Biological Molecules

A balanced diet contains the correct amounts and proportions of the different nutrients that will maintain the body in a healthy condition.

Importance of Nutrients for Organisms:

- They provide energy for vital activities
  - These activities include growth, reproduction, and muscle contraction.
  - The energy they provide is not created or destroyed – it is only transferred from one form to another.
    - For example, the stored energy in candy is broken down into glucose, following which it is transported via blood to cells, which, via cellular respiration, release energy from it
    - However, this process is not 100% efficient, due to which some energy is lost during conversion as thermal energy. This occurs even when the body is at rest, which is why you burn calories while sleeping.
- They help in the synthesis of new protoplasm.
  - They help in the repair of worn-out parts of the body.
  - They are necessary for reproduction.
- Maintenance of health:
  1. They prevent deficiency.
  2. They maintain cells to make vital activities possible.

Organic and Inorganic Nutrients: nutrients are classified as organic & inorganic materials

- Organic Materials:
  - These include carbohydrates, fats/lipids, proteins, and vitamins.
  - They are obtained from living organisms, due to which they are compounds of carbon.
- Inorganic Materials:
  - These include non-living substances needed by the body such as water and mineral salts.

> For nutrients to be digested, they need to be broken down into simpler molecules by enzymes.
> - Proteins are broken down by peptides into amino acids.
> - Lipids are broken down in the small intestine into fatty acids and glycerol.
> - Carbohydrates are broken down by amylase into simple sugars.
>
> Most macromolecules are polymers.
> - Polymers are made up of small repeating chains of units.
> - They are made of small materials called monomers, which are 'linked' together.
> - They are created via condensation and broken down via hydrolysis.

2.1 Testing for Biological Molecules

1. Test for (glucose & maltose) monosaccharides:
   - Add 2ml of Benedict solution to a test tube containing hot water and 2ml of 1% monosaccharide solution.
   - Mix the solution thoroughly.
   - Boil the solution slowly using a water bath.
   - Shake the test tube continuously while boiling.
   - If color changes occur the used monosaccharide is a reducing agent.

Test tube 1st: Benedict's initially turns blue. No reducing sugars present.	Test tube 2nd: Benedict's + glucose turns green. Trace amounts of reducing sugars present.
Test tube 3rd: Benedict's + more glucose dissolved turns orange or yellowish green. Moderate amounts of reducing sugars present.	Test tube 4: Benedict's + the most amount of dissolved glucose turns brick-red. Large amounts of reducing sugars present.

	Reducing Sugars	**Non-Reducing Sugars**
	Glucose, Fructose, Lactose, Galactose, Maltose	Sucrose
Results	These sugars can reduce the copper sulfate (blue) in Benedict's reagent to copper oxide (brick red).	The reducing group is involved in the glycosidic bond in sucrose, therefore sucrose cannot reduce copper sulfate to copper oxide. When sucrose is hydrolyzed (through boiling with acid) the glycosidic bond is broken & therefore the reducing group gets exposed. A positive result is achieved with benedicts reagent following hydrolysis.

Differences b/w Reducing and Non-Reducing Sugars		
Character	**Reducing Sugar**	**Non- Reducing Sugar**
Nature	Reduce cupric ions of Fehling's reagent & Benedict's reagent to cuprous ions to produce brick-red precipitates.	Don't form brick-red precipitates with Fehling's reagent & Benedict's reagent.
Structural Peculiarity	Have a free carbonyl group (either aldehydic or ketonic group).	Don't have a free carbonyl group.
Examples	All monosaccharides maltose, lactose, etc.	Sucrose & all polysaccharides.

Acid Hydrolysis Test for Non-Reducing Sugars:

- Take 2ml unknown solution in a test tube and add 1ml of dilute HCl.

- Heat the test sample with dilute hydrochloric acid in the water bath for uniform heating.
- Remove from the beaker.
- Neutralize the test sample by adding sodium hydro-carbonate with a spatula.
- Now heat the test sample with 3ml/equal volume Benedict's Reagent in the water bath.
- Observe the color change. A brick red precipitate indicates the presence of a reducing sugar.

2. Test for starch:
   - Add a few drops of iodine solution or potassium iodide on a spotting tile.
   - Add 2 ml of dilute starch solution to one of the depressions & note the colour change.

Presence of starch: iodine turns blue-black	Absence of starch: iodine stays yellow-brown

3. Test for lipids:
   - Label the test tubes suitably for the foods to be tested.
   - Chop solid food on a tile or grind with a pestle & mortar.
   - Add the food to a labelled test tube to a depth of about 1 cm. For olive oil, add a few (2) drops.
   - Add 3 cm^3 of 95% ethanol to each test tube.
   - Put a clean bung into each test tube & shake carefully at least 10 times. This will help any lipids dissolve in the ethanol.
   - Allow time for food particles to settle. You may proceed when the ethanol above the food has cleared.
   - Use the wash bottle to dispense about 3 cm depth of distilled water into the test tubes containing the solute & mix.
   - Observe & note any changes in the test tube contents. Record your results in a suitable table.

A white cloudy emulsion or a precipitate is formed to show the presence of lipids. The oil is dispersed within the water.

