Biological molecule

- Structure of carbohydrates, lipids and proteins and their roles in living organisms.
- Water and living organisms

Learning objective:

a. **Carry out tests for reducing and non- reducing sugars (including using colours standards as a semi- quantitative use of the Benedict's test), the iodine in potassium iodine solution test for starch, the emulsion test for lipids and the biuret test for protein.**

Reducing sugars:

1. Add equal volumes of the sample to be tested (ground up in water) and Benedict's solution to a test tube.
2. Heat the test tube is a water bath with a temperature of 95oC.
3. Leave for 5 minutes.
4. An orange/brick red colour shows that there is a reducing sugar present.

Non- reducing sugars:

1. Carry out the normal test to check for a reducing sugar.
2. Take a fresh sample, but the same type as the one just used.
3. Add equal volumes of this fresh sample and hydrochloric acid.
4. Heat for 5 minutes. The HCl should hydrolyse the glycosidic bonds and break the disaccharides into monosaccharides.
5. Now add some sodium hydrogen carbonate, since Benedict's will not work in acidic conditions. Test with pH paper to ensure a neutral or alkaline solution has been made.
6. Now add Benedict's and heat in a water bath for 5 minutes.
7. An orange/brick red shows the presence of non-reducing sugar.

Starch:

1. Add 10 drops of iodine to the sample.

2. A black-blue colour indicates the presence of starch.

Protein:

1. Add equal volumes of the sample and sodium hydroxide. *The sample must be ground in water.*
2. Add some copper sulphate and stir gently.
3. A purple colour indicates the presence of peptide bonds and hence proteins.
4. A blue colour indicates no proteins.

Lipids:

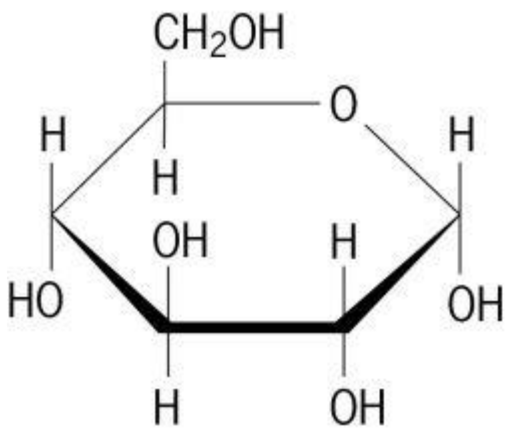
1. Add equal volumes of the sample and ethanol.

2. Add equal volumes of water.

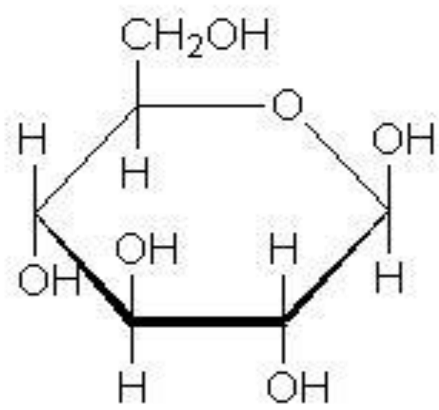
3. Shake solution gently.

4. A cloudy colour indicates the presence of lipids.

b. Describe the ring forms of α-glucose and β-glucose



α-glucose: The hydrogen on carbon 1 is above the plane of the ring.



β-glucose: The hydrogen on carbon 1 is below the plane of the ring.

c. Describe the formation and breakage of a glycosidic bond with reference both to polysaccharides and to disaccharides including sucrose;

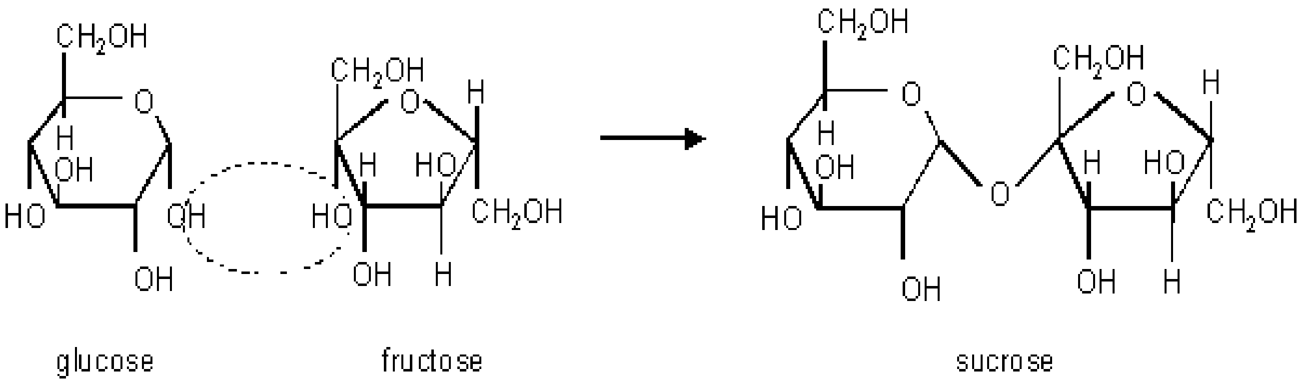
Glycosidic bond – a C-O-C link between two monosaccharide molecules, formed by a condensation reaction.

Disaccharides – like monosaccharides, are sugars. They are formed by two monoccharides joining together.

