

Unit 2

Biochemical Molecules

2.1 Inorganic and organic molecules

Classification of inorganic and organic molecules

➤ Biological molecules can be classified into two main types:

1. organic molecules

➤ always contain both carbon and hydrogen

2. Inorganic molecules

➤ may contain one or the other (or neither), but not both.

Some inorganic molecules	Some organic molecules
Calcium carbonate CaCO_3	Glucose $\text{C}_6\text{H}_{12}\text{O}_6$
Carbon dioxide CO_2	Glycine (an amino acid) $\text{C}_2\text{H}_5\text{NO}_2$
Water H_2O	Linoleic acid (a fatty acid) $\text{C}_{18}\text{H}_{32}\text{O}_2$
Iron III oxide Fe_3O_4	Methane CH_4

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

➤ **Place the following substances in the correct columns.**

- | | |
|--|---------|
| 1. $C_{12}H_{22}O_{11}$ (sucrose) | Organic |
| 2. CO (carbon monoxide) | Ino |
| 3. $C_5H_{10}O_4$ (deoxyribose) | OR |
| 4. $C_{18}H_{36}O_2$ (stearic acid - a fatty acid) | ORG |
| 5. NO_2 (nitrogen dioxide) | INOR |
| 6. H_2SO_4 (sulphuric acid) | INORG |
| 7. $C_3H_6O_3$ (lactic acid) | ORG |
| 8. $C_6H_{14}N_2O_2$ (lysine - an amino acid) | ORG |
| 9. $C_{10}H_{16}N_5O_{13}P_3$ (ATP) | ORGA |
| 10. NaCl (sodium chloride) | INOR |

- **ORGANIC**

- **INORGANIC**

Which chemical elements are found most frequently in living organisms?

- The elements that are listed below 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.

➤ The most common elements in many cells are:

a. Hydrogen (H) 59%

b. Oxygen (O) 24%

c. Carbon (C) 11%

d. Nitrogen (N) 4%

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

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

➤ **SPONCH**

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

- **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

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

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

- So, whilst a carbon atom can bond with four hydrogen atoms, each hydrogen atom can only bond with one carbon.
- Because carbon can bond with four other atoms, it can make large molecules with chains of carbon atoms.
- These are the organic molecules that are the basis of life.

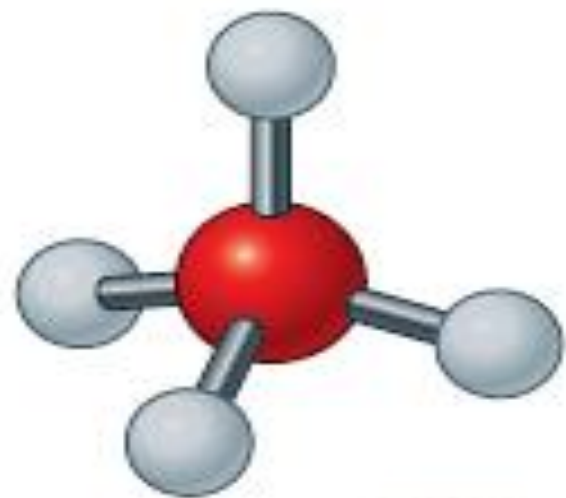


Figure 2.2 The structure of methane. In a molecule of methane, a carbon atom bonds with four hydrogen atoms. Each hydrogen atom only bonds with one carbon atom.

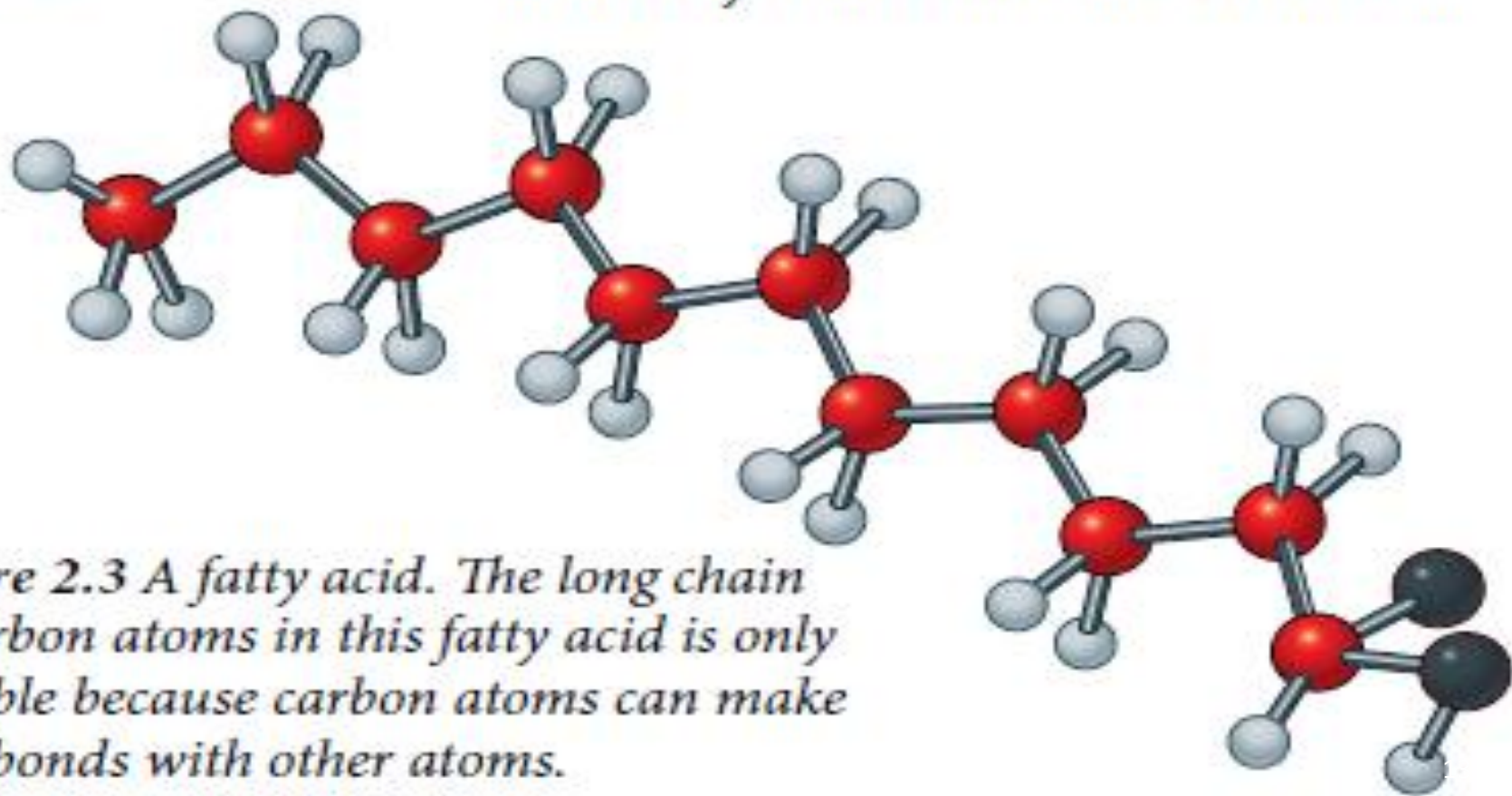


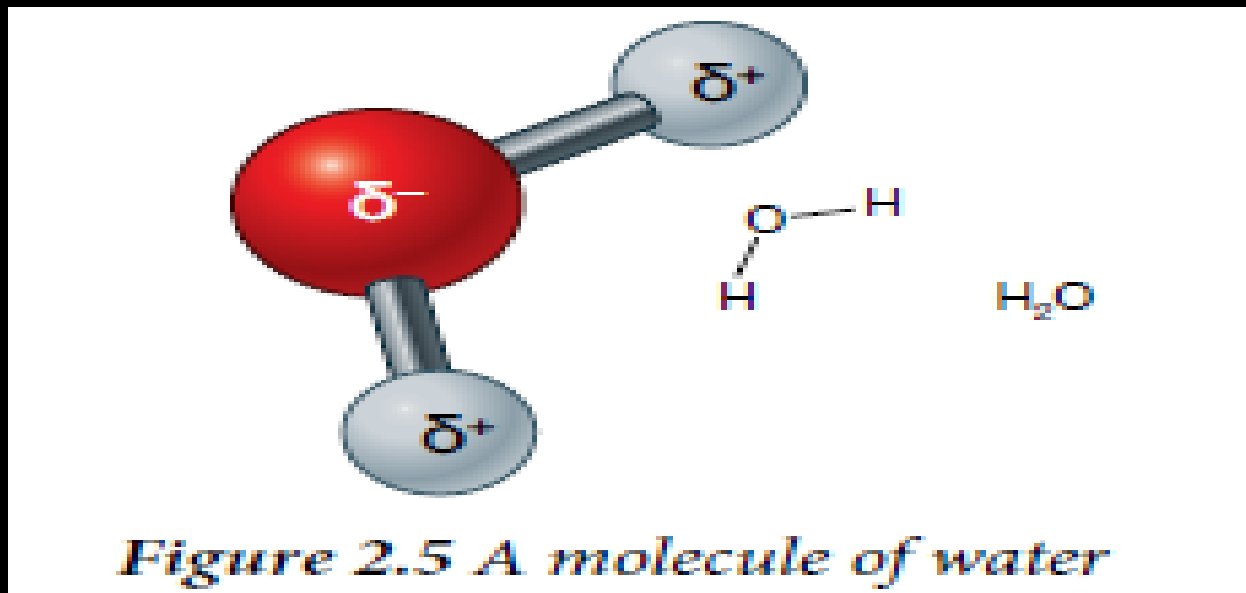
Figure 2.3 A fatty acid. The long chain of carbon atoms in this fatty acid is only possible because carbon atoms can make four bonds with other atoms.

Water

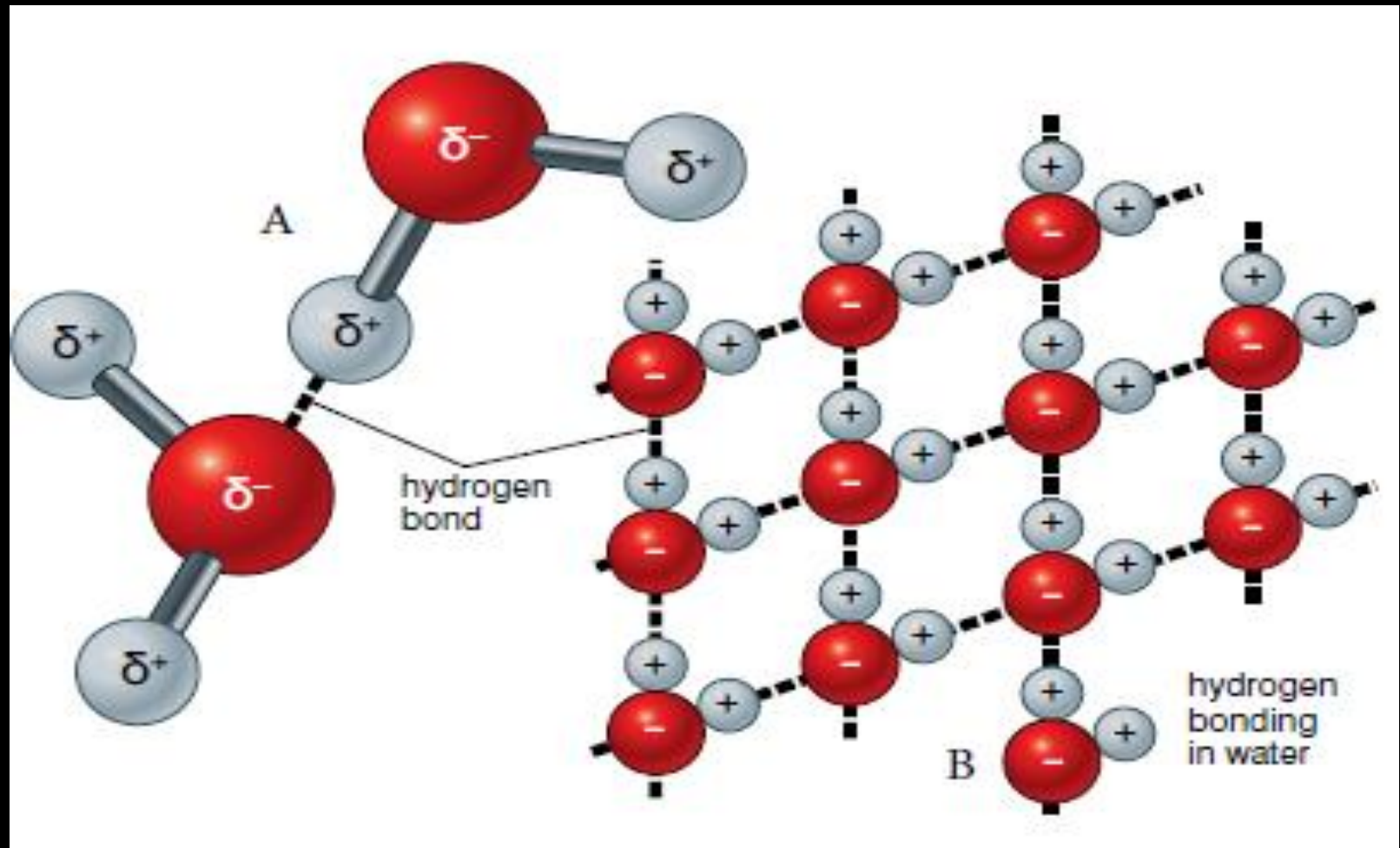
- Water covers three -quarters of the planet and on the remaining one-quarter, which is land, water is often not very far away.
- It may be in streams, rivers, ponds, lakes or in huge underground aquifers.
- And, of course, it is in all living things.
- Most cells are about 70% water and some are as high as 90%.

- Water 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.
- 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).

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



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



- 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.

Why is water so important to living things?

- The very first cells on Earth evolved in water about 3.5 billion years ago.
- Water has many properties that make it important to living things in a number of ways, such as:
 - A. a place to live
 - B. a transport medium
 - C. a reactant in many chemical reactions
 - D. a place for other reactions to take place
 - E. water is a vital chemical constituent of living cells

A. Water is a place to live in

- Many organisms live in water.
- Plants and algae both live in water as do many different types of animals.