4. Test for proteins:
   - Add a small quantity of egg white (albumin) to test tube A containing water forming a 1ml protein solution & add 1 ml of 5% KOH & mix well.
   - Next add two drops of 1% $CuSO4$ & mix. This is a biuret test

Negative Result: Pale blue colour	Positive Result: pale mauve colour (polypeptide chain chelates with a copper ion)

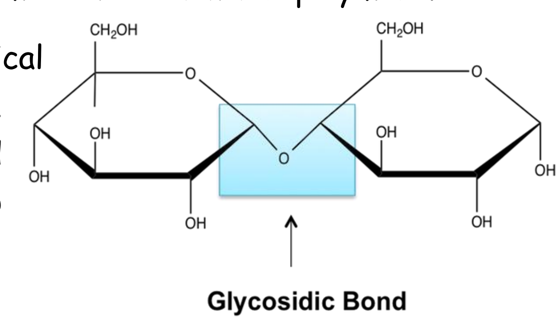
2.2 Carbohydrates and Lipids

Carbohydrates

- Carbon, Hydrogen, Oxygen
- Carbohydrates are a group of substances used as both energy sources and structural materials in organisms.
- Glucose, Fructose, Galactose are monosaccharides (simple sugars, mostly hexose sugars)
  - General Formula: $C_6H_{12}O_6$
- 2 monosaccharides (small simple sugars) join to form a disaccharide (large sugars); maltose (Cereals and Grains), sucrose (Cane Sugar), lactose (pigeon's milk).
  - General Formula: $C_{12}H_{22}O_{11}$
- A chain of monosaccharides forms a polysaccharide (long chain carbohydrates): starch (insoluble store of food in animals and plants), glycogen (insoluble storage of glucose in animals and fungi), cellulose (plant cell walls).
- Carbohydrates supply cells with instant energy for respiration.
  - It is stored as glycogen in the liver.
- Source: Rice, Bread, Potatoes

Monomers and Polymers: The building blocks of polymers are monomers. Polymers contain repeating molecular units which are generally connected by covalent bonds.

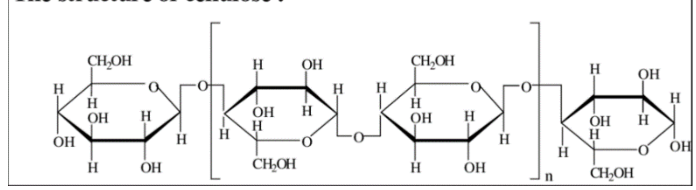
Monomers (one-past): Monomers are referred to as small molecules that are connected in a repeating fashion to create complex molecules known as polymers.



- Monomers form polymers through chemical bonds through the process of polymerization.
- In some instances, polymers are generated from bound groups of monomer subunits (up to a few dozen monomers) called oligomers.
- Examples of monomers:
  - Glucose - polymerizes into starch, cellulose, laminarin, and glucans.
  - Amino acids - polymerizes into peptides, polypeptides, and proteins.
  - Vinyl chloride - polymerizes into polyvinyl chloride or PVC.
- Glucose is the most abundant natural monomer and it polymerizes by forming glycosidic bonds.

Polymers (many-part): A polymer could be a synthetic or a natural macromolecule consisting of repeating units of a smaller molecule i.e. monomers.

- While a lot of people use the terms ‘plastic’ and ‘polymer’ interchangeably, polymers are a much larger class of molecules that includes cellulose, natural rubber, amber, and plastics.

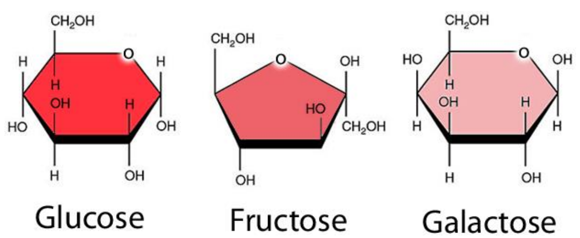

The structure of cellulose :

- Examples of polymers
    - Silicones such as silly putty.
    - Plastics such as polyethylene.
    - Biopolymers such as DNA and cellulose.
    - Natural polymers like shellac and rubber.

Macromolecule:

Carbohydrates	Polymers are polysaccharides and disaccharides; monomers are monosaccharides (simple sugars) formed from C,H,O.
Lipids	Diglycerides, triglycerides; formed from glycerol and fatty acids.
Proteins	Polymers are polypeptides; monomers are amino acids formed from C,H,O,N and sometimes S.
Nucleic Acids	Polymers are DNA and RNA; monomers are nucleotides, which in turn consist of a nitrogenous base, pentose sugar, and a phosphate group.

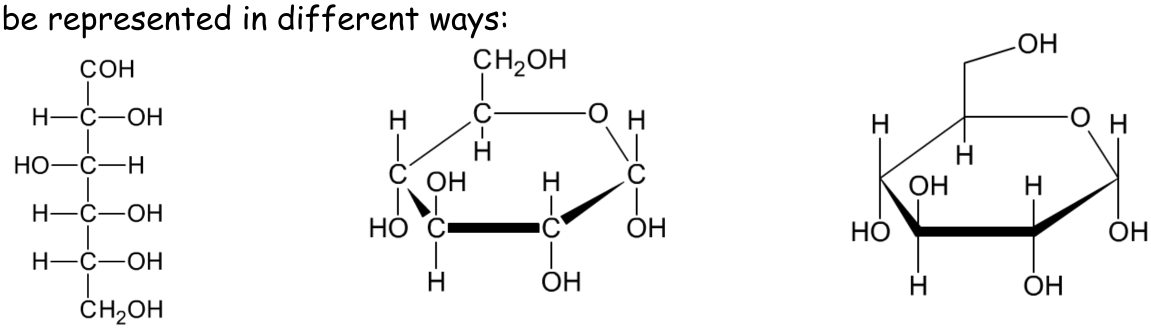
Monosaccharides: these are simple sugars, with the general formula $(CH_2O)_n$, where n can be 3–7.



Is fructose a Levorotatory or Dextrorotatory?