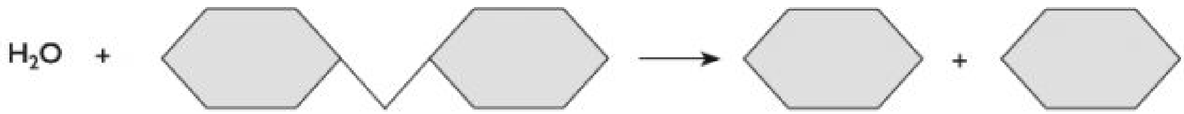
Disaccharide	**Monosaccharides**
Maltose	Glucose + Glucose
Lactose	Glucose + Galactose
Sucrose	Glucose + Fructose

Polysaccharides – subunits whose molecules contain hundreds or thousands of monosaccharides linked together into long chains. Because their molecules are so enormous, the majority do not dissolve in water. This makes them good for storing energy or forming a strong structure.

As two monosaccharides react and the glycosidic bond forms, a molecule of water is released. This type of reaction is known as condensation reaction.

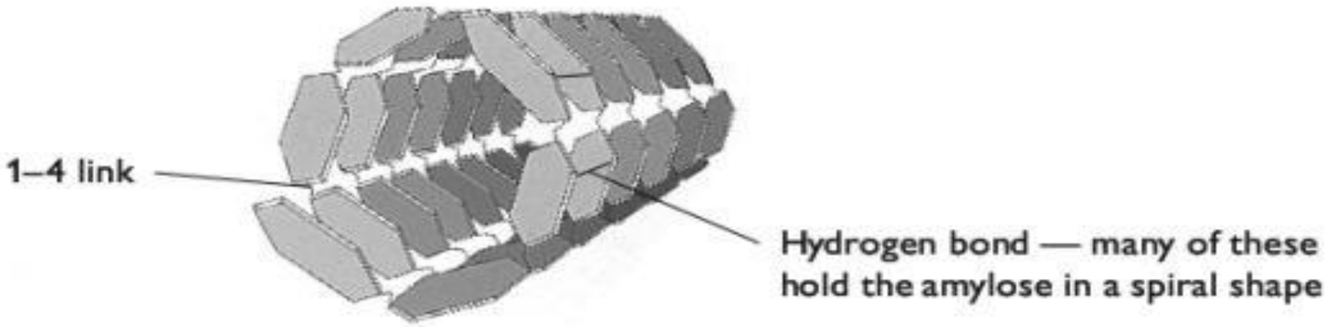


Disachharides can be split apart into two monosaccharides by breaking the glycosidic bond. To do this, a molecule of water is added. This is called an hydrolysis.



d. Describe the molecular structure of polysaccharides including starch (amylose and amylopectin), glycogen and cellulose and relate these structures to their functions in living organisms

Amylose: A long unbranching chain of several thousand 1,4 linked glucose molecule is built up. The chains are curved and coil up into helical structures like springs, making the final molecule more compact.



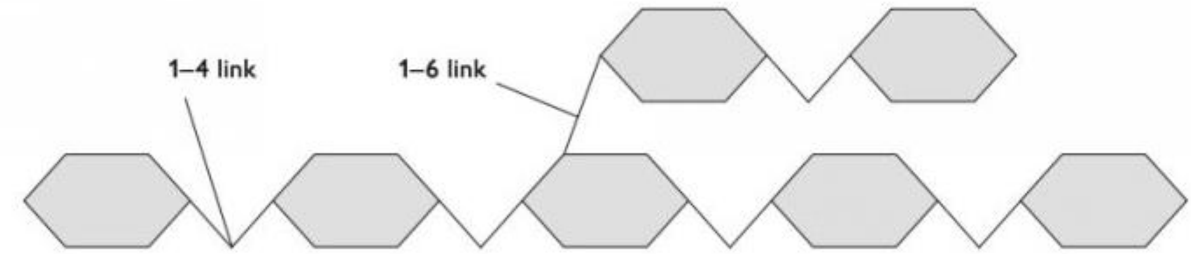
Amylopectin: amylopectin is also made of many 1,4 linked α-glucose molecules, but the chains are shorter than in amylose, and branch out to the sides. The branches are formed by 1,6 linkage.

Mixture of Amylose and Amylopectin: molecules build up into relatively large starch grains, which are commonly found in: chloroplasts in storage organs such as potato tubers the seeds of cereals and legumes. Starch is never found in animal cells.

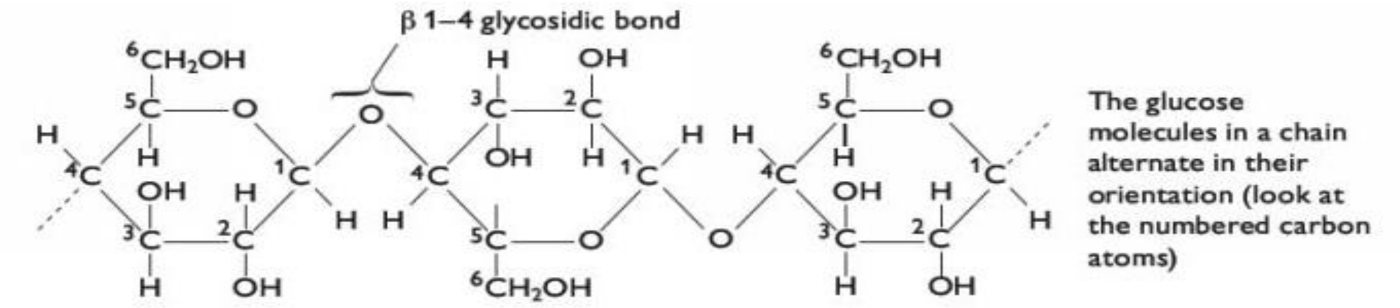
Glycogen:

- A substance with molecules very like those of amylopectin is used as the storage carbohydrate. This is called Glycogen.
- Glycogen like amylopectin, is made of chains 1,4 linked α-glucose with 1,6 linkages forming braches.
- Glycogen molecules tend to be even more branched than amylopectin molecules.
- Glycogen molecules clump together to form granules. Which are visible in liver cells and muscle cells where they form an energy reserve.