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

B. Water is transparent.

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

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

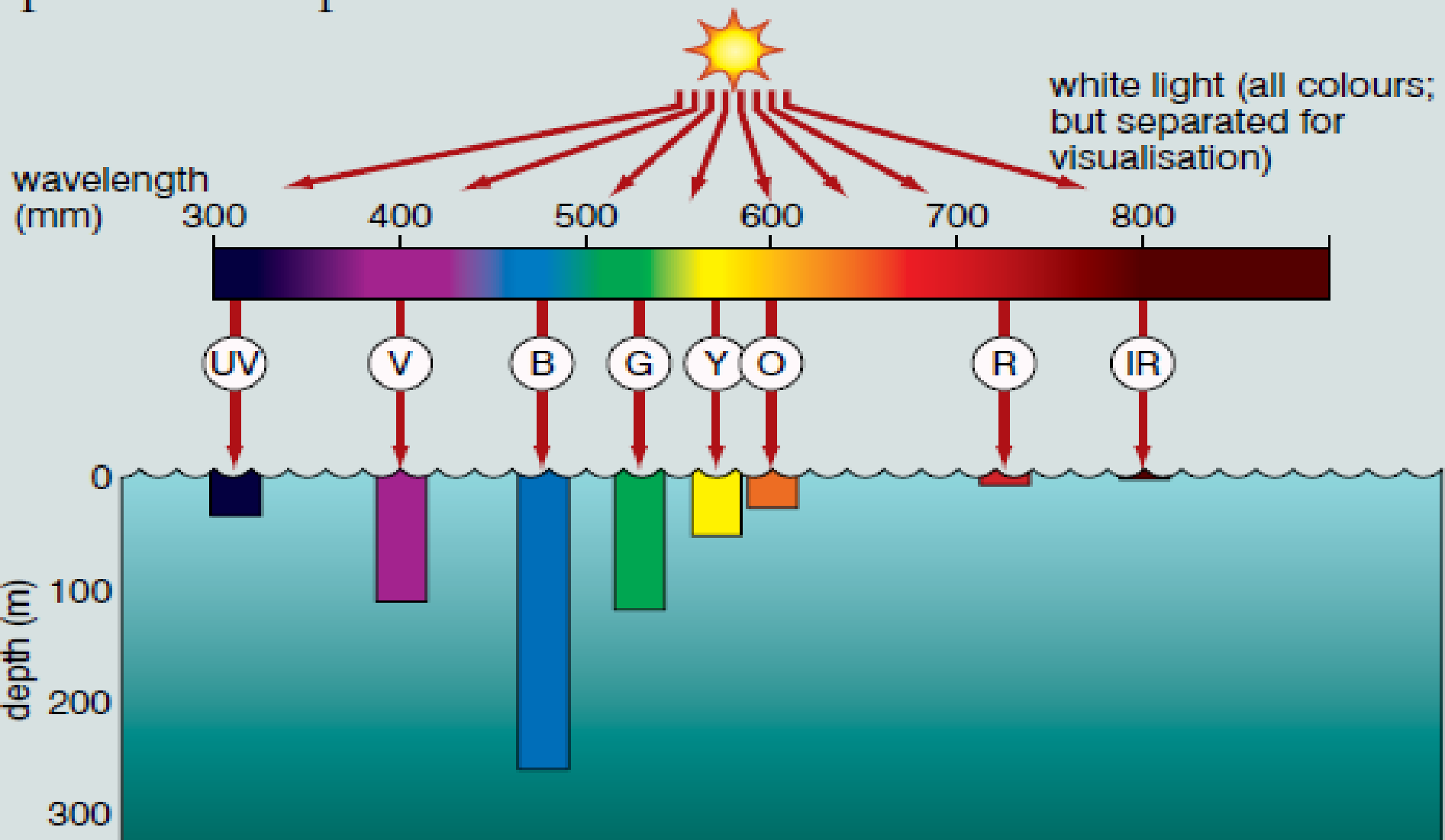


Figure 2.8 Penetration of different wavelengths of light

- ROYGBIV

C. 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.

D. 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.

E. Water has a high latent heat of vaporisation

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

F. Water has a high surface tension.

- ❖ surface tension the tension at the surface of a liquid resulting from unbalanced forces acting on the molecules at the surface
- 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 pulled together more strongly.

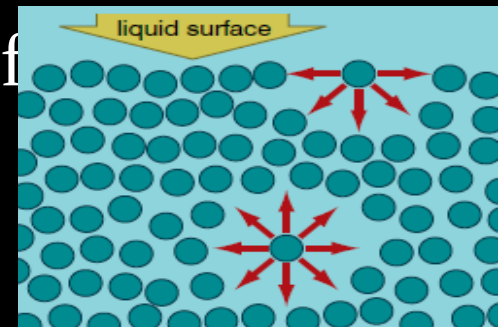


Figure 2.9 The surface tension of water

- 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 2.10 A water strider walking on water

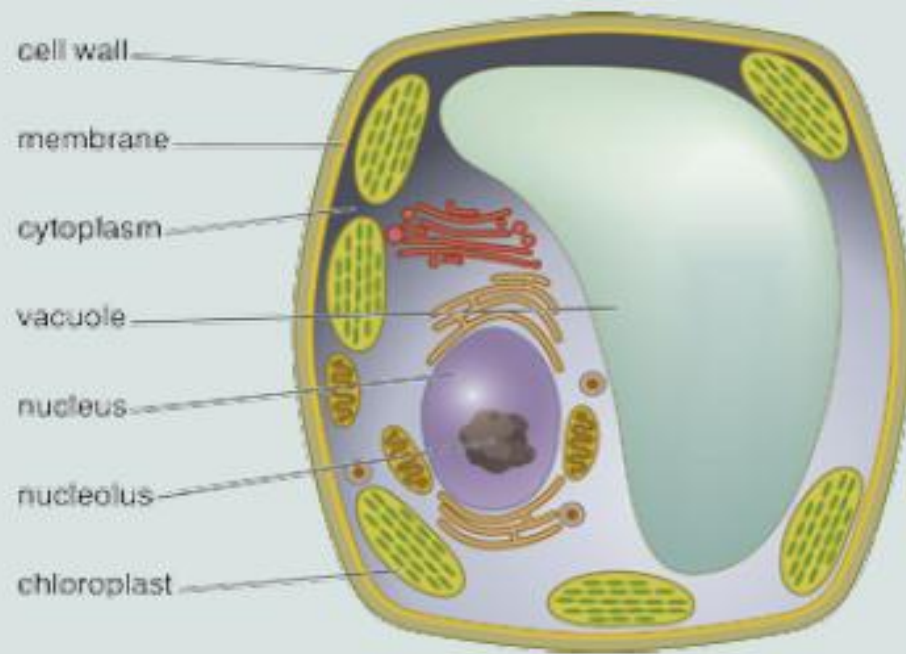


Figure 2.11 Mosquito larvae

- Water is a **good solvent** for many substances.
- Many organic and inorganic substances important to life dissolve in water, but don't dissolve either at all or as well in other liquids.
- Water is **very versatile**.
- Because these substances dissolve in water, they can be transported in a water-based transport medium.
- Biological mechanisms such as active transport, diffusion and facilitated diffusion move the substances into and out of the water (in the transport medium).
- In mammals, the plasma of blood is 90% water.

- Water has the ideal / best 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/gas) than it is, then the heart would not be able to move it through the blood vessels and also it would flow too easily and, inside cells, the organelles would not be supported.
- Also, the water inside cells transports substances around the cell; if it were more viscous, it would damage the delicate organelles in the cells.

Water and support in cells



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

Figure 2.12 A turgid plant cell



Figure 2.13
A A well-watered coleus plant



B A coleus plant that has not been well-watered

G. Water as a reactant.

- Many reactions in living things need water as a raw material.
- *Photosynthesis* - the process which begins the process of energy transfer between living things - requires water as one of its reactants.



- Water is also involved in digesting large food molecules into smaller ones.
- Reactions that use water to split large molecules are called *hydrolysis reactions*.

- **Hydro** = **water**; **lysis** = *splitting*.
- Water molecules are used to split large food molecules into smaller ones that can be absorbed into the bloodstream.
- *reactant* a substance that takes part in a chemical reaction.
- *hydrolysis* using water to split large molecules.

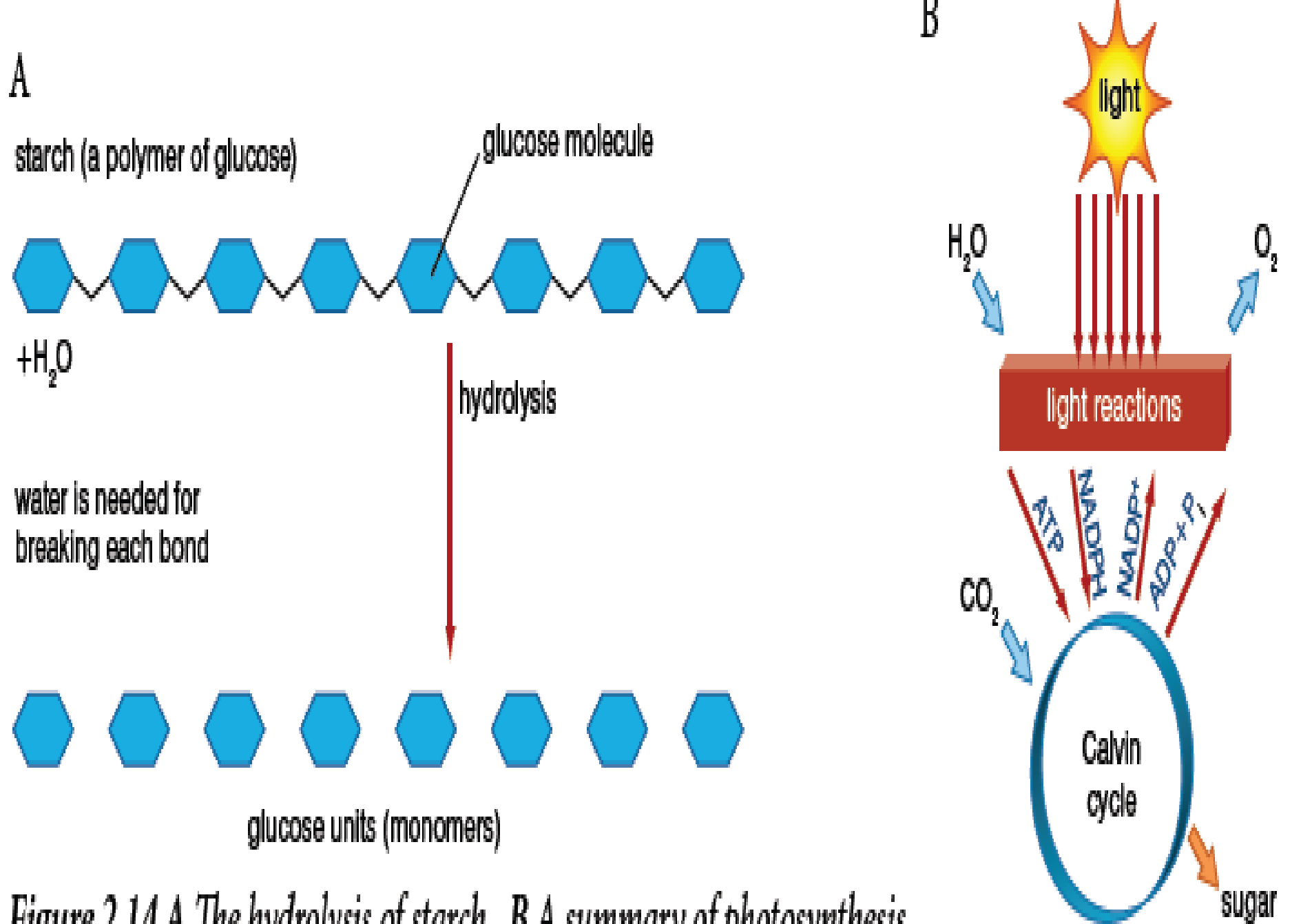


Figure 2.14 A The hydrolysis of starch B A summary of photosynthesis

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

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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 including **photosynthesis** and **respiration**

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

2.2 Organic molecules

What are carbohydrates and why do we need them?

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

❑ Carbohydrates have a range of functions:

- a. They are used to *release energy* in respiration - glucose is the main respiratory substrate of most organisms.
- b. Carbohydrates are a convenient form in which to *store chemical energy*; storage carbohydrates include:
 - starch in plants
 - glycogen in animals
- c. 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.

What different types of carbohydrates are there?

1. Monosaccharides

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

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

A. **A triose** monosaccharide has three carbon atoms – formula $C_3H_6O_3$.

Glycerate phosphate is a triose important in photosynthesis.

B. **A pentose** monosaccharide has five carbon atoms – formula $C_5H_{10}O_5$.

Ribose is found in RNA nucleotides.

C. **A hexose** monosaccharide has six carbon atoms – formula $C_6H_{12}O_6$.

Glucose is the hexose produced in photosynthesis and used in respiration.

- There are several different trioses, pentoses and hexoses.
- Each triose has the same number of each kind of atom (hence the formula $C_3H_6O_3$), but the atoms are put together in a different way.
- They are *isomers* of each other. The same is true for the *pentoses* and *hexoses*.
- Monosaccharides can be classified in a different way - according to the functional group that they possess.

- There are two functional groups in monosaccharides:
 - A. *the aldehyde group* with the formula CHO (monosaccharides with this group are aldoses), and
 - B. *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*.

KEY WORDS

- A. *monosaccharide* a single sugar
- B. *isomers* molecules with the same chemical composition, but a different arrangement of atoms
- C. *functional group* a group of atoms within a molecule that behaves in a particular way
- D. *aldoses* monosaccharides with an aldehyde group in the molecule
- E. *ketoses* monosaccharides with a ketone group in the molecule

