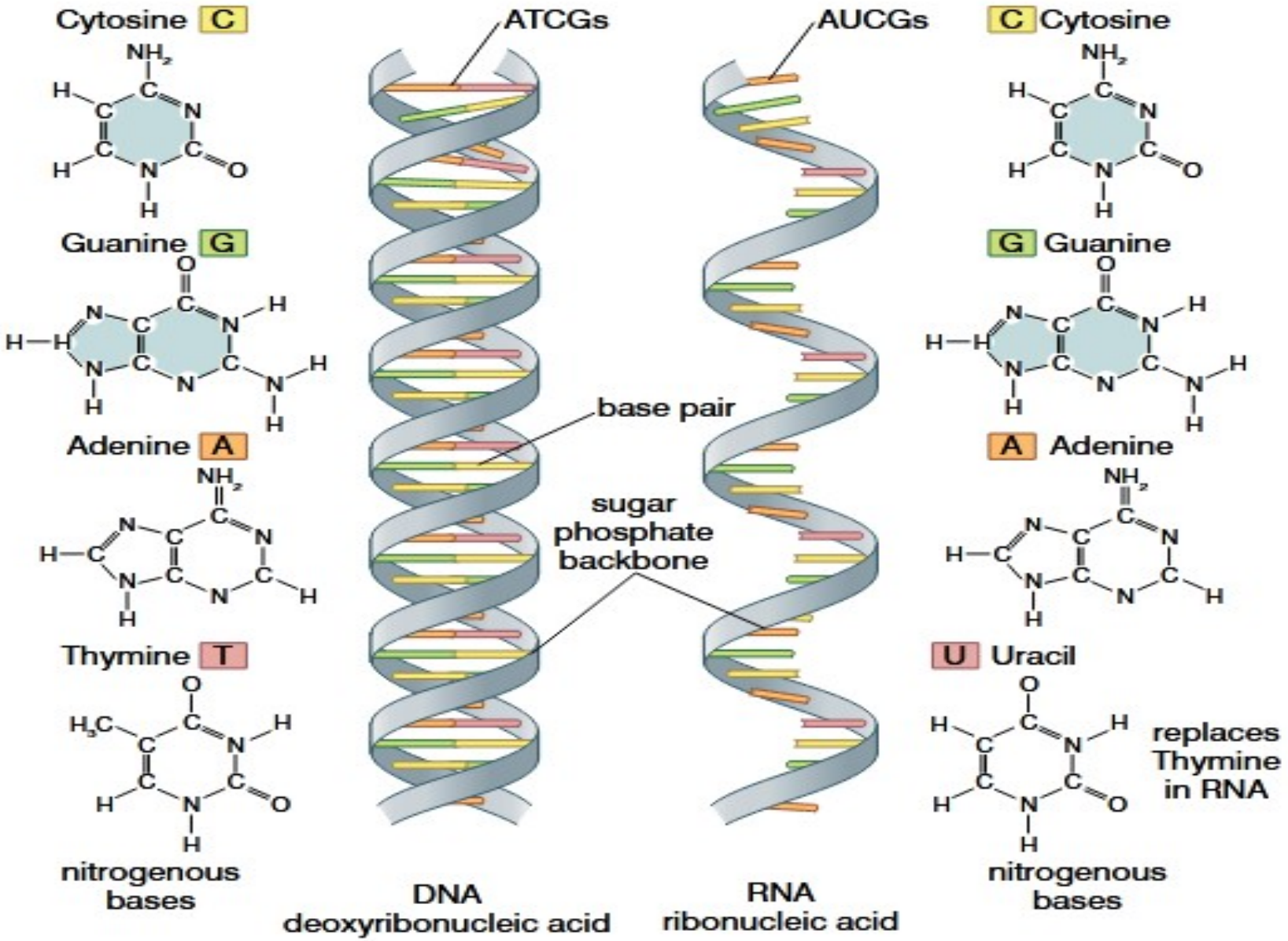


Figure 2.37 *The structures of DNA and RNA.*

- 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 which** is shown in the figure below.

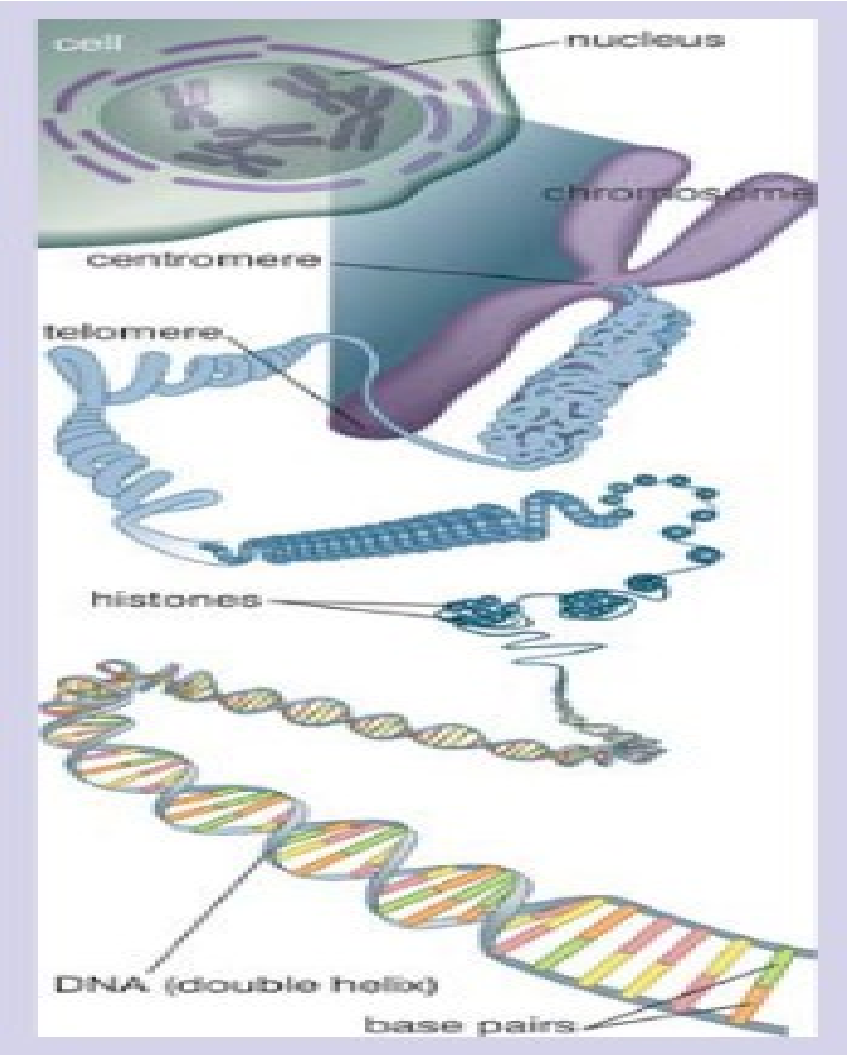


Figure 2.38 *Where DNA is found in a cell.*

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:

- **Iodine test-** for **starch**
- **Benedict's test -** for **reducing sugars**
- **Benedict's test -** for **non-reducing sugars**
- **Emulsion test-** for **lipids**
- **Biuret test** -for **proteins**

Activity: discuss the required materials, chemicals, procedure and the expected result for each type of food test.