Cellulose:



- Its presence in plant cell walls shows the rate of breakdown in water.
- It has a structure role, being mechanically strong molecule unlike starch and glycogen.
- The only difference cellulose and starch and glycogen is that cellulose is a polymer of **β-glucose** not **α-glucose**



- This arrangement of β-glucose molecules results in a strong molecule because the hydrogen atoms of –OH groups are weakly attracted to oxygen atoms in the same cellulose molecules and also to oxygen atoms of –OH groups in neighbouring molecules. These hydrogen bonds are individually weak, but so many can form due to the large number of –OH groups, that collectively they develop enormous strength.

Structure and function of cellulose

Between 60 and 70 cellulose molecules become tightly cross-linked to form bundles called microfibriles. Microfibriles are in turn held together in bundles called fibres by hydrogen bonding.

A cell wall typically has several layers of fibres, running in different direction to increase strength.

Cellulose comprises about 20-40 % of the average cell wall; other molecules help to cross-link the cellulose fibres and some form a glue-like matrix around the fibres, which further increases strength.

Cellulose fibres have a very high tensile strength, almost equal to that of steel.

- Difficult to stretch or break
- Makes it possible for a cell to withstand the large pressures that develop within it as a result of osmosis.

Without the walls, the cell would burst when in a dilute solution.

These pressures help provide support for the plant by making tissue rigid and are responsible for cell expansion during growth.

The arrangement of fibres around the cell helps to determine the shape of the cell as it grows.

Despite their strength, cellulose fibres are freely permeable allowing water and solutes to reach or leave the cell surface membrane.

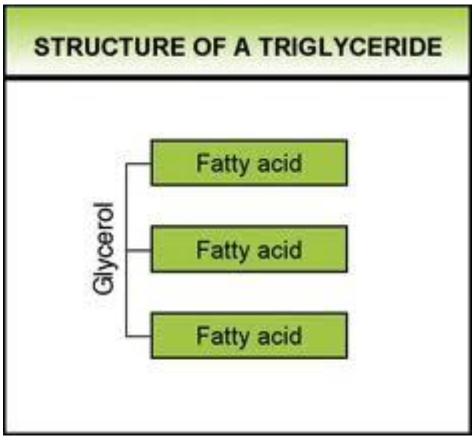
Cellulose fibres – 50nm diameter

Microfibril – 10nm diameter

e. Describe the molecular structure of a triglyceride and a phospholipid and relate these structures to their functions in living organisms;

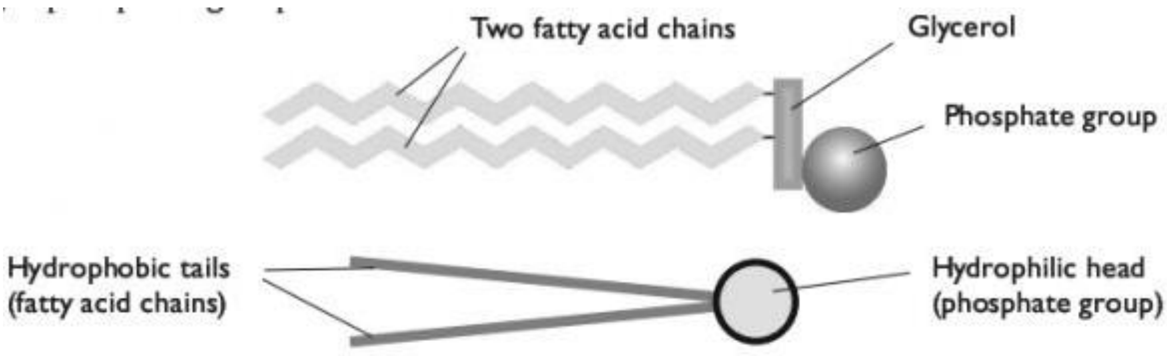
Triglycerides – a lipid whose molecules are made up of a glycerol molecule and three fatty acids.

Triglycerides are made by the combination of three fatty acid molecules with one glycerol molecule. Fatty acids are organic molecules which all have a –COOH group attached to a hydrocarbon tail.



- Triglycerides are used as energy storage compounds in plant, animals and fungi. Their insolubility in water helps to make them suitable for this function.
- They contain more energy per gram than polysaccharides, so can store more energy in less mass.
- In mammals, stores of triglycerides often build up beneath the skin, in the form of adipose tissue. The cells in adipose tissue contain oil droplets made up of triglycerides.
- This tissue also helps to insulate the body against heat loss. It is a relatively low-density tissue, and therefore increases buoyancy. These properties make it useful for aquatic mammals that live in cold eater such as whales and seals.
- Adipose tissue also forms a protective layer around some of the body organs, for example the kidneys.