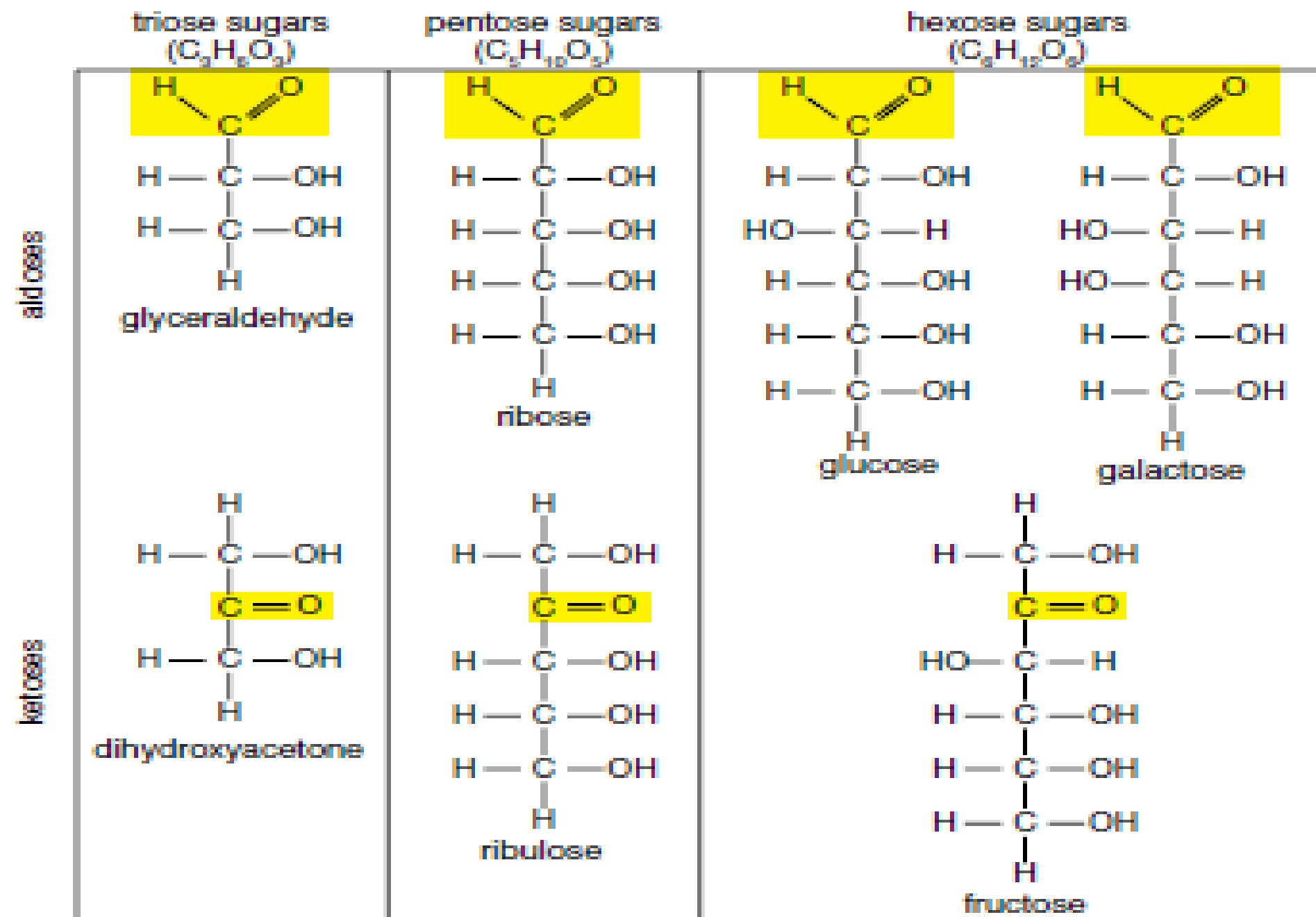


Figure 2.16 Aldose and ketose monosaccharides

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

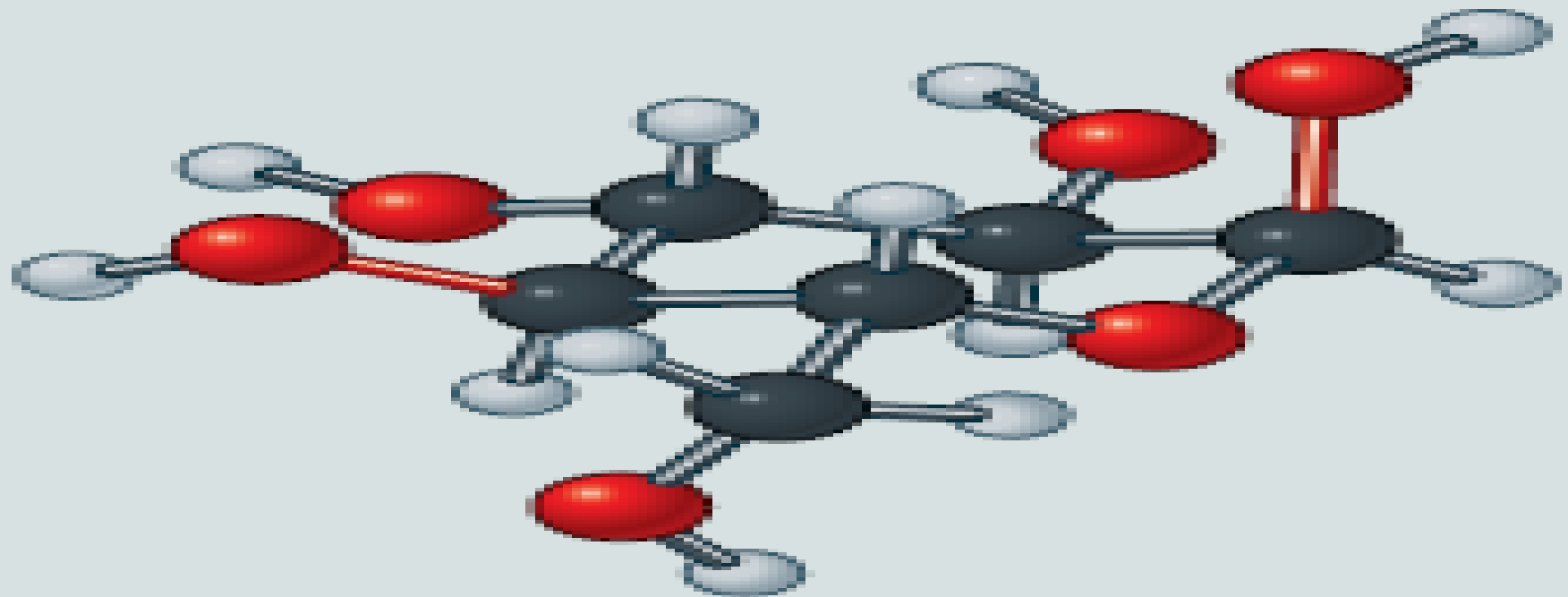
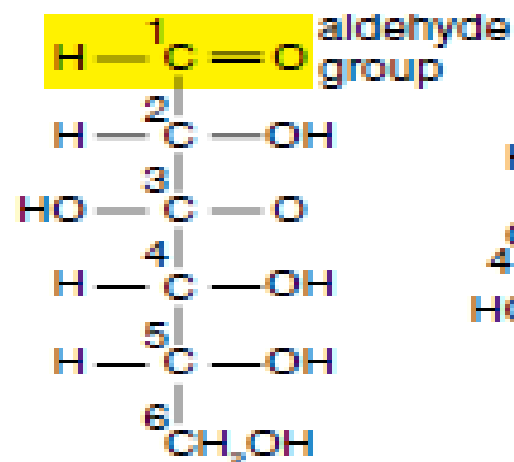
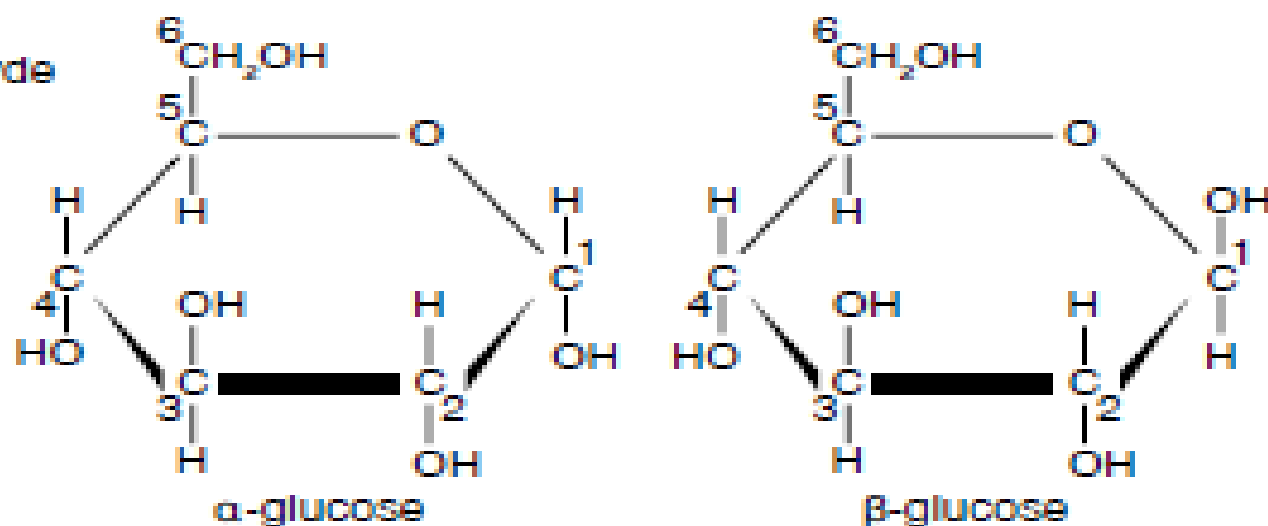


Figure 2.18 A 3-D representation of the α -glucose molecule

glucose (an aldohexose)

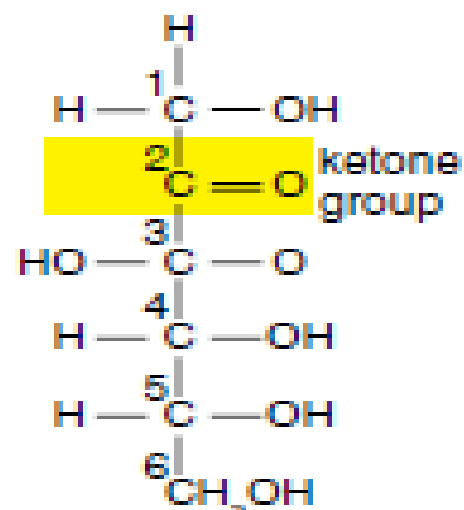


straight-chain form



ring forms

fructose (a ketohexose)



straight-chain form

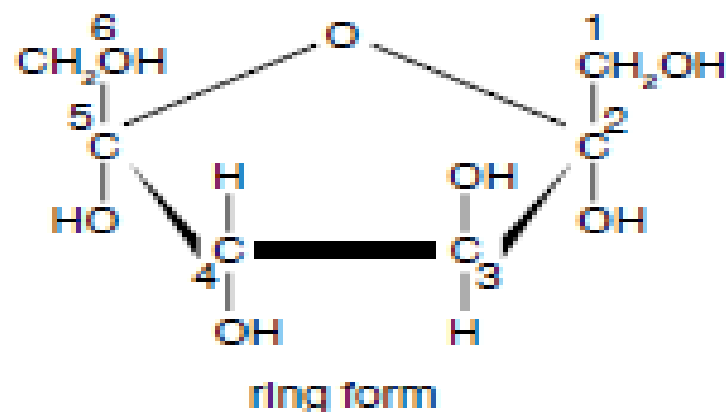
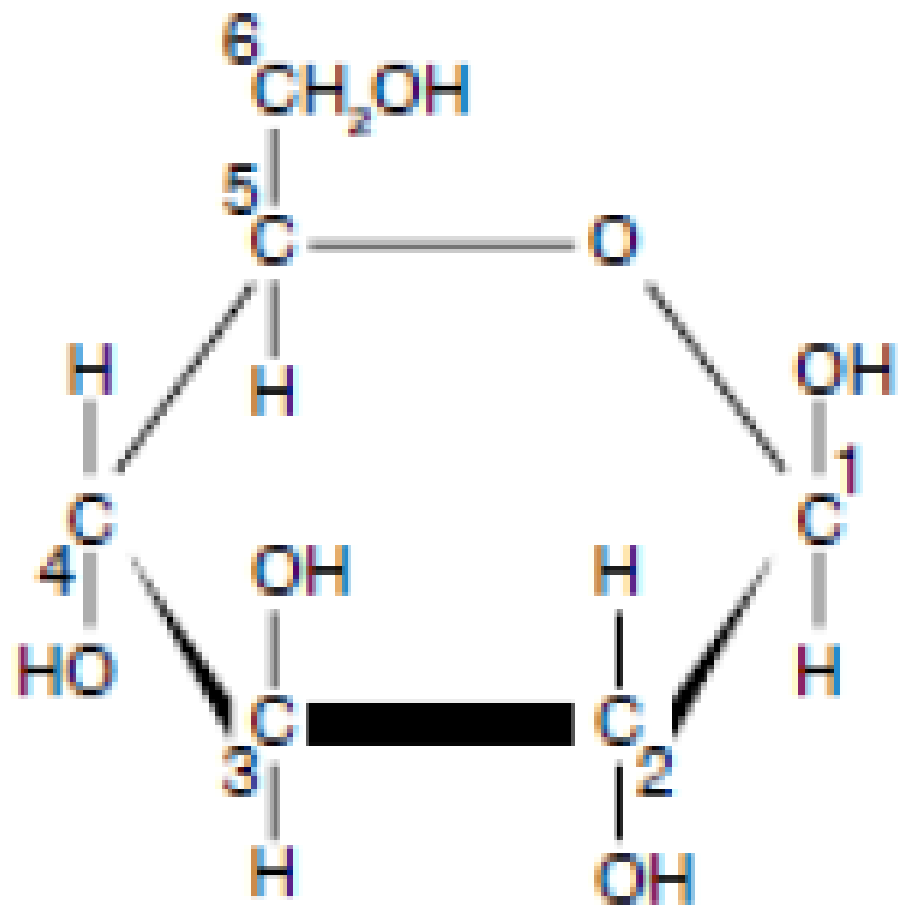
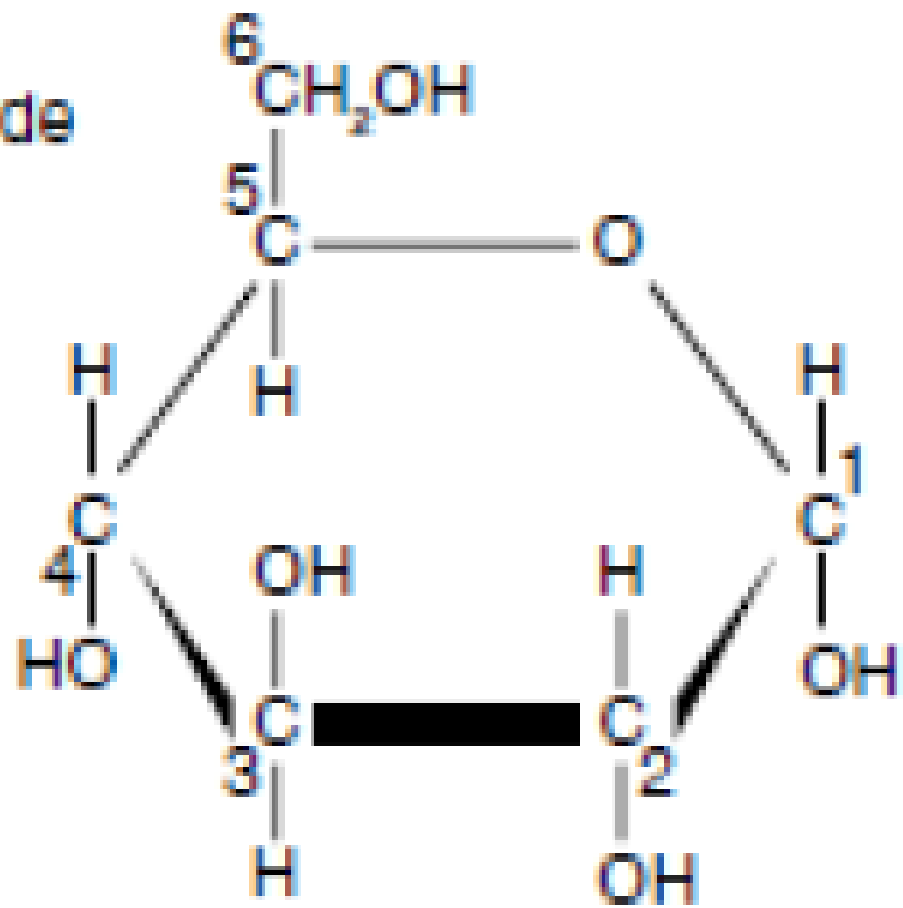


Figure 2.17 Straight chain forms and ring forms of glucose and fructose

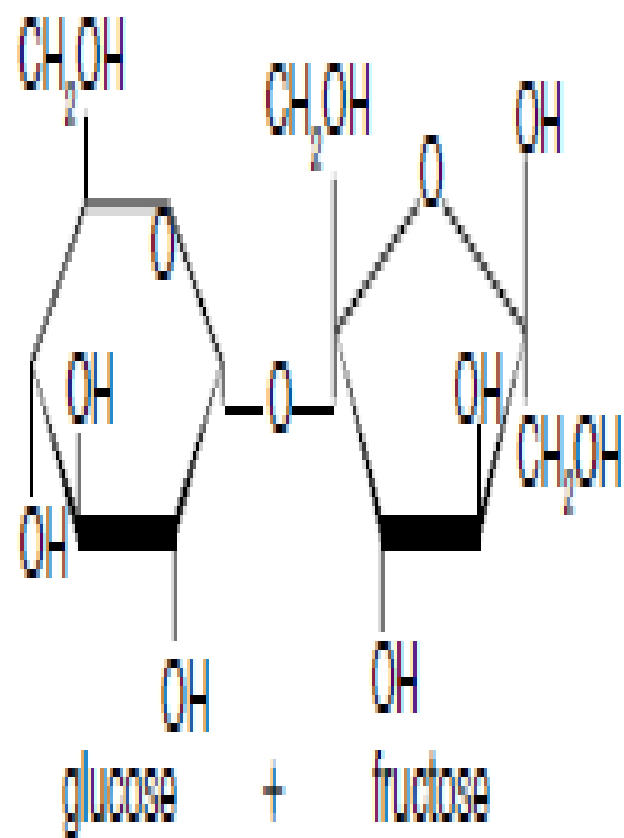


ring forms

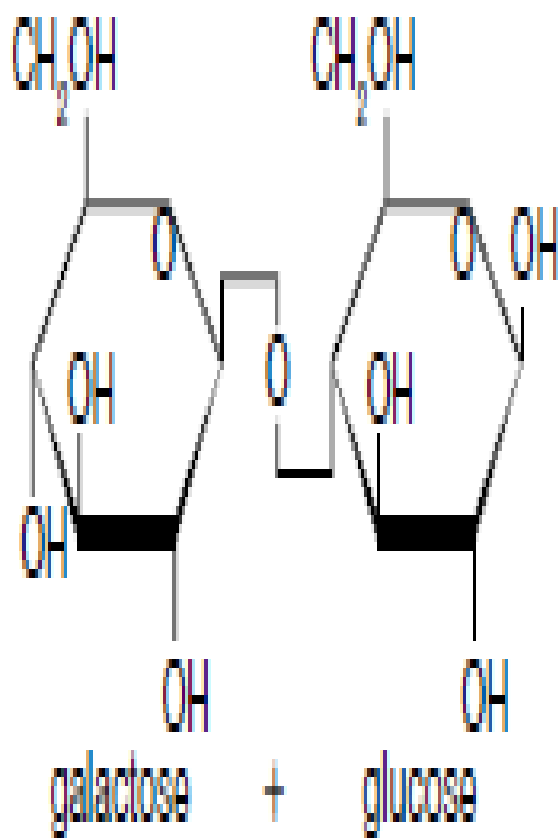
- The straight chain form of glucose can produce two different ring forms - α -glucose and β -glucose.
- There is only one difference between these two.
- The straight chain form of fructose produces only one ring form.
- In these structural diagrams, the carbon atoms in the molecules are numbered according to their positions in the molecule.