- Fructose which is mainly found in fruits, and nuts as the monosaccharide unit of sucrose, is a levorotatory sugar as it rotates the plane of polarized light in an anticlockwise direction.
- Glucose is a dextrorotatory sugar.
- A dextrorotatory compound is a compound that rotates the plane of polarized light clockwise.

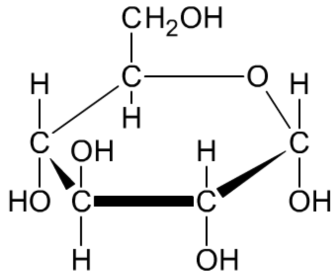
<u>Glucose:</u> is an abundant and very important monosaccharide. It contains six carbon atoms so it is a hexose sugar. Its general formula is $C_6H_{12}O_6$. Glucose is the major energy source for most cells. It is highly soluble and is the main form in which carbohydrates are transported around the body of animals. The structure of glucose can be represented in different ways:

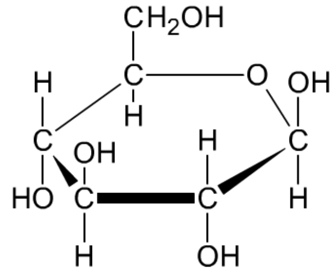


<u>Alpha (α) and Beta (β) Glucose:</u>

- Glucose exists in different forms called structural isomers.
- Two common isomers and monosaccharides are alpha (α) glucose & beta (β) glucose.
- The only difference between these two isomers is the position of the –OH group attached to carbon 1.
- In α glucose it is below the carbon and in β glucose, it is above the carbon.
- This minor structural difference has a major effect on the biological roles of alpha α and beta β glucose.
- Examples of Alpha α and Beta β Glucose:
  - Alpha α Glucose: Starch
  - Beta β Glucose: Cellulose

α - glucose

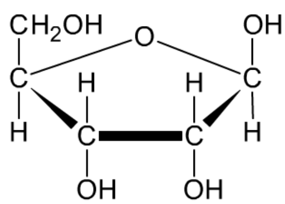


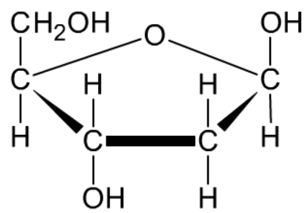


β - glucose

Pentoses (Sugars of DNA): Pentose monosaccharides contain five carbon atoms. Like hexoses, pentoses are long enough to form a ring. Two important pentose molecules are the structural isomers ribose and deoxyribose. These are important constituents of RNA and DNA. The only difference is that ribose has one H atom and one –OH group attached to carbon 2, whereas deoxyribose has 2 H atoms and no –OH group.

ribose





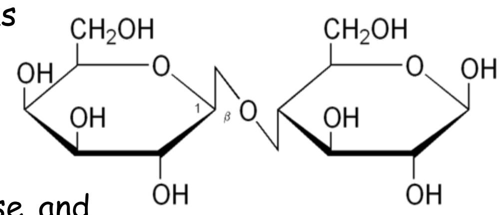
deoxyribose

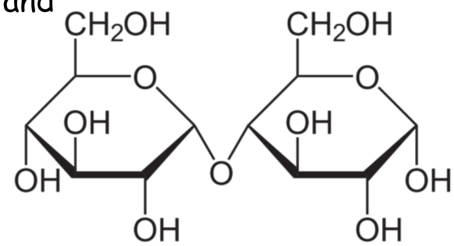
Condensation and Hydrolysis Reaction:

- Condensation: is a reaction between 2 monosaccharides to form a disaccharide with the simultaneous loss of a small molecule such as water. As the two OH are so close they react, forming a covalent bond called a glycosidic bond between 2 glucose molecules.
- Hydrolysis: is a reaction used to break polysaccharides & disaccharides into monosaccharides by the addition of water. It's the opposite of condensation.

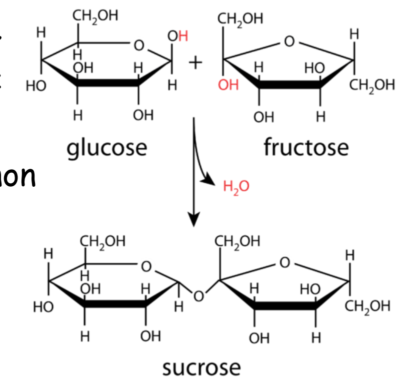
Disaccharides: these are 'double sugars', formed from two monosaccharides.

- A glycosidic bond is formed between monosaccharides. A water molecule is removed during the reaction hence they are known as condensation reactions. The general molecular formula is $C_x(H_2O)_{x-1}$. For example:
  - Glucose + Galactose → Lactose
    Lactose (milk sugar) is formed from galactose and glucose joined by a beta 1–4 glycosidic bond.
  - Glucose + Glucose → Maltose
    Maltose (malt sugar) is formed from two glucose molecules joined by an alpha 1–4 glycosidic bond.





- α Glucose + β Fructose → Sucrose
  Sucrose (table sugar) is formed from alpha glucose and beta fructose joined by an alpha 1–2 glycosidic bond.



- According to the structures, sucrose behaves as a non reducing sugar.
- The remaining 2 disaccharides behave as reducing sugars.