Phospholipids – a substance whole molecules are made up of a glycerol molecule, two fatty acids and a phosphate group; a bilayer of phospholipids forms the basic structure of all cell membranes.



Phospholipid molecules

The fatty acid chains have no electrical charge and so are not attracted to the dipoles of water molecules. They are hydrophobic.

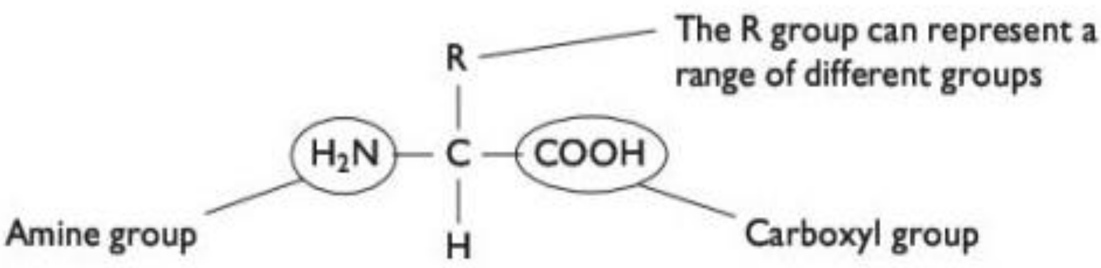
The phosphate group has an electrical charge and is attracted to water molecules. It is hydrophobic.

In water, a group of phospholipid molecules therefore arranges itself into a bilayer, with the hydrophobic heads facing outwards into the water and the hydrophobic tails facing inwards, therefore avoiding contact with water.

f. Describe the structure of an amino acid and the formation and breakage of a peptide bond;

Amino acids

All amino acids have the same basic structure, with amine group and a carboxyl group attached to central carbon atom. It is these two groups which give amino acids their name. The third component which is always bonded to the carbon is hydrogen atom.

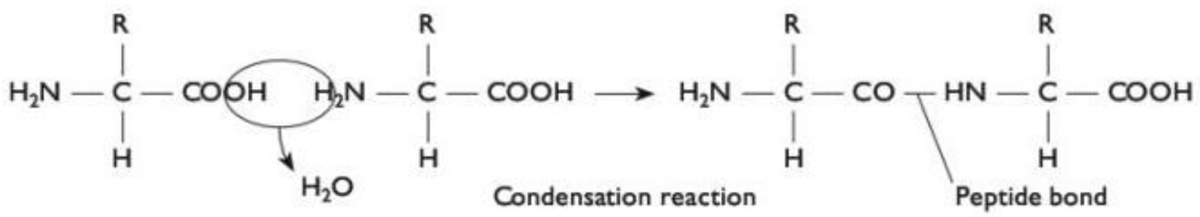


An amino acid

The only way in which amino acids differ from each other is In the remaining, fourth, group of atoms bonded to the central carbon. This is called the **R group.** There are 20 different amino acids which occur in the proteins of living organisms, all with a different R group.

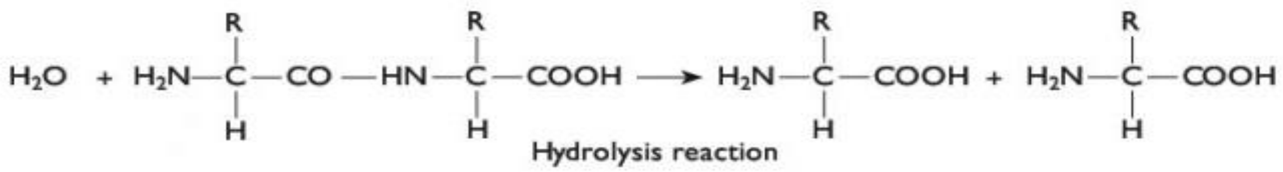
The peptide bond

two amino acids can link together by a condensation reaction form a dipeptide. The bond that links them is called **peptide bond,** and water is produced in the reaction.



Formation of a dipeptide

The peptide can be broken down in a hydrolysis reaction, which breaks the peptide bond with the addition of a molecule of water.



Breakdown of a dipeptide

- Strong covalent bond
- A molecule made up of many amino acids linked together by peptide bonds is called a poplypeptide.
- A complete protein molecule may contain just one polypeptide chain, ot it may have two or more chains which interact with each other.
- In living cells, ribosomes are the sites where amino acids are joined together to form polypeptides. This reaction is controlled by enzyme
- A hydrolysis reaction, involving the addition of water, and happens naturally in the stomach and small intestine during digestion. Protein molecules in food are hydrolysed into amino acids before being absorbed into the blood.

g. Explain the meaning of the terms primary structure, secondary structure, tertiary structure and quaternary structure of proteins and describe the types of bonding (hydrogen, ionic,

disulfide and hydrophobic interactions) that hold the molecule in shape;

Primary structure – the sequence of amino acids in a polypeptide or protein.

- A polypeptide or protein molecule may contain several hundred amino acids linked into a long chain.
- The particular amino acids contained in the chain, and the sequence in which they are joined, is called the primary structure of the protein.
- There are an enormous number of different possible primary structures. Even a change in one amino acid in a chain made up of thousands may alter the properties of the polypeptide or protein.