Disaccharides

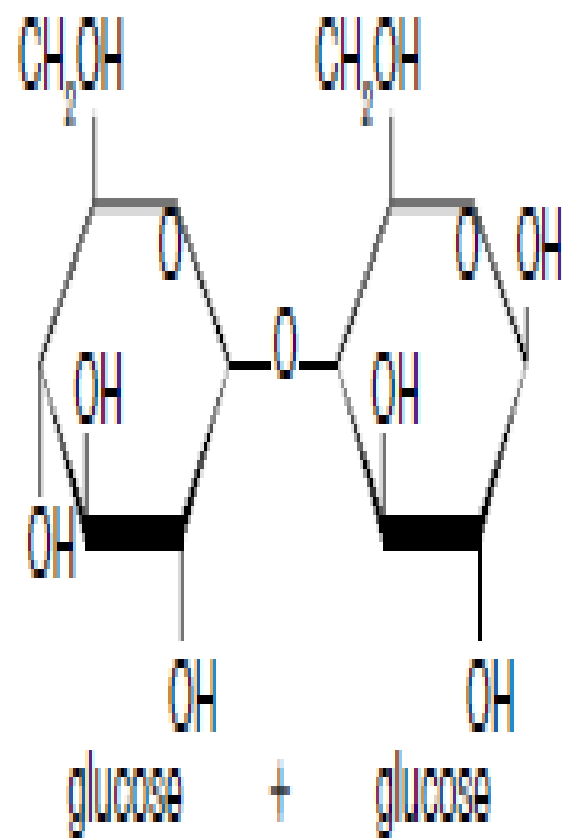
- carbohydrate molecules are made by two monosaccharide molecules joining together.
- For example, a molecule of:
 - a. maltose is derived from two α -glucose molecules
 - b. sucrose is derived from an α -glucose molecule and a fructose molecule
 - c. lactose (milk sugar) is derived from a β -glucose molecule and an α -galactose molecule.
- Two hexose monosaccharides have reacted to form a disaccharide molecule.



sucrose



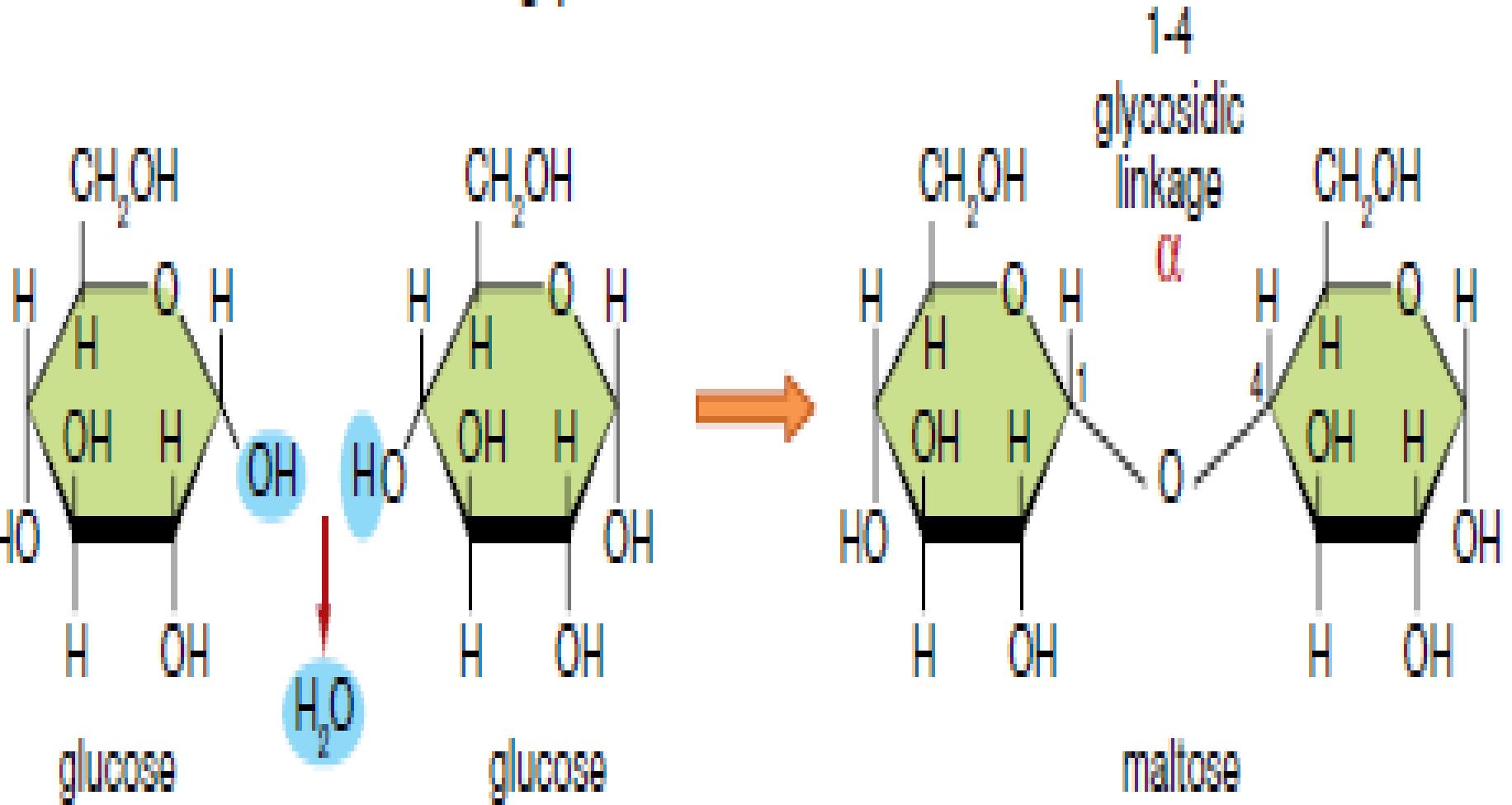
lactose



maltose

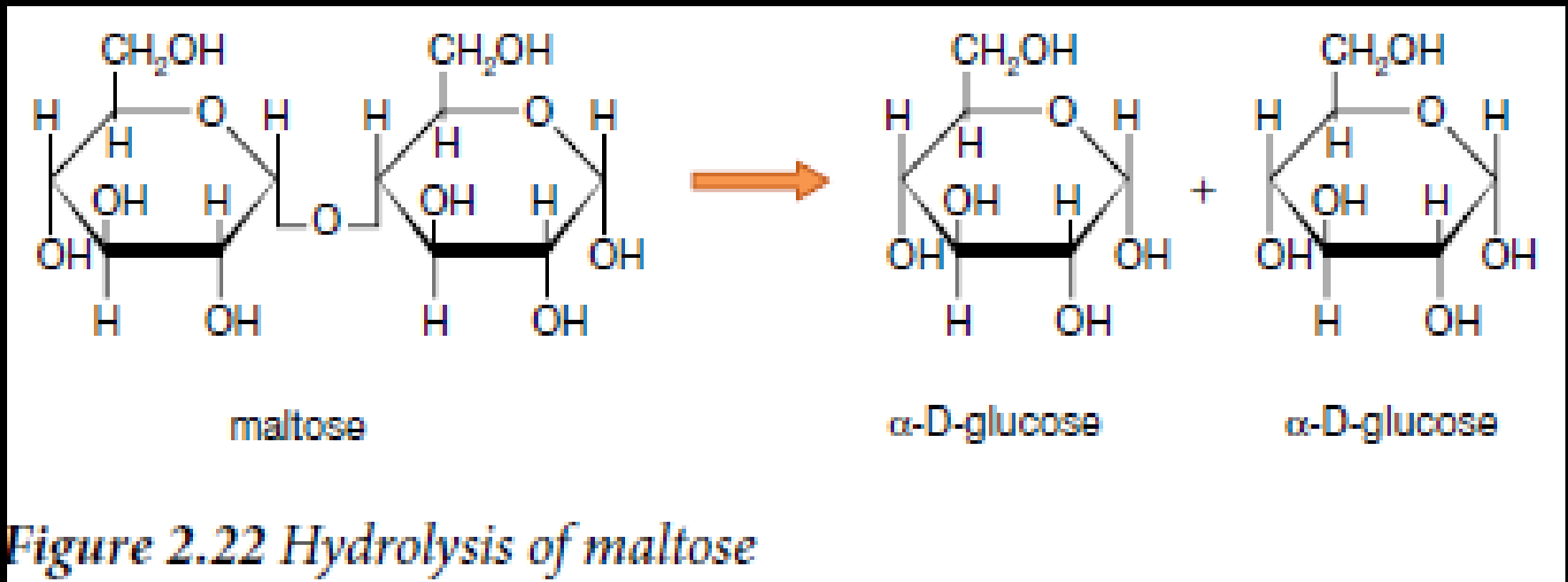
Figure 2.20 The structures of three disaccharides

- As the formula of a hexose is $C_6H_{12}O_6$, you might expect the formula of the disaccharides to be $C_{12}H_{24}O_{12}$.
- In fact, the formula is $C_{12}H_{22}O_{11}$. A molecule of water (H_2O) is formed from a hydroxyl group from one monosaccharide and a hydrogen atom from the other
- 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, *α -1,4-glycosidic bond*.



This process is known as **condensation**

- The reverse process is *hydrolysis* (of the disaccharide).
- This involves 'putting back' the water that was removed during condensation and splitting the molecule into its component, smaller molecules.



KEY WORDS

- *condensation* the process in which two molecules combine to form a larger molecule, producing a smaller molecule (often water) as a by-product
- *glycosidic bond* the bond that holds two monosaccharide units together.
- *polysaccharide* a carbohydrate whose molecules consist of a number of monosaccharide molecules bonded together

Polysaccharides

- are complex carbohydrates.
- Their molecules are built as many hundreds of monosaccharide molecules join together by forming condensation links.
- *Starch is a polymer of α -glucose.*
- Some polysaccharides are *storage molecules*.
- These offer a convenient way of storing carbohydrates that will not interfere with the metabolism of cells.
- Others *are structural carbohydrates*.
- As the name suggests, these carbohydrates are used to build structures -like plant cell walls and insect exoskeletons.

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.

α -(1 $\rightarrow$ 4) linkage

formed, this long chain winds itself into a helix.

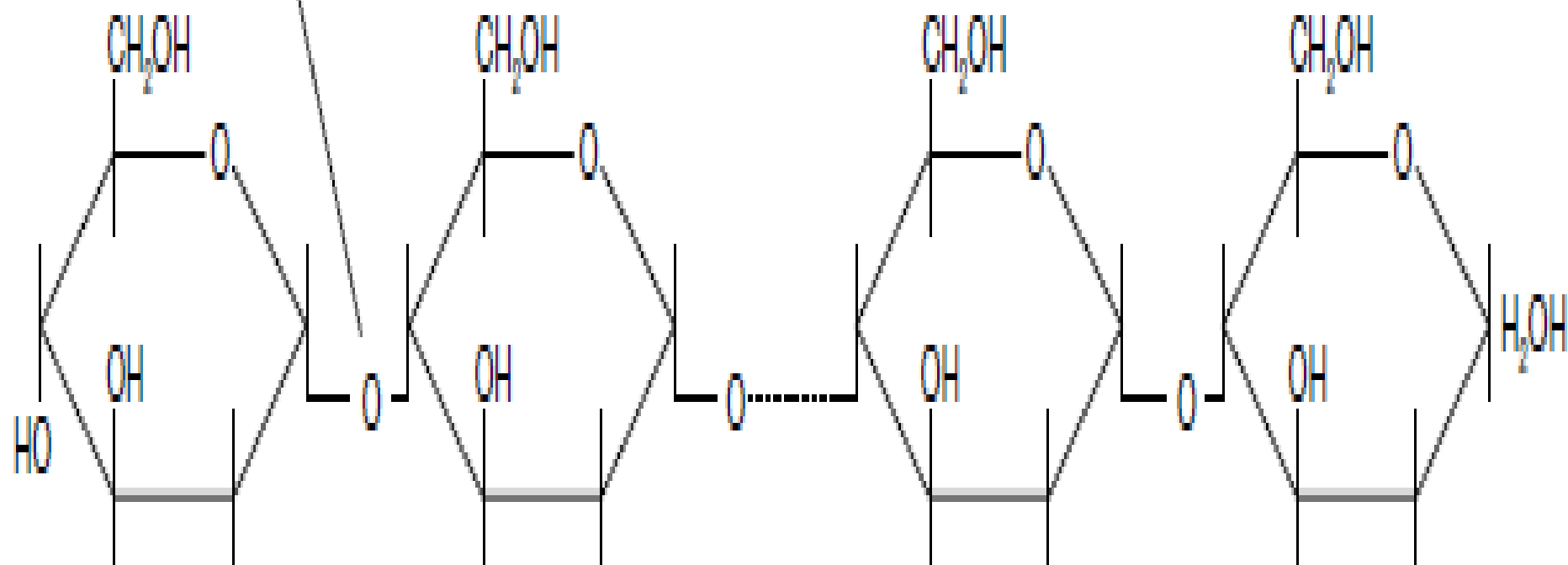


Figure 2.23 Linkages in amylose

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

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

α -glucose molecule

iodine molecule

amylose helix

Figure 2.24 Iodine stains starch blue-black.

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

- This allows it to be quickly hydrolysed by enzymes acting at the ends of the chains to release glucose for respiration.