<u>Reducing Sugars:</u>

- The reducing sugars include all monosaccharides, such as glucose, lactose, galactose & fructose, & some disaccharides, such as maltose.
- The only common non-reducing sugar is sucrose.
- Reducing sugars are so called because they can carry out a chemical reaction called reduction. In the process, they are oxidized.
- This is made use of in the Benedict's test using Benedict's reagent. Benedict's reagent is copper (II) sulfate in an alkaline solution and has a distinctive blue color. Reducing sugars reduce soluble blue copper sulfate, containing copper (II) ions, to insoluble brick-red copper oxide, containing copper (I). The copper oxide is seen as a brick-red precipitate.
  Reducing Sugar + Cu^{2+} → Oxidized sugar + Cu^{+} blue red-brown
- The carbonyl group is present in all monosaccharides.
- Reducing sugars have the carbonyl group in them which is present in 2 forms:
  - As an aldehyde: the monosaccharide is named as aldose.
  - As a ketone: the monosaccharide is named as ketose.
- Glucose, Galactose, and Ribose are called aldoses because they have an aldehyde group attached to their carbon-1. Fructose is called a ketose because it has a keto group attached to its carbon-2.

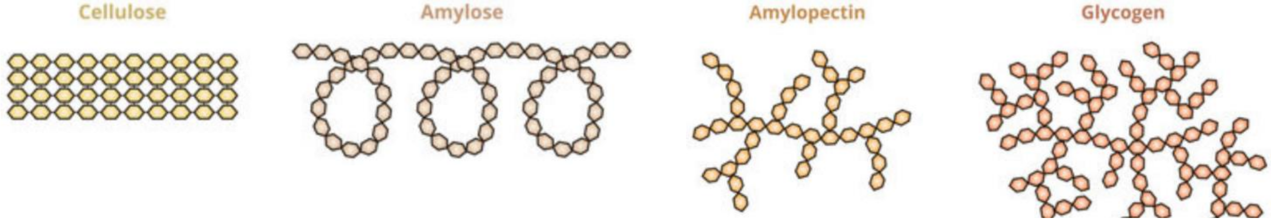
The R group represents a side chain from the central 'alpha' carbon atom can be anything from a simple hydrogen atom to a more complex ring structure.

Polysaccharides: these are large molecules formed from a chain of monosaccharides linked by glycosidic bonds.

- Like disaccharides, polysaccharides are formed by condensation reactions.
- Polysaccharides are mainly used as an energy store and as structural components of cells.
- The major polysaccharides are starch & cellulose in plants, & glycogen in animals.

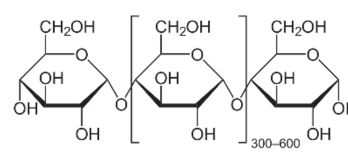
Storage Polysaccharides		
Polysaccharide	**Monomer**	**Organism**
i) Starch ii) Amylose iii) Amylopectin	Alpha α Glucose	Algae, all Plants
Glycogen	Alpha α Glucose	Animals

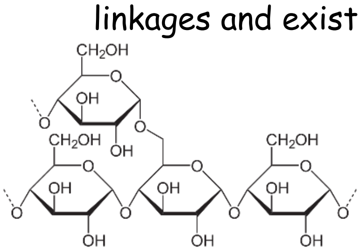
Structural Polysaccharides		
Polysaccharide	**Monomer**	**Organism**
Cellulose	Beta β Glucose	Algae, all Plants



Starch: Starch is the major carbohydrate storage molecule in plants. Starch is produced from glucose made during photosynthesis. It is broken down during respiration to provide energy & is also a source of carbon for producing other molecules.

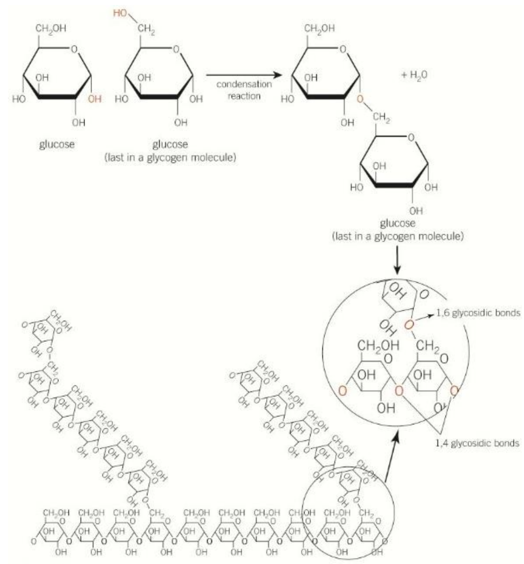
Amylose: Amylose is a helical long thread-like molecule formed by the polymerization of glucose molecules. They contain α-1,4-glycosidic linkages and exist as chains.





Amylopectin: Amylopectin is a branched molecule made out of α-1,4 (chained) & α-1,6 (branched) glycosidic linkages of glucose monomers.

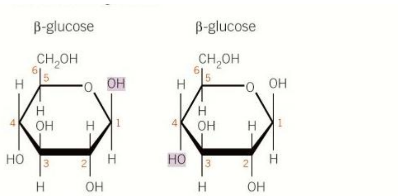
Glycogen: Animals do not store carbohydrates as starch but as glycogen. Glycogen is similar to amylopectin, containing α-1,4 & many α-1,6-glycosidic bonds that produce an even more branched structure. Glycogen is stored as small granules, particularly in muscles and liver. Glycogen is less dense, more soluble than starch, & is broken down more rapidly. This indicates the higher metabolic requirements of animals compared with plants.
Glycogen is a highly branched polymer made of α-1,4 (chained) & many α-1,6 (branched) glycosidic linkages of glucose monomers.



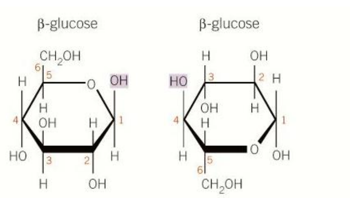
▲ Figure 4 Formation of glycogen. Note that a new glucose chain starts to form from the main chain forming a branc

Cellulose: Cellulose is the main part of plant cell walls. It is the most abundant organic polymer. Cellulose is very strong & prevents cells from bursting when they take in excess water. Cellulose is made by many condensation reactions joining long chains of beta-glucose molecules joined by β-1,4-glycosidic linkages. The glucose chains form rope-like microfibrils, which are layered to form a mesh network.