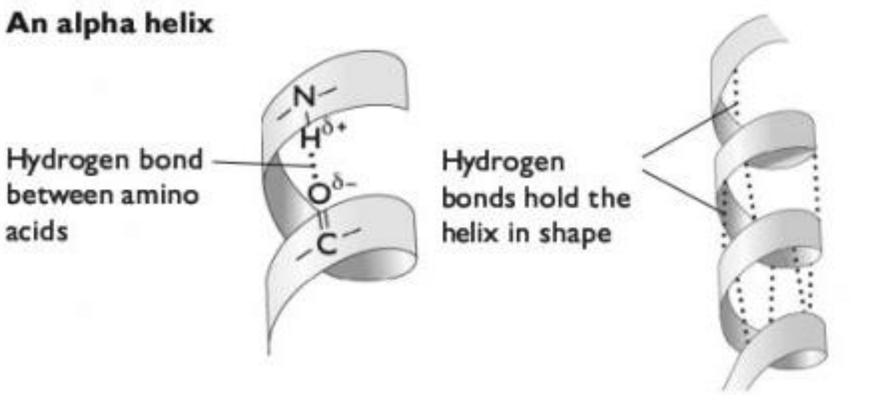
Val - Leu - Ser - Pro - Ala - Asp - Lys - Thr - Asn - Val - Lys - Ala

The primary structure of a small part of a polypeptide

Secondary structure

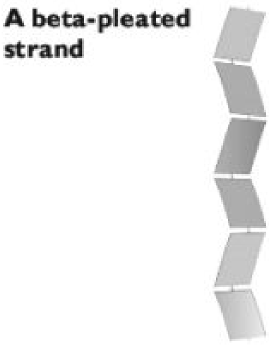
Secondary structure – the structure of a protein molecule resulting from the regular coiling or folding of the chain of amino acids, e.g. an alpha helix or beta pleated sheet.

- The amino acids in a polypeptide chain have an effect on each other even if they are not directly next to each other.
- A polypeptide chain, or part of it, often coils into a corkscrew shape called an **α-helix**. This is due the hydrogen bond. Hydrogen bonding is a result of the polar characteristics of the –CO and –NH group.



- Sometimes hydrogen bonding can result in much looser, straighter shape than the **α- helix** being formed, called a **β- pleated sheet.**

- Hydrogen bonds, although strong enough to hold the α- helix and β- pleated sheet structures in shape, are easily broken by high temperatures and pH changes.

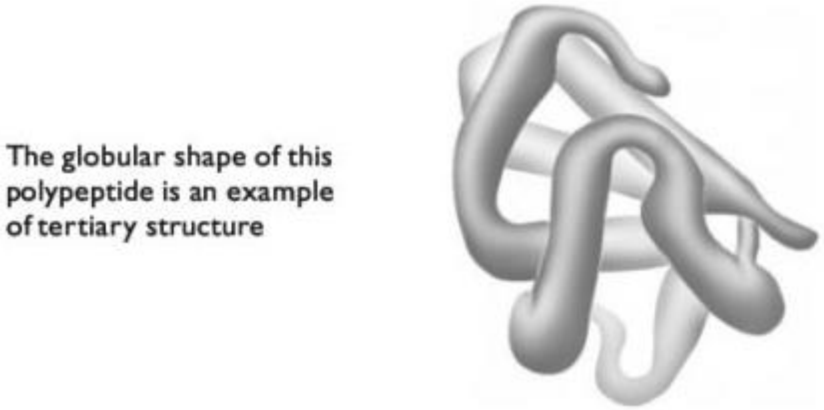


Some proteins or parts of proteins show no regular arrangement at all. It all depends on which R groups are present and therefore what attractions occur between amino acids in the chain.

Tertiary structure

Tertiary structure – the compact structure of a protein molecule resulting from the 3-D coiling of the already- folded chain of amino acids.

- The shape of the molecules is very precise, and the molecules are held in these exact shapes by bonds between amino acids in different parts of the chain.



Tertiary structure of a protein

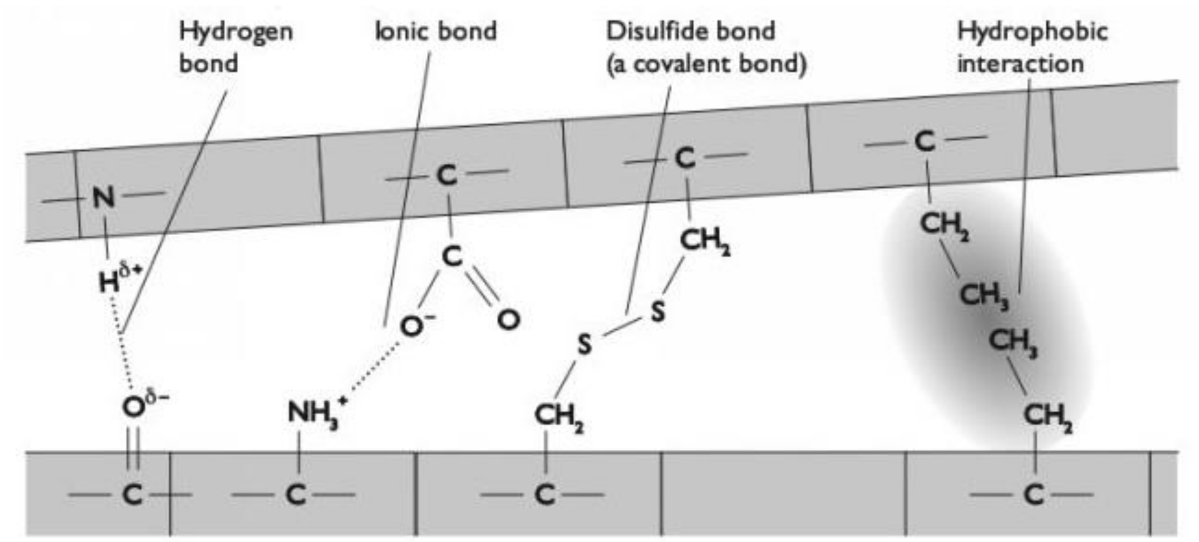
- Hydrogen bonds can form between a wide variety of R groups.
- Disulfide bonds form between two cysteine molecules, which contain sulfur atoms.
- Ionic bonds form between R groups containing amine and carboxyl groups.