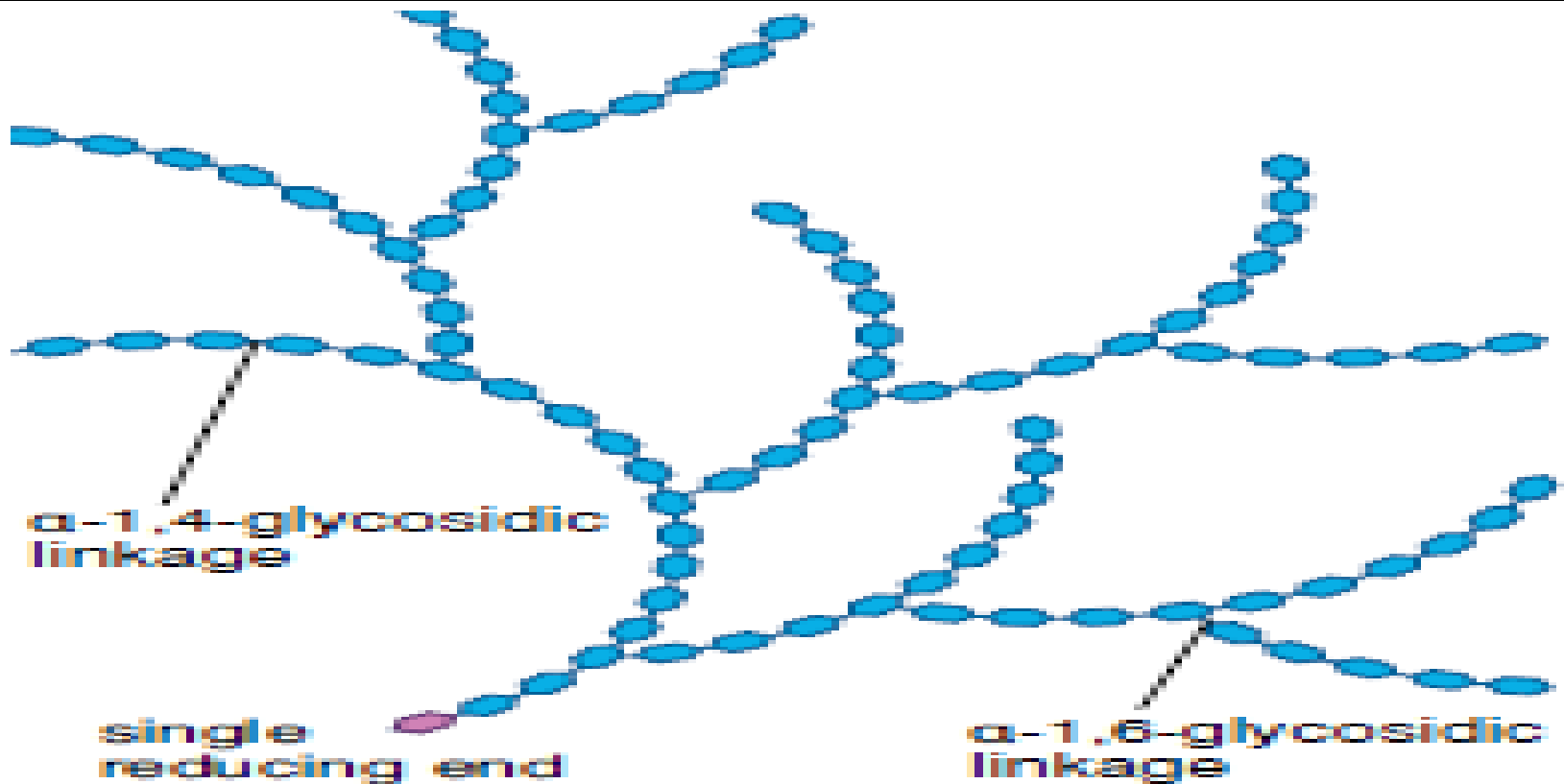


Figure 2.25 The structure of amylopectin

How the structure of starch is suited to its function

- Starch is a plant storage carbohydrate. How does its structure suit it to this function?
 - a. Both amylose and amylopectin are compact molecules, so many α -glucose molecules can be stored in a small space, without affecting cell metabolism.
 - b. 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.

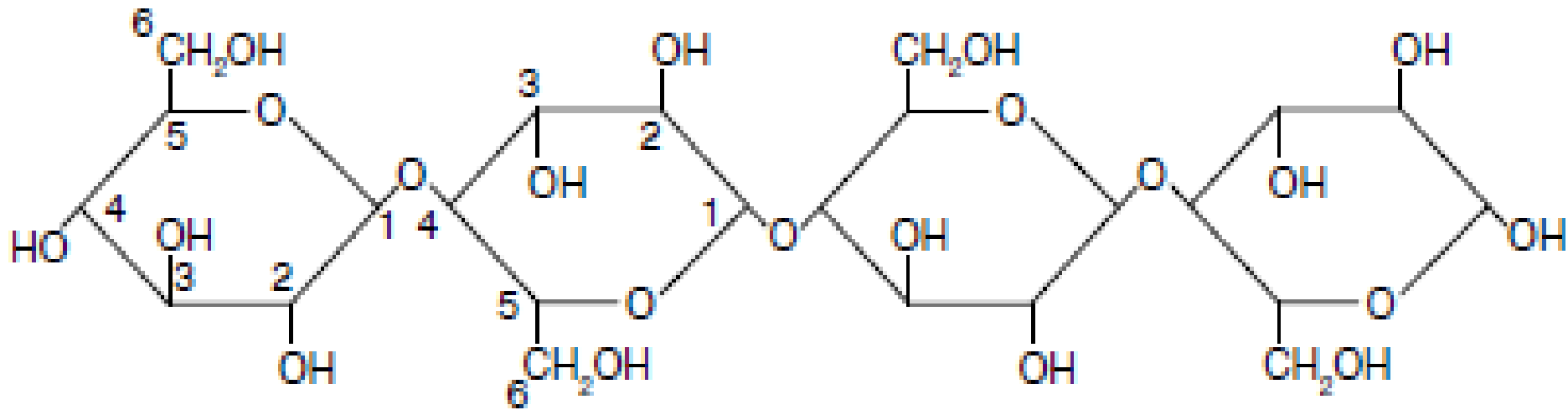
- c. In addition, because amylose and amylopectin are insoluble the molecules cannot move out of cells - they remain in storage organs.
- d. The branched nature of amylopectin means that there are many 'ends' to the molecule. Therefore, starch can be quickly hydrolysed (by enzymes acting at the ends 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.

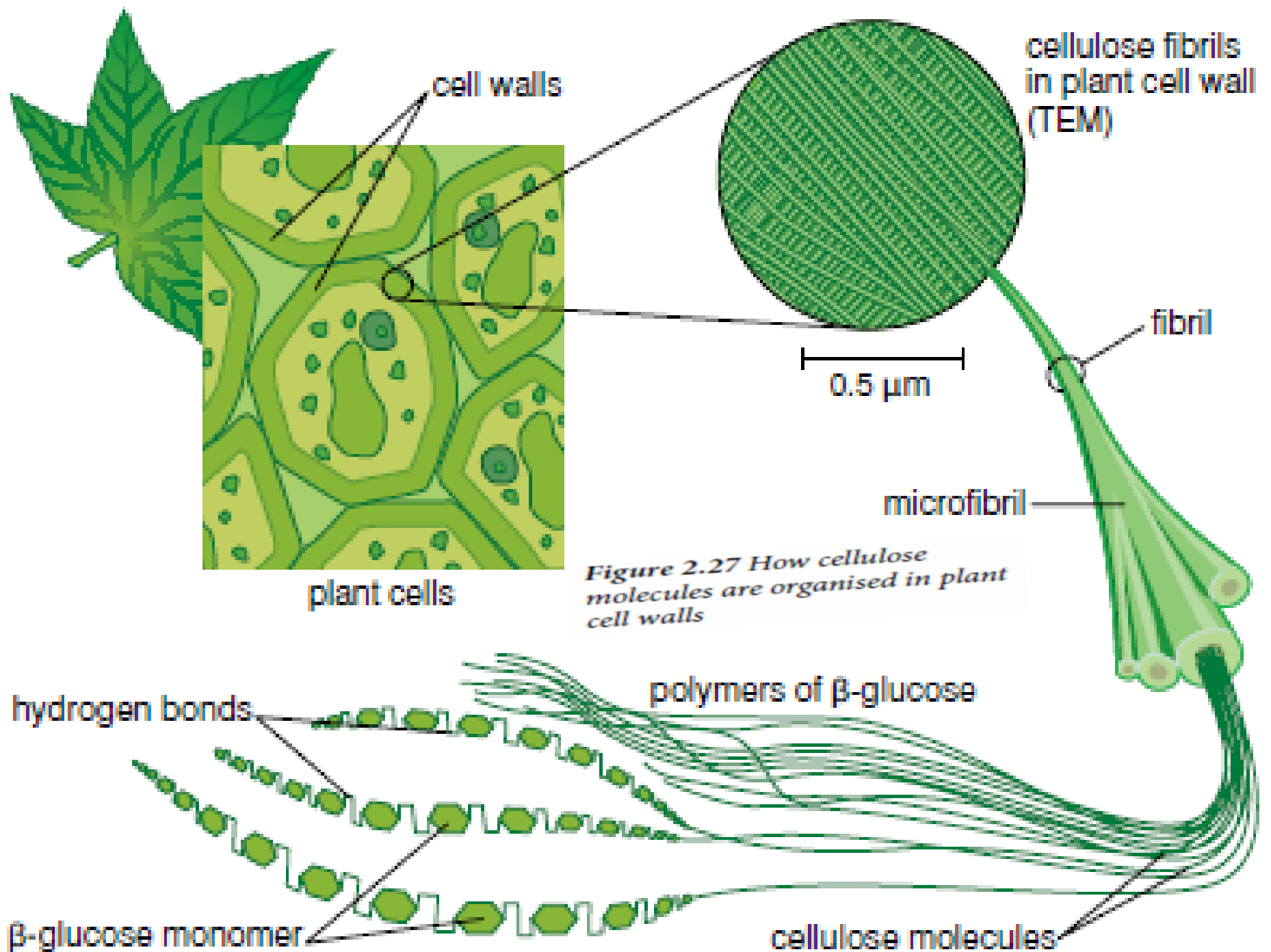
Cellulose

- 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 & is unbranched.



cellulose: 1-4 linkage of β -glucose monomers

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



What are lipids?

- Like carbohydrates, nearly all lipids contain only the elements carbon, hydrogen and oxygen, but they contain much less oxygen than carbohydrates.
- Lipids are a varied group of compounds that include:
 - I. *triglycerides* - formed from glycerol and three fatty acids
 - II. *phospholipids* - formed from glycerol, two fatty acids and a phosphate group
 - III. *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:
 - A. respiratory substrate** - a molecule of triglyceride yields over twice as many molecules of ATP (twice as much energy) as a molecule of glucose
 - B. thermal insulation** - the cells of adipose tissue found under the skin of many animals contain large amounts of triglycerides, which give good thermal insulation

C. buoyancy - lipids are less dense than water (oil float on water),so the presence of large amounts of lipid reduces the density of an animal, making it more buoyant

D. Water proofing - 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**
- The carboxyl group which is the functional group of the fatty acid is **ionic** and dissociates in solution to form **COO-** and **H+**.

- The hydrogen ions released make the solution acidic.



Figure 2.29 The structure of a triglyceride

KEY WORDS

- A. **saturated fatty acid** all the carbon-carbon bonds in the hydrocarbon chain are **single bonds**
- B. **monounsaturated fatty acid** one of the carbon-carbon bonds is a double bond
- C. **polyunsaturated fatty acid** more than one carbon-carbon bond is a double bond
- D. **ester bond** the bond that forms between a carboxyl group and a hydroxyl group

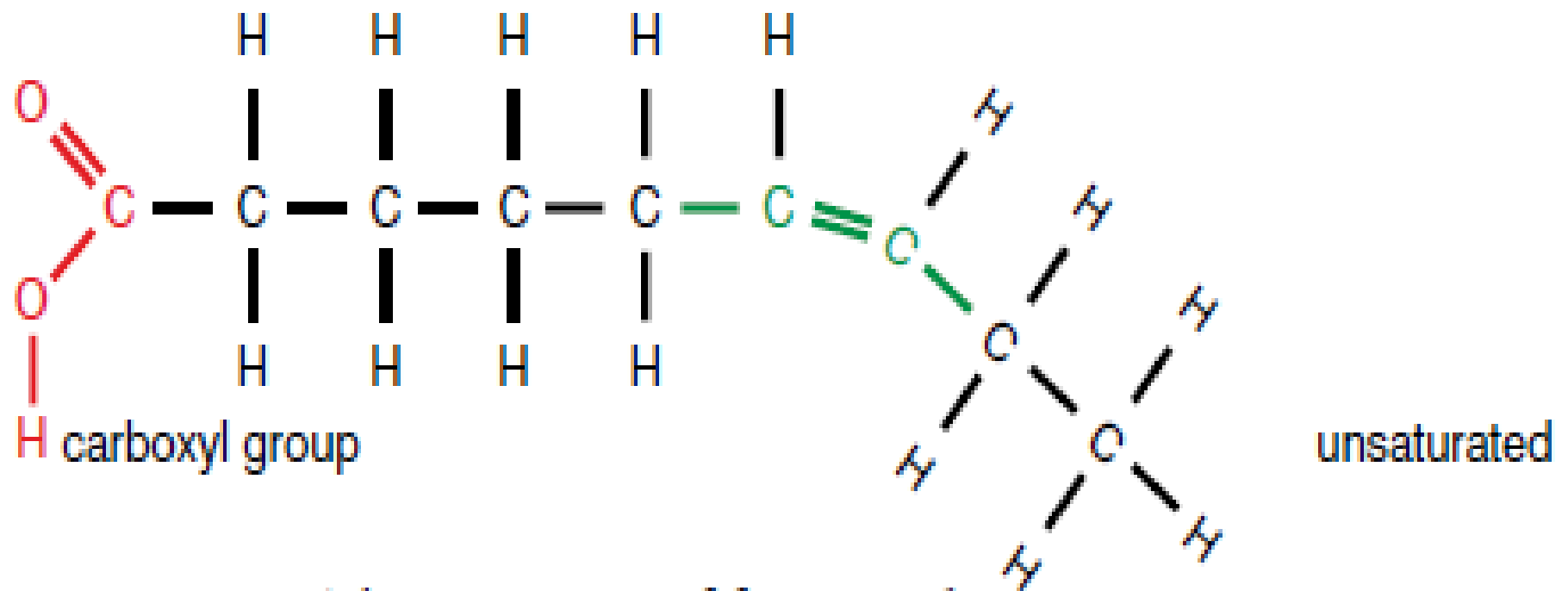
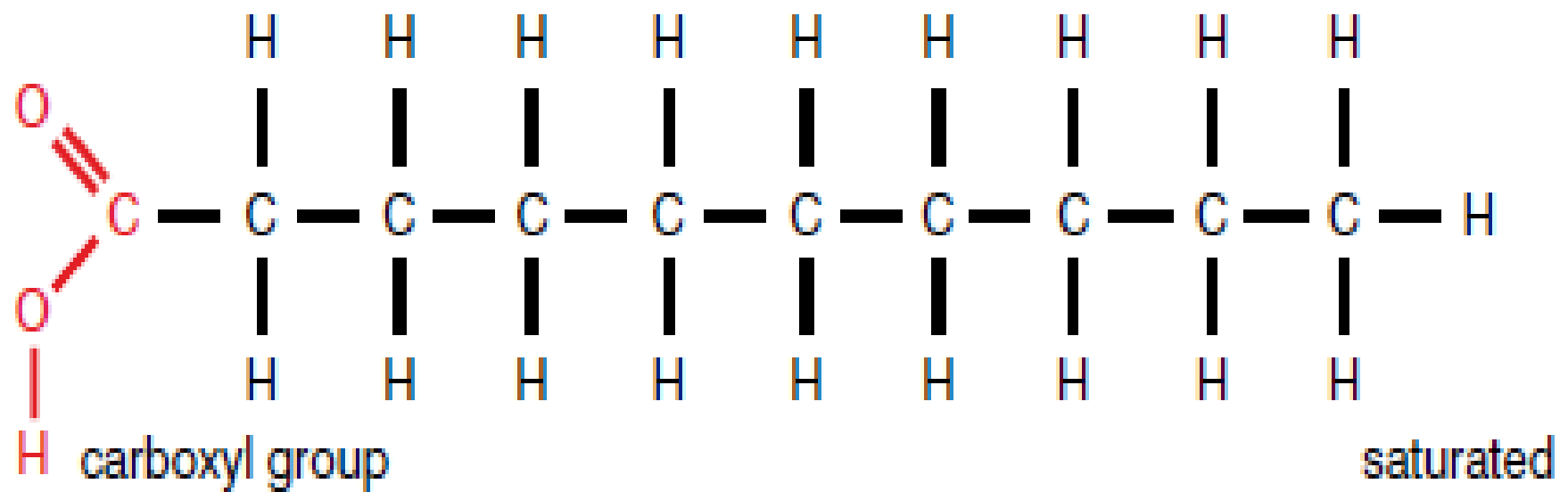


Figure 2.30 The structure of fatty acids

- The nature of the hydrocarbon chains in fatty acids can differ in **two** main ways:
 1. The *number of carbon* atoms in the chains can vary.
 2. *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*.
- When triglyceride molecules are formed, *condensation* reactions take place to join three fatty acid molecules to a glycerol molecule.
- The *bonds formed* are called *ester bonds*. These ester bonds can be broken by hydrolysis to give glycerol and fatty acids once again.