Long straight chains lie parallel & held together by many hydrogen bonds. This is fibril. Hydrogen bonds are weak, however collectively they provide strength.

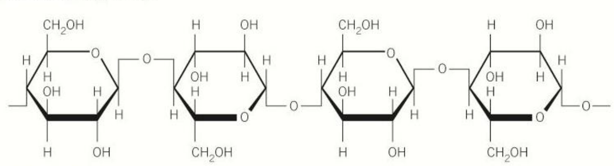


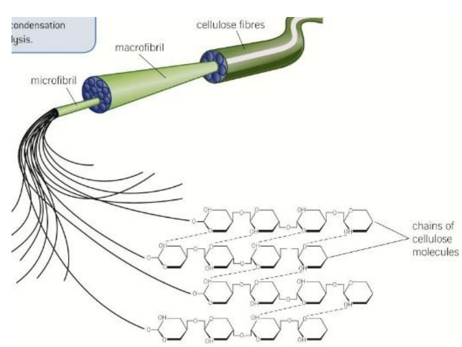
▲ Figure 5 Note how far apart the OH groups are on these two β-glucose molecules



▲ Figure 6 The OH groups of the two β-glucoses are now close enough to react and a 1,4 glycosidic bond is formed

When a polysaccharide is formed from glucose in this way it is unable to coil or form branches. A straight chain molecule is formed called **cellulose** (Figure 7).


▲ Figure 7 The cellulose molecule is straight and unbranched



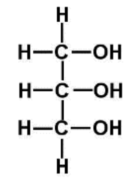
	Cellulose	Starch		Glycogen
		Amylose	Amylopectin	
Monomers	β-glucose	α-glucose	α-glucose	α-glucose
Location	Plant (Cell Wall)	Plant Cells	Plant Cells	Animals (muscle & liver)

Bonds	1-4 glycosidic bonds	1,4 glycosidic bonds	1,6 glycosidic bonds	1,4 glycosidic bonds & 1,6 glycosidic bonds
Branches	No	No	Yes (per 20 monomers)	Yes (per 10 monomers)
Function	Structural Strength	Store of glucose	Store of glucose	Store of glucose
Structure	Polymer forms long, straight chains. Chains are held in parallel by many hydrogen bonds to form fibrils.	An unbranched helix.	A branched molecule.	A highly branched molecule.
Diagram				
Shape				
Explanation of how the structure leads to the function	Many hydrogen bonds provide collective strength. Insoluble & won't affect water potential.	Helix can compact to fit a lot of glucose in a small space. Insoluble & won't affect water potential.	Structure increases S.A for rapid hydrolysis back to glucose. Insoluble & won't affect water potential.	Structure increases S.A for rapid hydrolysis back to glucose. Insoluble & won't affect water potential.

Lipids

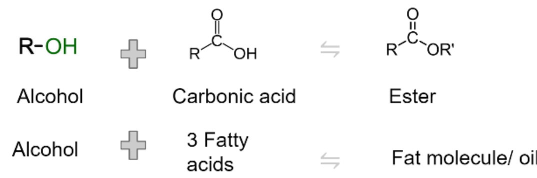
- Carbon, Hydrogen, Oxygen; some may also contain Nitrogen & Phosphorus.
- The value of H:O ratio is more than 2:1.
- The proportion of oxygen to carbon and hydrogen is smaller than in carbohydrates.
- Lipids are stored in adipose tissue.
- They are non-polar, hydrophobic molecules & so are insoluble in water.
- Fats/triglycerides are made of glycerol and fatty acids. To break these large molecules, add three water molecules.
- They are soluble in organic solvents such as alcohols.
- Phospholipids (containing Phosphorus), present in cell membranes.

- Steroids include cholesterol & hormones:
  - Cholesterol provides the starting point for lipids such as Vitamin D, Estrogen, Testosterone, & Cell Membranes.