- Hydrophobic interactions occur between R groups which are non-polar, or hydrophobic.

Quaternary structure

Quaternary structure – the 3-D arrangement of two or more polypeptides, or of a polypeptide and a non-protein component such as haem, in a protein molecule.

- Many protein molecules are made up of two or more polypeptide chains. Haemoglobin is an example of this, having four polypeptide chains in each molecule.
- The association of different polypeptide chains is called the quaternary structure of the protein.
- The chains are held together by the same type of bond as in the tertiary structure.



h. Describe the molecular structure of haemoglobin as an example of a globular protein, and of collagen as an example of a fibrous protein and relate these structures to their functions (the importance of iron in the haemoglobin molecule should be emphasised);

Globular protein – a protein whose molecules are folded into a relatively spherical shape, and which is often water-soluble and metabolically active, e.g. insulin and haemoglobin

Fibrous protein – a protein whole molecules have a relatively long, thin structure that is generally insoluble and metabolically inactive, and whose function is usually structure, e.g. keratin and collagen

Globular protein:

- A protein whose molecules curl into a ‘ball’ shape, such as myoglobin or haemoglobin, is known as globular protein. In a living organism, proteins mat be found in cells and in other aqueous environments such as blood, tissue fluid and in phloem of plants.
- In a living organisms, proteins may be found in cells and in other aqueous environments such as blood, tissue fluid and in phloem of plants.
- Globular proteins usually curl up so that their non-polar, hydrophobic R groups point into the centre of the molecule, away from their watery surroundings. Water molecules are excluded from the centre of the folded protein molecule. The polar, hydrophilic R groups remain on the outside of the molecule. Globular proteins, therefore, are usually soluble, because water molecules clusters around their outward – pointing hydrophilic R group.
- Many globular proteins have roles in metabolic reactions. Their precise shape is the key to their functioning. Enzymes, for example, are globular proteins.

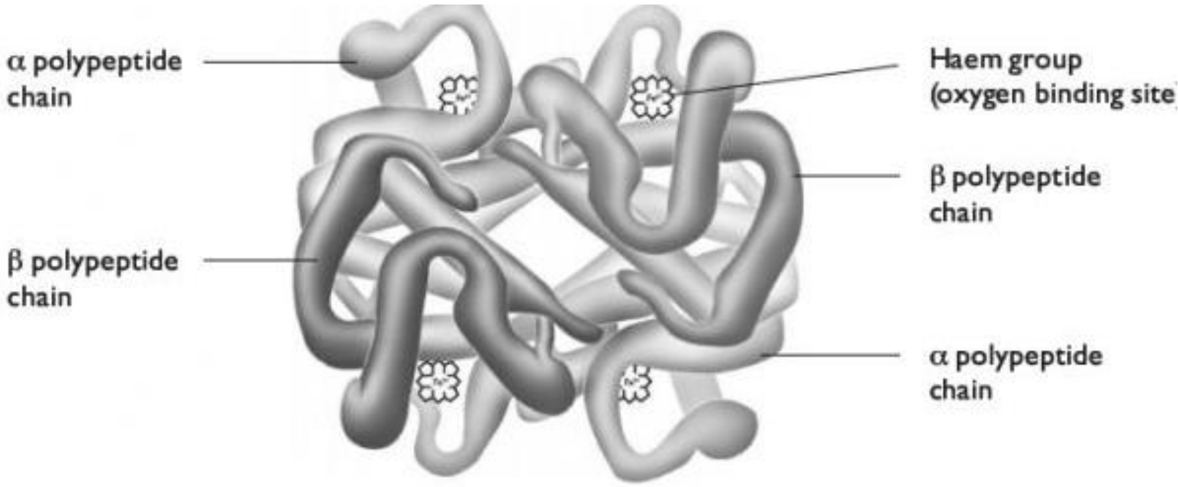
Fibrous protein

- Fibrous proteins are usually soluble in water and most have structural roles. For example, Keratin forms hair, nails and outer layers of skin, making these structures waterproof.