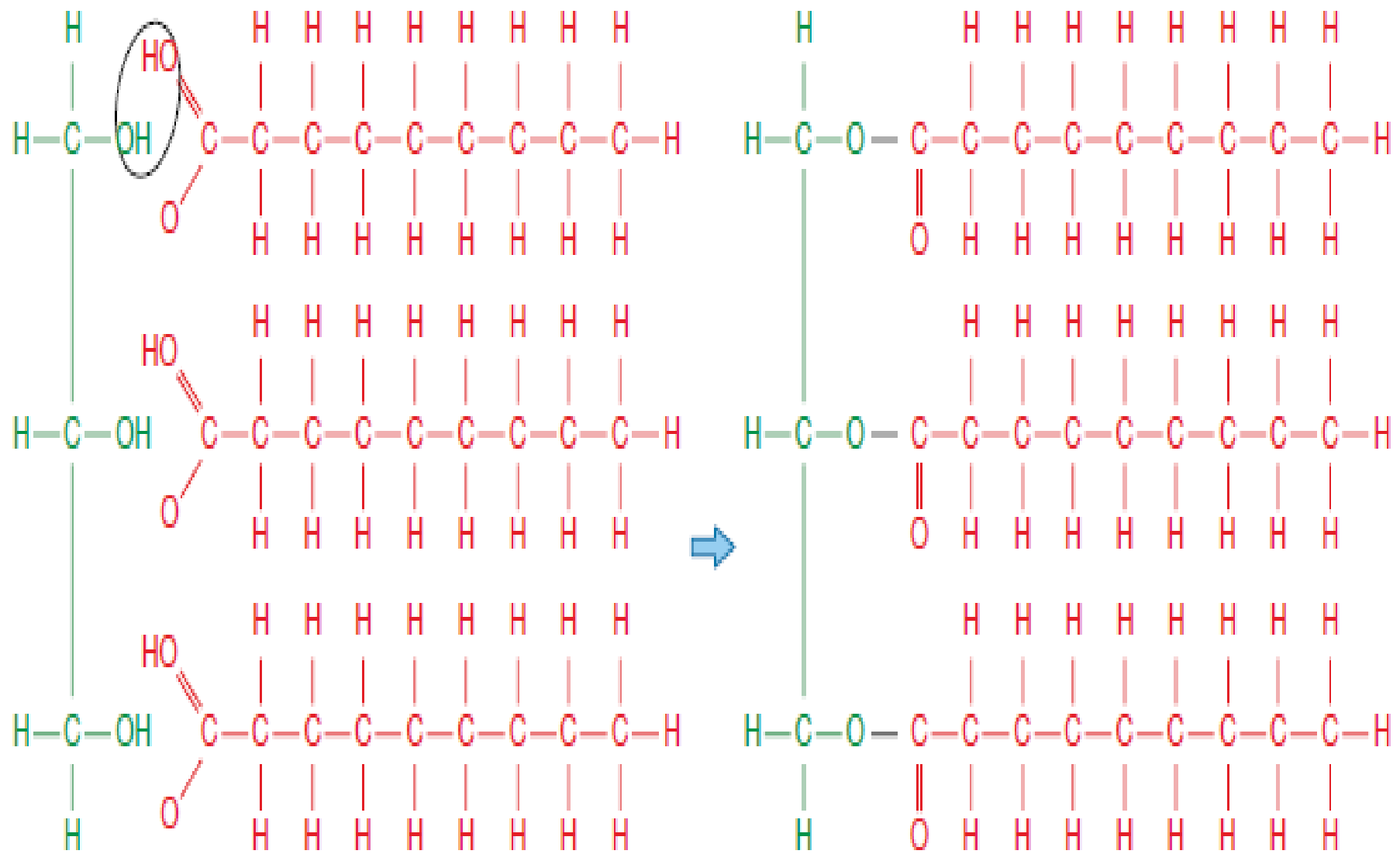
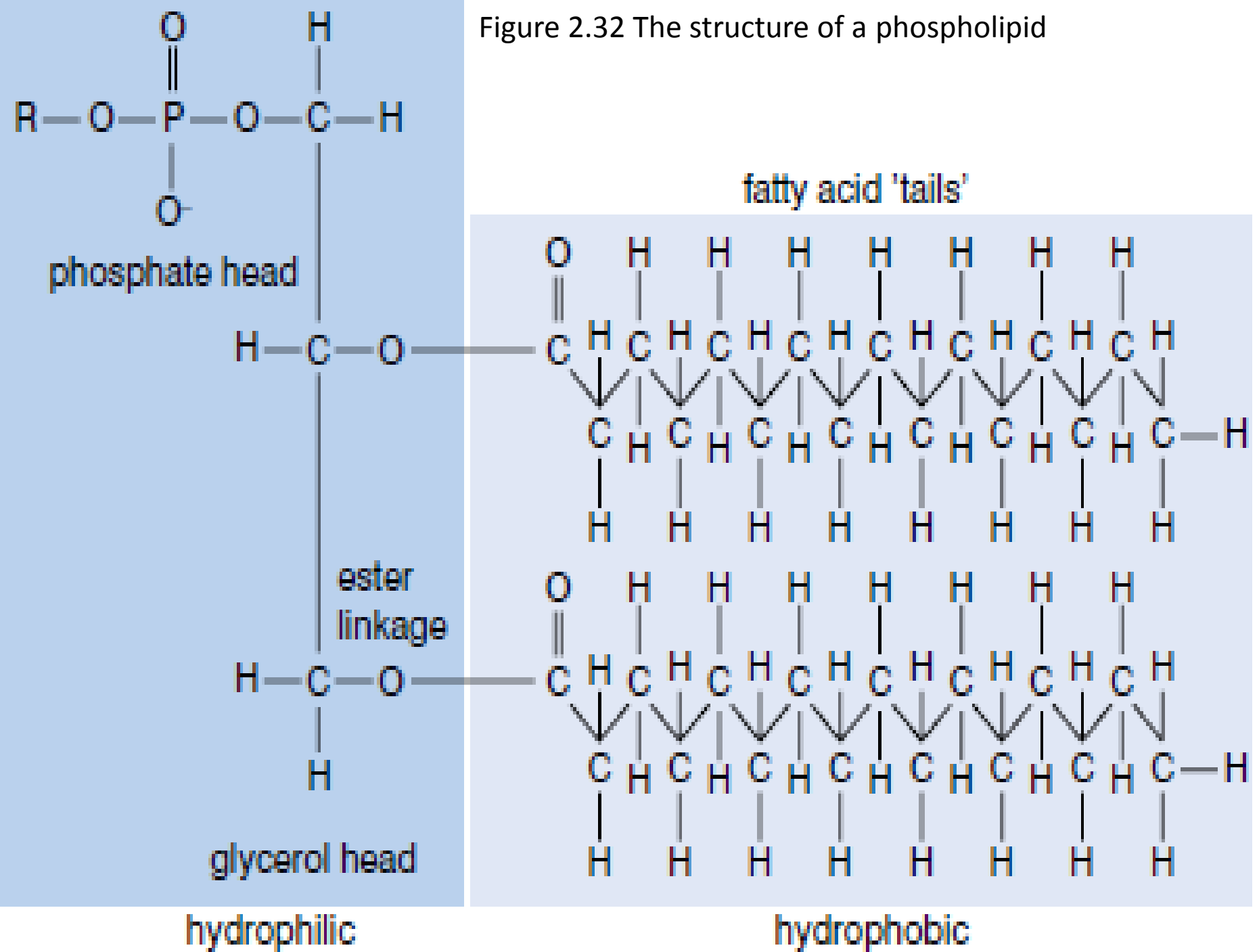


Figure 2.31 The formation of a triglyceride.

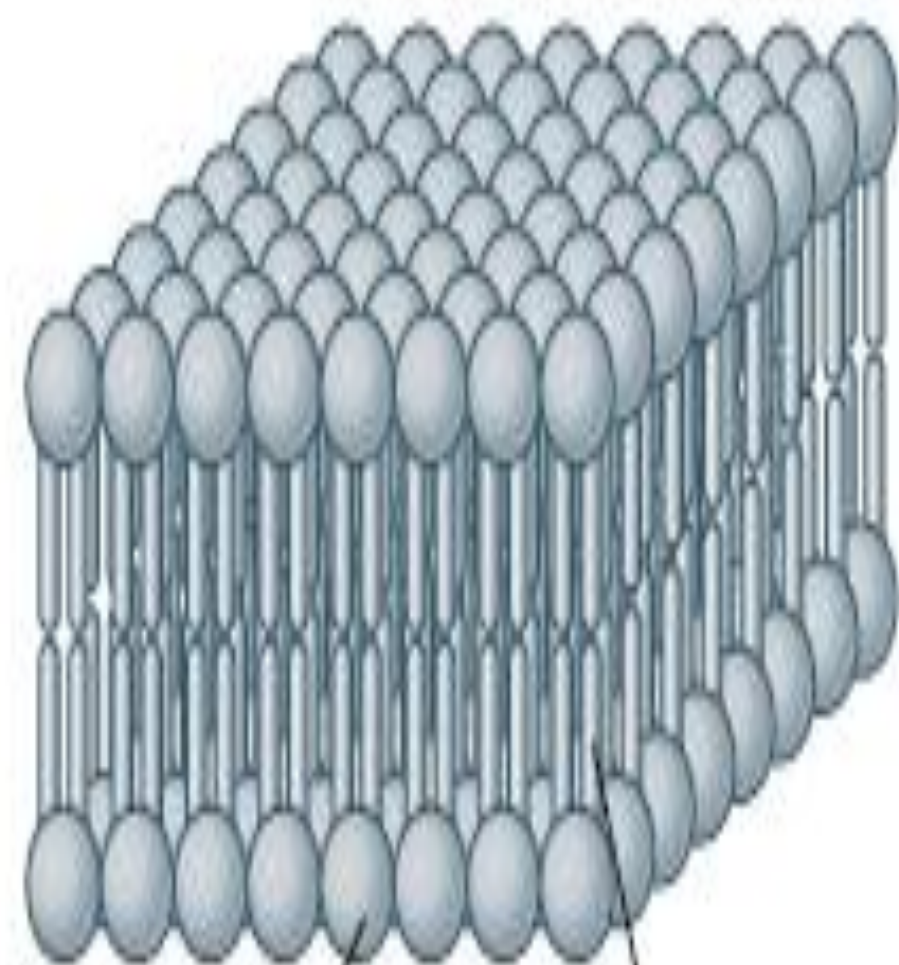
Phospholipids

- Phospholipids are formed when two fatty acid molecules are bonded to the glycerol and the place of the third is taken by a phosphate group.
- Since the phosphate group is ionic and the hydrocarbon chains of the two fatty acids are covalently bonded, there are two distinct regions to a phospholipid molecule:
 - A. a hydrophilic (water-loving) region, consisting of the phosphate 'head'
 - B. a hydrophobic (water-hating) region, consisting of the hydrocarbon 'tails'

Figure 2.32 The structure of a phospholipid



- In water, phospholipids become organised into a bilayer (two layers sandwiched together).
- In this configuration, the hydrophilic heads face outwards into the water and the hydrophobic tails face inwards, away from the water.
- Phospholipid bilayers are the basis of plasma membranes.



hydrophilic
head group

hydrophobic
fatty acids

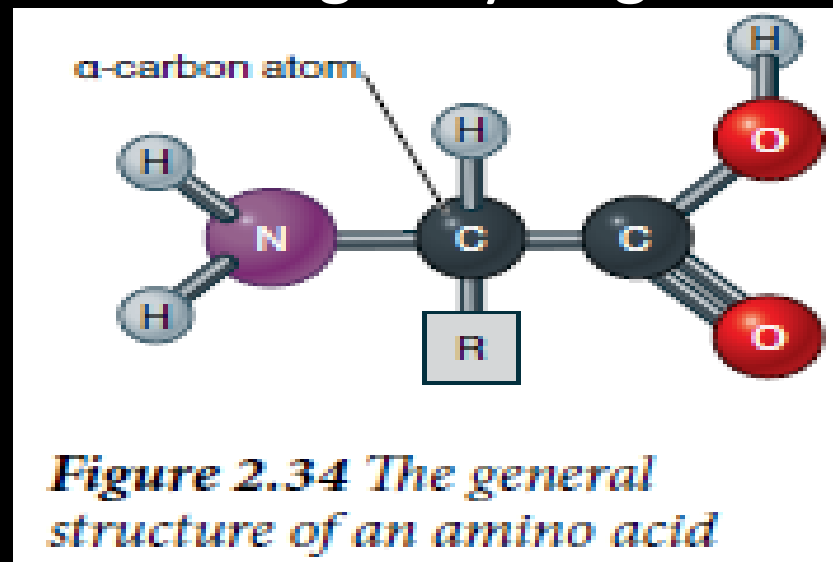


proteins

- 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:
- A. the structure of plasma membranes - protein molecules form ion channels, transport proteins and surface receptors for hormones, neurotransmitters and other molecules
 - B. the immune system - antigen and antibody molecules are proteins .
 - C. the control of metabolism by enzymes - all enzymes are proteins
 - D. the structure of chromosomes - DNA is wound around molecules of the protein histone to form a chromosome

- All amino acid molecules are built around a carbon atom (the α -carbon) to which is attached chain or a more complex structure a hydrogen atom
 - I. an amino group ($-\text{NH}_2$)
 - II. a carboxyl group ($-\text{COOH}$)
 - III. an 'R' group, which represents the other atoms in the molecule, such as a single hydrogen atom, a hydrocarbon