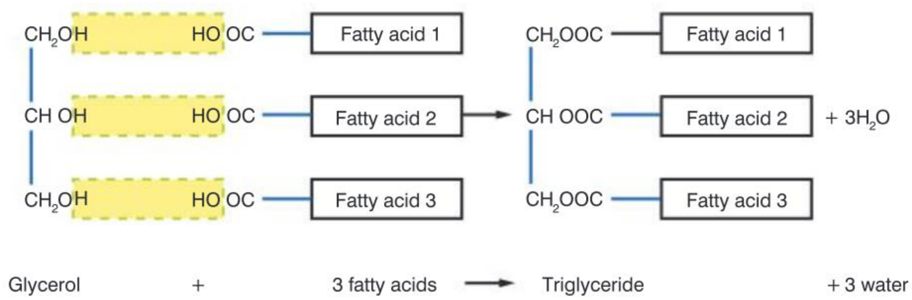


- Fats are solid at room temperature, while oils are liquid.
- Complex lipids consist of Fatty Acids & Alcohol.
- Glycerol is the alcohol that is present in most of the complex lipids.
- General formula of fatty acid = R-COOH.
- The ratio of C, H, O of a fatty acid: $C_nH_{2n}O_2$.
- Fatty Acids can be divided into 2 groups; Saturated & Unsaturated Fatty Acids according to the type of bonds present between C & C:
  - Saturated:
    1. Solid at r.t.
    2. Can be created by animals such as bacon grease.
    3. Don't have double bonds: only single bonds are present b/w 2 carbons.
    4. E.g. animal fat, some of the plant fat (cashew nut, peanuts).
  - Unsaturated:
    1. Vegetable fats; normally known as oils.
    2. Don't cause heart disease.
    3. Have kinks in fatty acid chains due to double or triple bonds b/w 2 carbons.
    4. E.g. coconut oil, sunflower oil.
- Lipids are insoluble in water; they are a store energy in the body.
  - Act as an insulator against heat loss: in mammals, adipose tissue underneath the skin helps reduce heat loss.
  - Protect organs against mechanical damage: adipose tissue around delicate organs such as the kidneys acts as a cushion against impacts.
  - Maybe used for respiration as an alternative.
  - Buoyancy (Lightweight): allowing a person to float.
  - Waterproof: insoluble in water.
  - Acts as a structural component.
  - Bees use wax to construct their honeycombs.
  - Plants produce scents which are mostly fatty acids or esters.
  - An energy source: providing more than twice the amount of energy as carbohydrates i.e. about 38 kJ/g.
  - Metabolic source of water: the caloric value of triglyceride is over twice that of glycogen or protein (per unit mass). Triglyceride provides more metabolic water upon oxidation than glycogen. When body fat content is high, total body water content is low.
  - Make up cell membranes for growth.
- Source: Butter, Oil, Margarine

Fats & Oils: are made out of glycerol and fatty acid. A triglyceride is formed when one glycerol molecule combines with three fatty acid molecules. A newly formed bond is known as an ester bond.

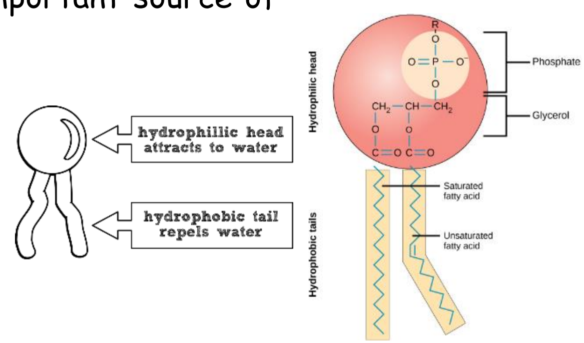


Triglycerides: There is no fundamental chemical difference between a fat & an oil. Fats are solid at room temperature (10–20°C), whereas oils are liquid. Triglycerides are so called because they have 3 (tri) fatty acids combined with glycerol (glyceride). Each fatty acid forms an ester bond with glycerol in a condensation reaction. Hydrolysis of a triglyceride therefore produces glycerol & three fatty acids.



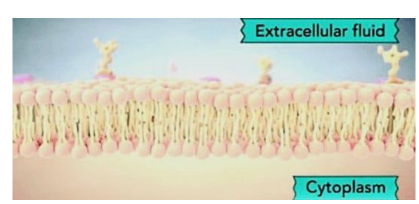
- Triglycerides have a high ratio of energy-storing carbon-hydrogen bonds to carbon atoms and are therefore an excellent source of energy.
- Triglycerides have a low mass-to-volume ratio making them good storage molecules because much energy can be stored in a small volume.
- Beneficial to animals, as it reduces the mass they have to carry as they move around.
- Being large, non-polar molecules, triglycerides are insoluble in water.
- Their storage does not affect the water potential of cells.
- As they have a high ratio of hydrogen to oxygen atoms, triglycerides release water when oxidized & therefore provide an important source of water, especially for organisms living in deserts.

Phospholipids: Phospholipids are similar to lipids except that one of the fatty acid molecules is replaced by a phosphate molecule. Whereas fatty acid molecules repel water (are hydrophobic), phosphate molecules attract water (are hydrophilic).



Alcohol + Organic Acid + Another Group ⇌ Ester

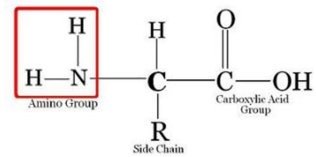
Glycerol + 2 Fatty Acids + Phosphoric Acid ⇌ Phospholipid



2.3 Proteins

Proteins

- Carbon, Hydrogen, Oxygen, Nitrogen; some may also contain Sulfur & Phosphorus.
- They are macromolecules made of amino acid residues (monomers).
- Amino Acids with a peptide bond & Antibodies.



- Proteins are a diverse group of large & complex polymer molecules comprising of long amino acid chains (monomer).
- 2 peptide bonds join to form a dipeptide.
- A chain of peptide bonds forms polypeptides. These amino acid chains are folded up, and twisted in coils with weak hydrogen, cross-linking bonds that can be easily denatured by heat, acids & alkalis.
    - Structural support in the:
        - Silk of insects and spiders.
        - Collagen in skin.
        - Keratin in hair & nails.
        - Elastin
        - Sclerotene
        - Mucoproteins
    - Formation of new protoplasm, which is essential for Growth and Repair of Tissues.
    - Structural: proteins are the main component of body tissues, such as muscle, skin, ligaments & hair.
    - Transport Proteins: Hemoglobin for transport of oxygen, haemocyanin, myoglobin, serum albumin.
    - Immunological: formation of antibodies; a defense mechanism, fibrinogen & fibrin.
    - Enzymes: all enzymes are proteins, catalyzing many biochemical reactions. E.g. amylase, lipase, pepsin, trypsin & chymotrypsin.
    - Contractile protein: Allow for movement by contracting like miocene, actin.
    - Storage proteins like: ovalbumin, casein.
    - Toxins: such as snake venom, diphtheria toxin
    - Hormones.
    - Chemical messengers/ signaling: many receptors are proteins.
- A deficiency causes kwashiorkor, which is characterized by swollen abdomens & cracked & scaly skin.
- Source: Meat, Eggs, Cheese

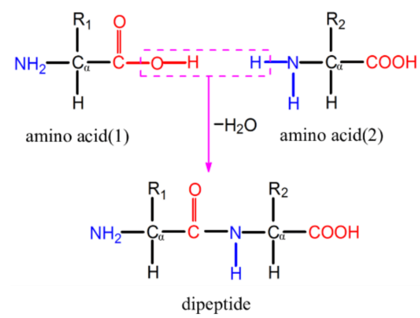
Amino Acids: have the same general structure: the only difference between each one is the nature of the R group. The R group therefore defines an amino acid. The R group represents a side chain from the central 'alpha' carbon atom and can be anything from a simple hydrogen atom to a more complex ring structure.