Haemoglobin – a globular protein

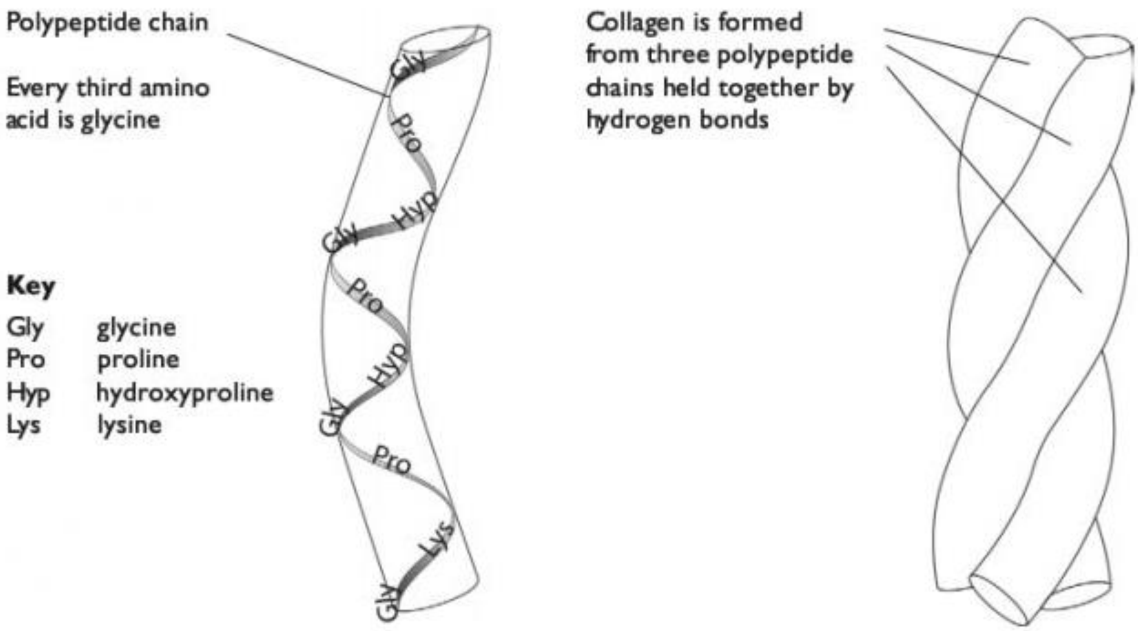
- **Solubility –** the tertiary structure of haemoglobin makes it soluble. The four polypeptide chains are coiled up so that R groups with small charges on them (hydrophilic groups) are on the outside of the molecule. They therefore form hydrogen bonds with water molecules. Hydrophobic R groups are mostly found inside the molecule.
- **Ability to combine with oxygen –** the haem group contained within each polypeptide chain enables the haemoglobin molecule to combine with oxygen. Oxygen molecules combine with iron ion, Fe^{2+}, in the haem group. One oxygen molecule (two oxygen atoms) can combine with each haem group, so one haemoglobin molecule can combine with four oxygen molecules (eight oxygen atoms).
- **Pick – up and release oxygen –** the overall shape of the haemoglobin molecule enables it to pick up oxygen when the oxygen concentration is high, and to release oxygen when the oxygen concentration is low. Small changes in oxygen concentration have a large effect on how much oxygen the haemoglobin molecule can hold. Once one oxygen molecule has combined with one haem group, the whole

molecule changes its shape in such a way that it is easier for oxygen to combine with the other three haem groups.



The structure of haemoglobin

Collagen – a fibrous protein



The structure of collagen

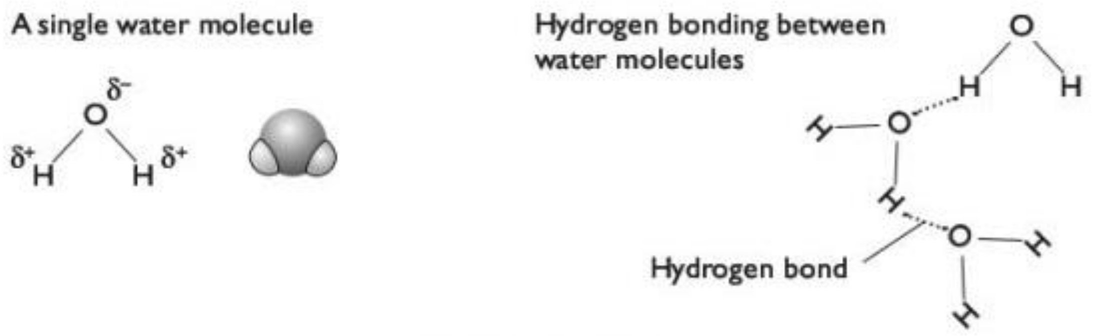
- **Insolubility-** collagen molecules are very long and are too large to be able to dissolve in water.
- **High tensile strength –** three polypeptide chains wind around one another, held together by hydrogen bonds, to form a three – stranded molecule that can withstand quite high pulling forces without breaking. This structure also allows the molecules to stretch slightly when pulled.

- **Compactness –** every third amino acid in each polypeptide is glycine, whose R group is just a single hydrogen molecule. Their small size allows the three polypeptide chains in a molecule to pack very tightly together.
- **Formation of fibres –** there are many lysine molecules in each polypeptide, facing outwards from the three- stranded molecule. This allows covalent bonds to form between the lysine R groups of different collagen molecules, causing them to associate to form fibres.

i. Describe and explain the roles of water in living organisms and as an environment for organisms;

About 80% of the body of an organism is water. Water has usual properties compared with other substances, because of the structure of its molecules. Each water molecule has a small negative charge (δ−) on the oxygen atom and a small positive charge (δ+) on each of the hydrogen atoms. This is called dipole.