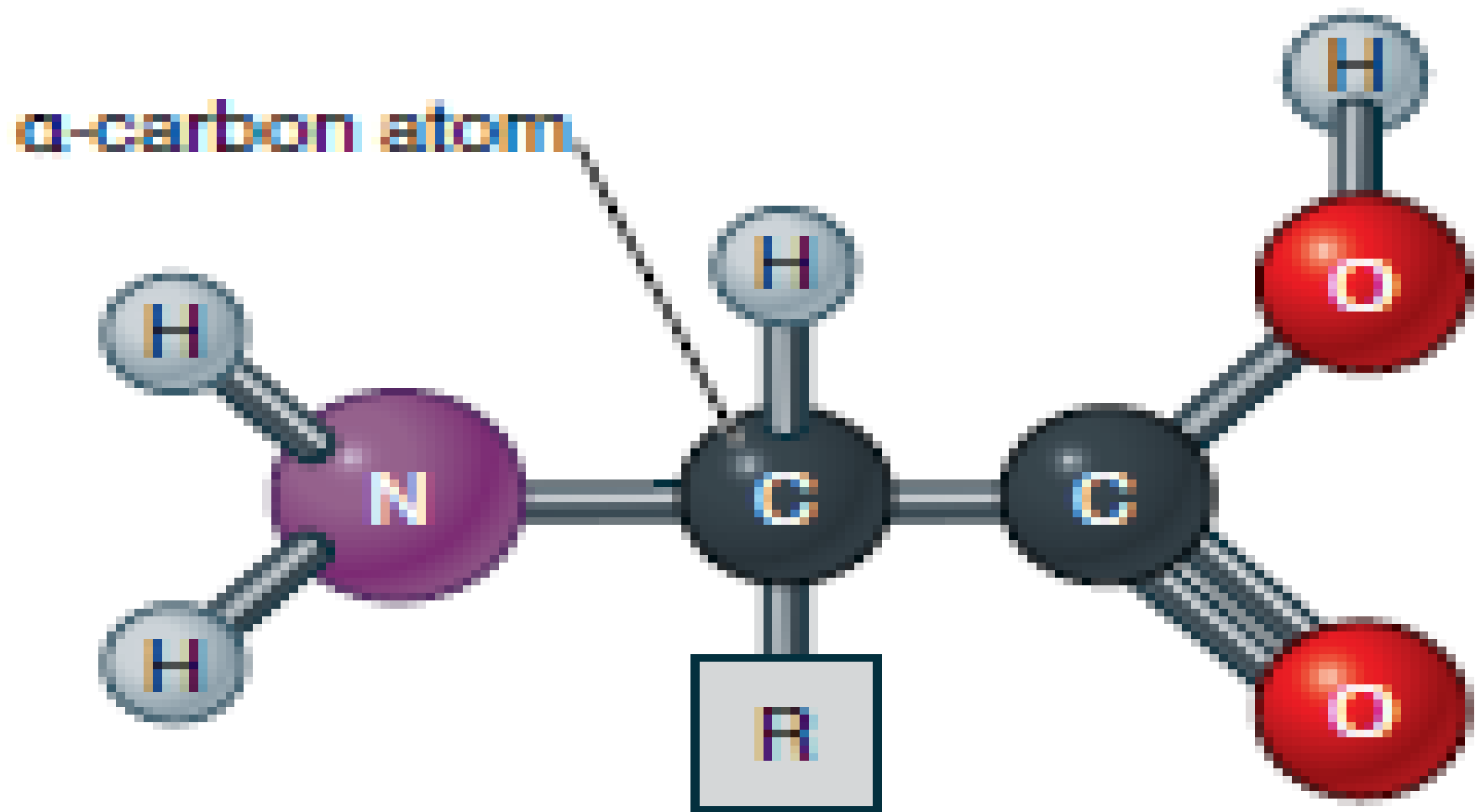


Figure 2.34 The general structure of an amino acid

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

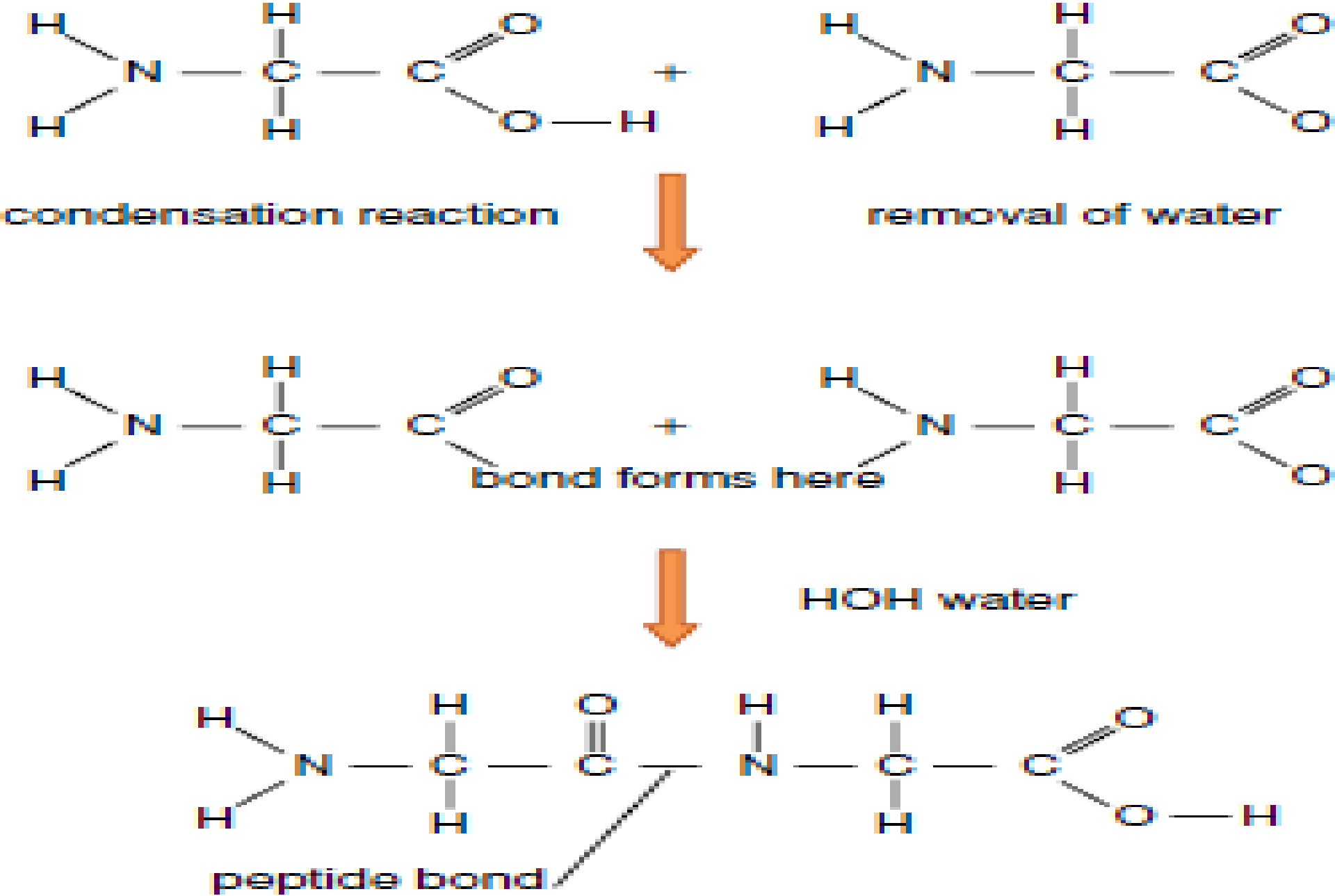


Figure 2.35 *How a dipeptide is formed*

KEY WORDS

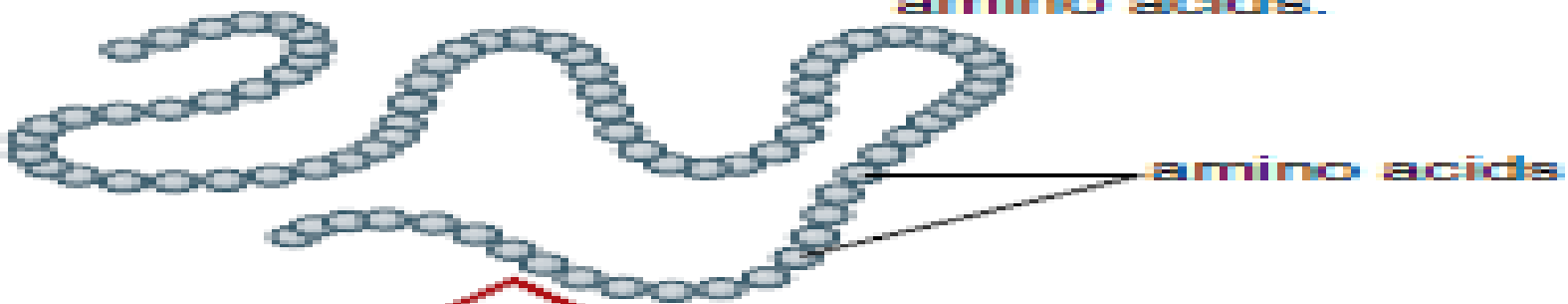
- A. **amino acids** are the building blocks of proteins and have two functional groups - the amino group and the carboxyl group. This allows them to behave both as a base and as an acid
- B. **peptide bond** the bond that links two amino acids.
- C. **polypeptide** a linear polymer consisting of amino acid residues bonded together in a chain forming a part or all of a protein molecule.
- D. **primary structure** the sequence formed by amino acids

- 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.
- 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:

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

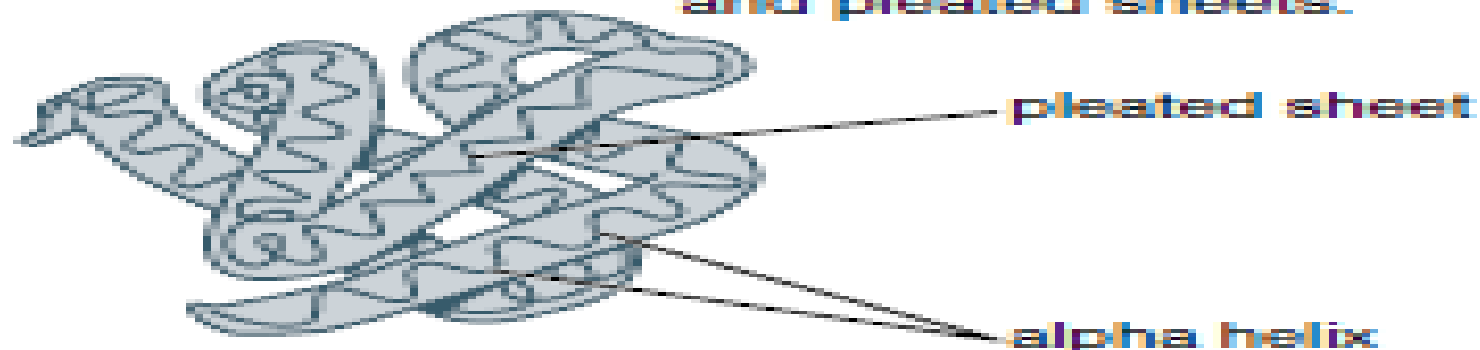
Primary protein structure is sequence of a chain of amino acids.



Secondary protein structure occurs when the sequence of amino acids are linked by hydrogen bonds.



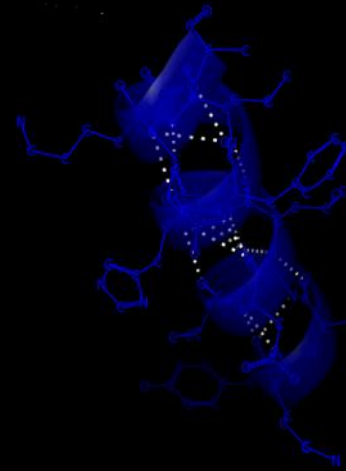
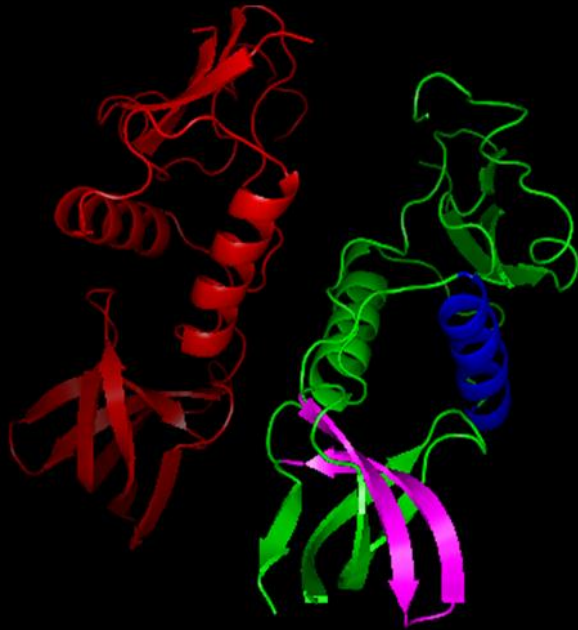
Tertiary protein structure occurs when certain attractions are present between alpha helices and pleated sheets.



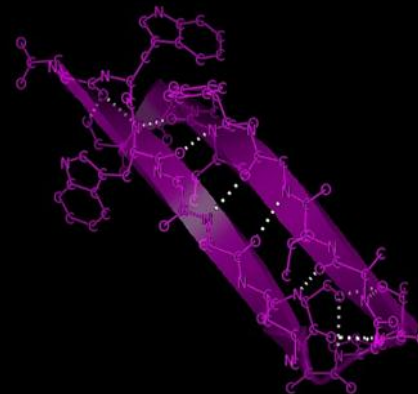
secondary structure

quarternary structure

tertiary structure



α -helix



β -sheet

primary structure

Tyr-Lys- Ala-Ala-Val-Asp-Leu-Ser-His-Phe-Leu-Lys-Glu-Lys

Asp-Trp-Trp-Glu-Ala-Arg-Ser-Leu-Thr-Thr-Gly-Glu-Thr-Gly-Tyr-Pro-Ser

- Each protein has a unique tertiary structure and so has a unique configuration (shape) because:
1. 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
 2. 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
 3. 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:
- a. the shape of the active site of an enzyme molecule lets it bind with only one substrate and catalyze only one reaction
 - b. 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
 - c. the shape of an antibody means it can bind with and destroy just one antigen

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

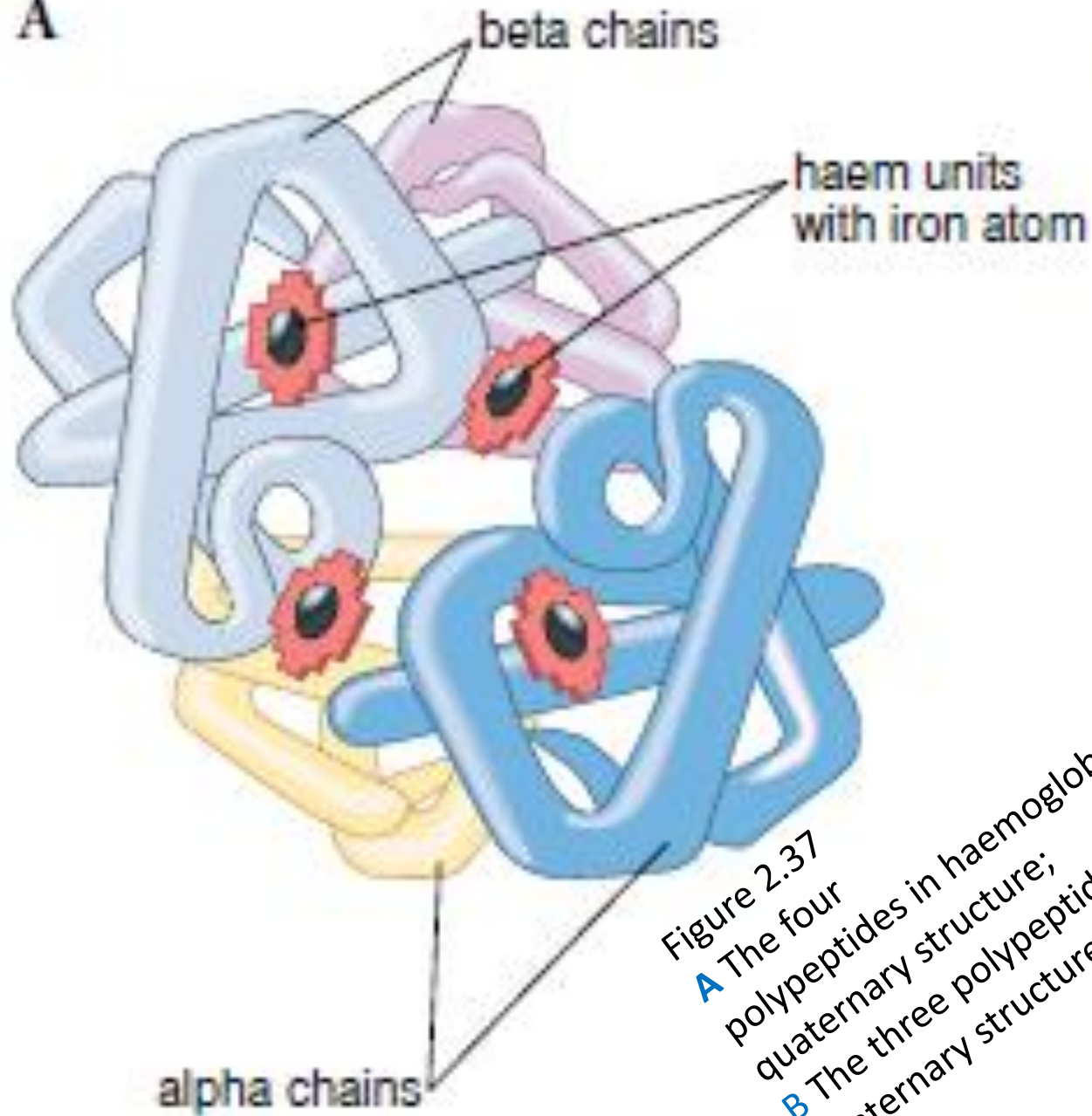
A**B**

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

- ❖ Proteins are classified into two main groups, according to their molecular shapes:
 - **fibrous proteins** that have a tertiary structure that resembles along string or fibre (for example, collagen and keratin)
 - **globular proteins** that have a tertiary structure that resembles a globule or ball (for example, enzymes and receptor proteins).