- There are about 150 types of amino acids in animal and plant tissues.
- Out of this, only 20 types of amino acids participate in protein synthesis.
- Plants can synthesize all the necessary amino acids. But animals cannot do so.
- Therefore, amino acids present within animals can be divided into 2 forms.

  - <u>Essential amino acids:</u> Amino acids which cannot be synthesized within animal bodies.
  - <u>Non-essential amino acids:</u> Amino acids which can be synthesized within animal bodies.

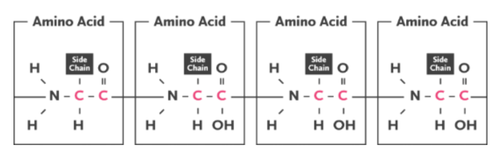
- There are about 10 types of essential amino acids.
- Amino acids can behave as amphoteric molecules.
- This nature helps to maintain a constant blood pH value.
- When pH value decreases it converts into a positively charged ion.
- When the blood pH value increases it converts into a negatively charged ion.
- There are 2 types of amino acids.

  - L amino acids
  - D amino acids



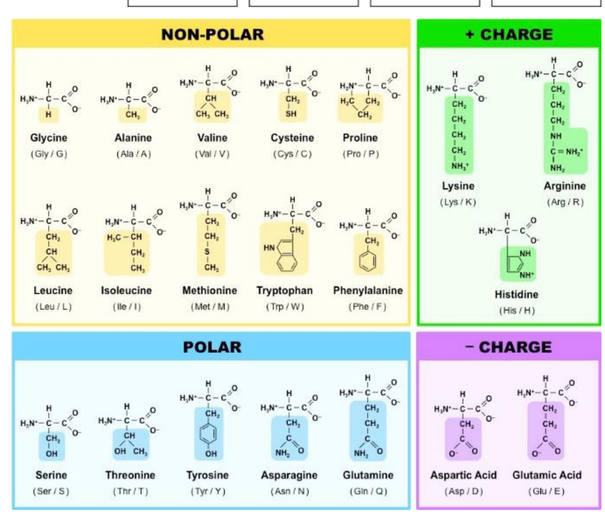
Polypeptide chain

- Only L form participates in the synthesis of protein.
- Amino acids are colorless and can be crystallized.
- Amino acids undergo condensation reactions and form polypeptide chains.
- Two amino acids form a peptide bond as follows to form a dipeptide molecule.
- Due to further condensation, amino acids form long polypeptide chains.



- There are 20 naturally occurring amino acids divided into:

  - Non-Polar:
  - Polar:
  - + Charge:
  - - Charge:



Protein Synthesis: Proteins or polypeptides are long chains of amino acids. These are formed in condensation reactions similar to that of carbohydrates. Peptide bonds form between individual amino acids molecules.

Polypeptides: When more amino acids are added to a dipeptide, a polypeptide chain is formed. A protein consists of one or more polypeptide chains folded into a highly specific 3D shape. There are up to four levels of structure in a protein: primary, secondary, tertiary, & quaternary. Each of these plays an important role in the overall structure and function of the protein.

Structural Organizational Levels of Proteins:

- Primary Structure:
  - Number and the amino acid sequence of a polypeptide chain.
  - Only peptide bond is present.
  - Simple long chains with no intramolecular bonds or interactions.
  - 1 polypeptide chain/ protein molecule.
  - E.g. a polypeptide chain of lysozyme enzyme (tears, saliva).
- Secondary Structure:
  - The secondary structure is arranged in a helical shape or folded sheet.
  - This is made of hydrogen (OH) & peptide bonds.
  - Hydrogen bonds form causing the molecule chain to either fold or coil itself.
  - It can either be α-helix or β-pleated.
  - E.g. collagen fibers, keratin.
- Tertiary Structure:
  - This is more complex than the other levels involving multiple types of bonds & interactions b/w the R-groups.
  - Helical form bends itself to form a more compact molecule; coils & folds.
  - Most enzymes are tertiary in structure.
  - The overall shape is more or less similar to a globe and hence known as a globular protein.
  - The following types of bonds are present: peptide bond, hydrogen bond, ionic bond, & di-sulfide bond (2 Cystine).
  - Hydrophilic/phobic interactions, hydrogen, ionic, & disulfide bonds hold the molecules together in shape.
- Quaternary Structure:

- These are the same as tertiary but with two separate polypeptide chains interlinked.
- Several globular molecules combine to form the quaternary structure.
- There may be 2-4 globular molecules in one quaternary protein molecule.
- 4 polypeptide chains at max including globular & fibrous structures.
- These are bonded by hydrogen & covalent bonds.
- Some proteins are formed from several polypeptides, also known as sub-units, & the interactions of these subunits form a quaternary structure.
- Examples:
    1. Insulin – 2 polypeptide chains (dimeric) held together by a disulfide bond.
    2. Collagen (Structural Bonds) – a fibrous & insoluble protein of 3 polypeptide chains (trimetric) that are supercoiled like a rope with high tensile strength. They lie parallel with staggered ends (no weak spots) & form covalent cross-links between R-groups of lysine a.a. They form fibrils & fibers.