There is an attraction between the δ− and δ+ parts of neighbouring water molecules. This is called a hydrogen bond.

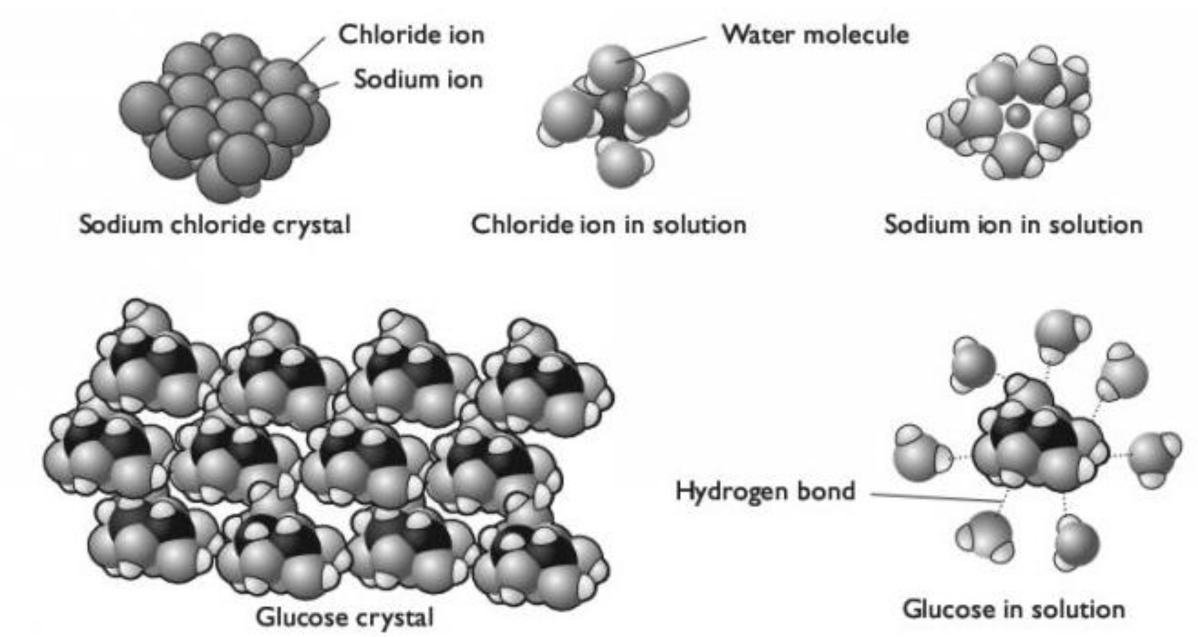


Water molecules

Solvent properties of water

The dipoles on water molecules make water an excellent solvent. For example, if you stir sodium chloride into water, the sodium and chloride ions separate and spread between the water molecules – they dissolve in the water. This happens because the positive charge on each sodium ion is attracted to the small negative charge on the oxygen of the water molecules. Similarly, the negative chloride ions are attracted to the small positive charge on the hydrogens of the water molecules.

Any substance that has fairly small molecules with charges on them, or that can separate into ions, can dissolve in water.



Because it is a good solvent, water helps to transport substances around the bodies of organisms. For example, the blood plasma of mammals is mostly water, and carries many substances in solution, including glucose, oxygen and ions such as sodium. Water also acts as a medium in which metabolic reactions can take place, as the reactants are able to dissolve in it.

Thermal properties of water

- **Water is liquid at normal earth temperatures.** The hydrogen bonds between water molecules prevent them flying apart from each other at normal temperatures on Earth. Between 0cel and 100c3el, water is in the liquid state. The water molecules move randomly, forming transitory hydrogen bonds with each other. Other substances whose molecules have a similar structure, such as hydrogen sulphide (H_2S) are gases at these temperatures, because there are no hydrogen bonds to attract their molecules to each other.
- **Water has a high latent heat of evaporation**. When a liquid is heated, its molecules gain kinetic energy, moving faster. Those molecules with the most energy are able to escape from the surface and fly off into the air. A great deal of heat energy has to be added to water molecules before they can do this, because the hydrogen bonds between them have to be broken. When water evaporates, it therefore absorbs a lot of heat from its surroundings. The evaporation of water from the skin of mammals when they sweat therefore has a cooling effect. Transpiration from plant leaves is important in keeping them cool in hot climates.
- **Water has a high specific heat capacity.** Specific heat capacity is the amount of heat energy that has to be added to a given mass of a substance to raise its temperature by 1cel. Temperature is related to the kinetic energy of the molecules – the higher their kinetic energy, the higher the temperature. A lot of heat energy has to be

added to water to raise its temperature, because much of the heat energy is used to break the hydrogen bonds between water molecules, not just to increase their speed of movement. This means that bodies of water, such as oceans or lake, do not change their temperature as easily as air does. It also means that the bodies of organisms, which contain large amount of water, do not change temperature easily.

- **Water freezes from the top down.** Like most substances, liquid water becomes more dense as it cools, because the molecules lose kinetic energy and get closer together. However, when it becomes a solid (freezes), water becomes less dense than it was at 4cel, because the molecules from a lattice in which they are more widely spaced than in liquid water at 4cel. Ice therefore floats on water. The layer of ice then acts as an insulator, slowing down the loss of heat from the water beneath it, which tends to remain at 4cel. The water under the ice therefore remains liquid, allowing organisms to continue to live in it even when air temperatures are below the freezing point of water.