What are nucleic acids?

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

A. 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.

B. 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.

- 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) a phosphate group
 - b) a pentose sugar (deoxyribose in DNA nucleotides and ribose in RNA nucleotides), and
 - c) 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**.

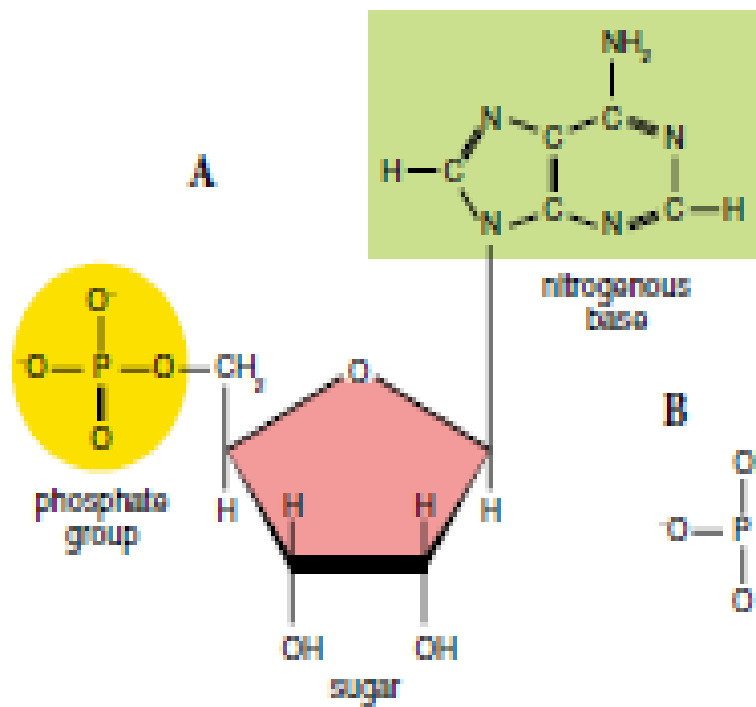
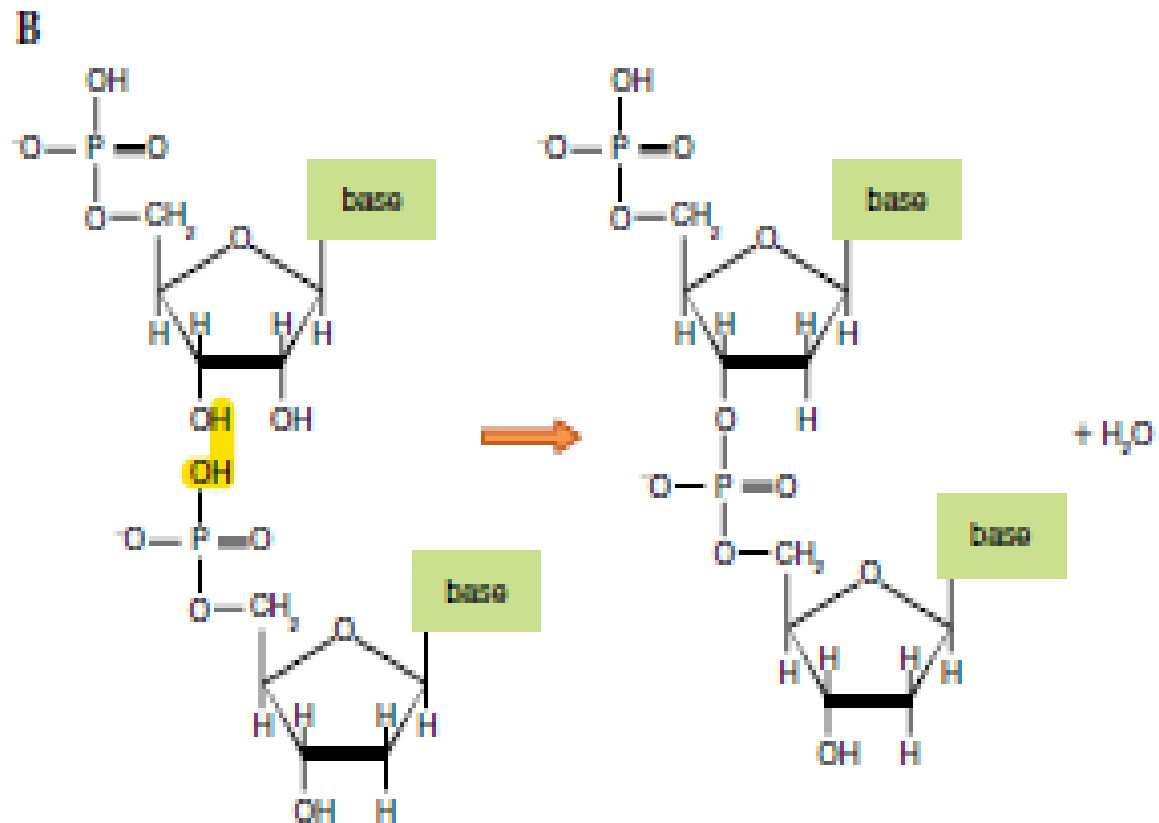
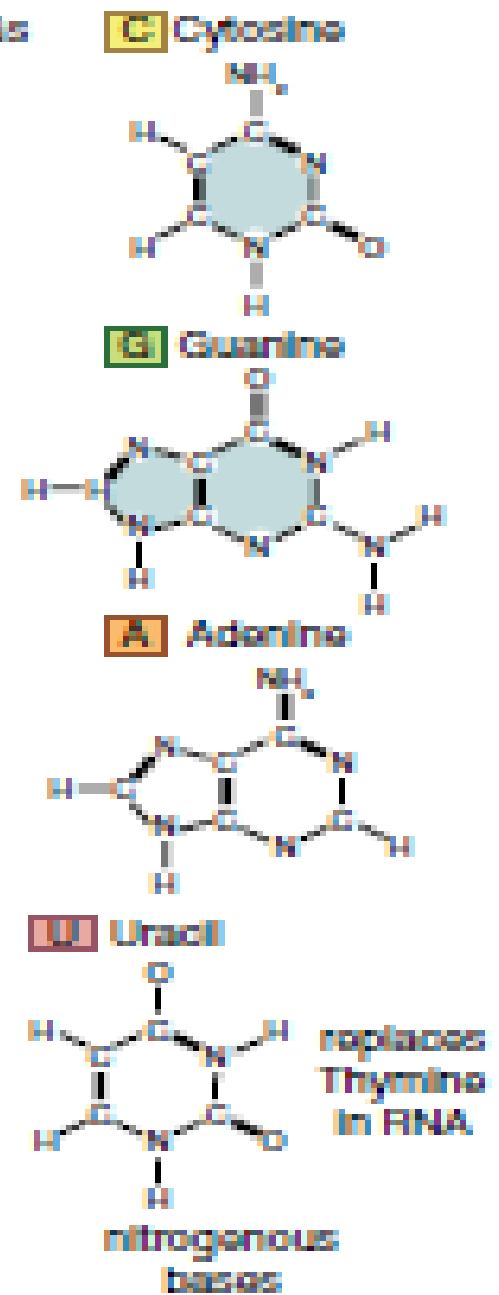
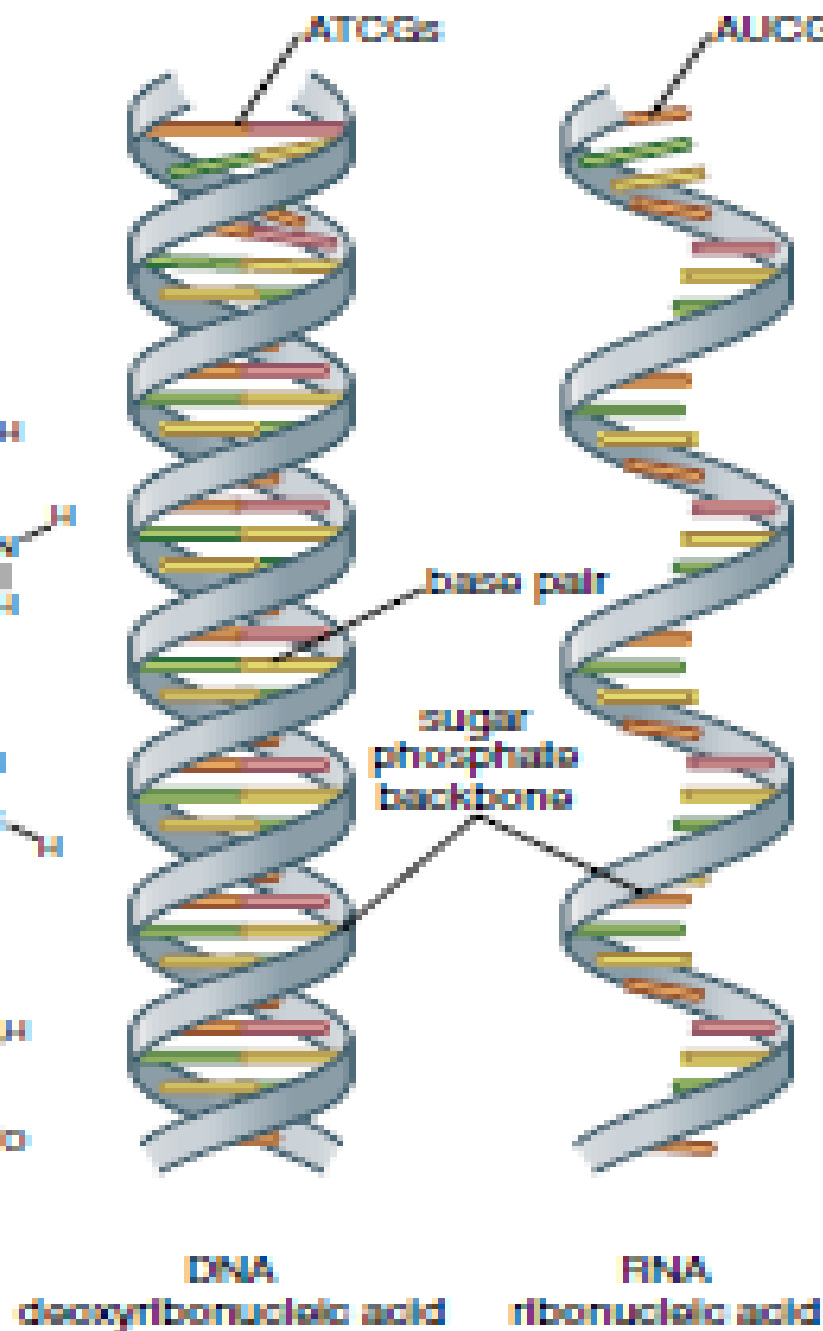
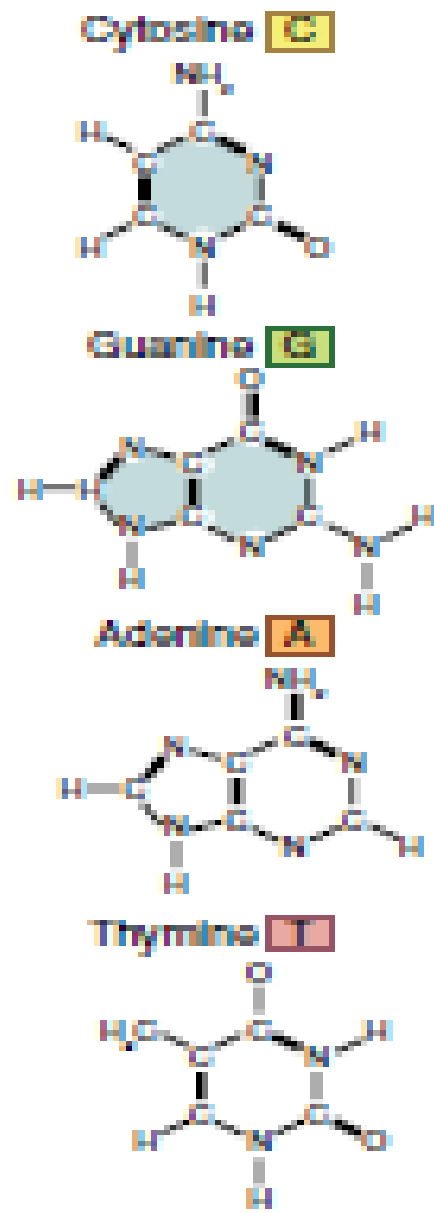


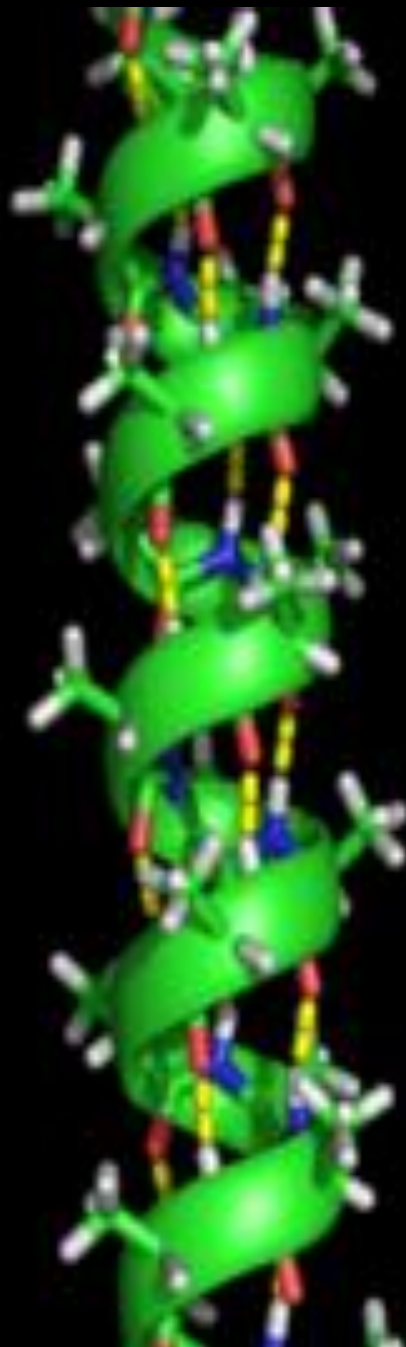
Figure 2.38 *A The structure of a nucleotide;
B Nucleotide, form a strand by condensation reaction.*





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Primary structure
amino acid sequence



Secondary structure
regular sub-structures



Quaternary structure
complex of protein molecules



Tertiary structure
three-dimensional structure