       E.g. Muscles, Ligaments, Skin, Bone, Blood vessels, Digestive tract, Corneas, Heart, Gallbladder, Hair & Nails.

       Collagen is an important structural protein, not only in humans but in almost all animals.

       A collagen molecule consists of three polypeptide chains, each in the shape of a helix. (This is not an αk helix- it is not as tightly wound). These three helical polypeptides are wound around each other, forming a three-stranded 'rope' or 'triple helix. The three strands are held together by hydrogen bonds and some covalent bonds. Almost every third amino acid in each polypeptide is glycine, the smallest amino acid. Glycine is found on the insides of the strands and its small size allows the three strands to lie close together and so form a tight coil. Any other amino acid would be too large.

       Each complete, three-stranded molecule of collagen interacts with other collagen molecules running parallel to it. Covalent bonds form between R groups of amino acids lying next to each other. These cross-links hold many collagen molecules side by side, forming fibrils.

The ends of the parallel molecules are staggered; if they were not, there would be a weak spot running right across the collagen fibril. Finally, many fibrils lie alongside each other, forming strong bundles called fibers.

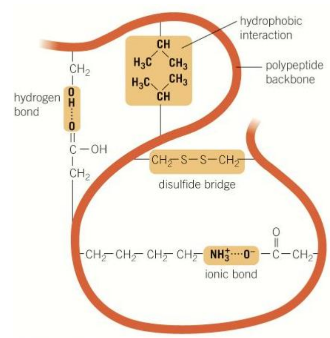
Polypeptide (mostly repeat of amino acid sequence proline-alanine-glycine) → Triple-helical collagen molecule → fibrils → fibers

3. Hb – a globular protein of 4 polypeptide chains (tetrametric).
   Hemoglobin is the oxygen-carrying pigment found in red blood cells & is a globular protein. We have seen that it is made up of 4 polypeptide chains. Each chain is itself a protein known as globin.
   There are many types of globin; α-globin, & β-globin. 2 hemoglobin chains are made of α-globin, while 2 chains are made of β-globin.
   Each polypeptide chain contains the haem group. A group like this is a permanent part of a protein molecule but is not made of amino acids, is called a prosthetic group.
   The importance of iron in hemoglobin:
   Each haem group contains an iron atom. One oxygen molecule, O, can bind with each iron atom. A complete hemoglobin molecule, with four haem groups, can carry four oxygen molecules (eight oxygen atoms) at a time.
   It is the haem group that is responsible for the color of hemoglobin. This color changes depending on whether or not the iron atoms are combined with oxygen.
   If they are, the molecule is known as oxyhemoglobin, & is bright red. If not, the color is purplish.

Globular Proteins	**Fibrous Proteins**
Spherical/ball-shaped.	Long, parallel strands.
Mostly tertiary, sometimes quaternary structure.	Mostly secondary structure & forms fibers.
Soluble – more functional roles. Amino acids with non-polar/ hydrophobic R groups are inside. Amino acids with polar/hydrophilic R groups are outside.	Insoluble – more functional roles.

E.g. all Enzymes, Antibiotics, some Hormones, Myoglobin, & Hemoglobin.	E.g. Collagen, Keratin

<u>Bonds in Proteins:</u> The 3D shape of a protein is maintained by several types of bonds, including:



- Hydrogen bonds: involved in all levels of structure.
- Hydrophobic interactions: between non-polar sections of the protein.
- Disulfide bonds: one of the strongest & most important types of bonds in proteins. Occur between two cysteine amino acids.

Denaturing Proteins: If the bonds that maintain a protein's shape are broken, the protein will stop working properly and is denatured. Enzymes exposed to different pH, salt concentration, or high temperatures different from the optimum would result in the active site of the enzyme being denatured, for the substrate is no longer able to fit the enzyme, (mismatched) however, the specific conditions will vary from protein to protein. Fibrous proteins lose their structural strength when denatured, whereas globular proteins become insoluble & inactive.

2.4 Water

Water
• Water has many essential roles in living organisms due to its properties: ➢ The polarity of water molecules. ➢ Water molecules are present as clusters in liquid form. ➢ The hydrogen bonding of water molecules makes the molecules more difficult to separate & affects the physical properties of water. ➢ The presence and number of hydrogen bonds between water molecules. • Physical properties of water are affected by hydrogen bonding. • Water is arguably the most important biochemical of all. Without water, life would not exist on this planet. It is important for two reasons. • First, it is a major component of cells, typically forming between 70% and 95% of the mass of the cell. You are about 60% water. • Second, it provides an environment for those organisms that live in water. Three- quarters of the planet is covered in water. • Melting points and boiling points are very high. • This ranges from 0-100°C. • Water molecules are dipoles. • Each water molecule has partial positive(δ+) hydrogen atoms and a partial negative(δ-) oxygen atom.

- The positively charged hydrogen atom of one water molecule is attracted to the negatively charged oxygen atom of another water molecule which results in hydrogen bonding.
- Each oxygen atom forms two hydrogen bonds/each hydrogen atom forms one hydrogen bond.
- It has several functions:
    - During digestion food is broken down into simpler soluble substances by a process of hydrolysis so that it can be absorbed by the gut stream and transported around the body and other cells.
    - Acts as a good solvent: As water is a polar molecule many ionic compounds (e.g. sodium chloride) and covalently bonded polar substances (e.g. glucose) will dissolve in it very easily. This allows chemical reactions to occur within cells (as the dissolved solutes are more chemically reactive when they are free to move about). Metabolites can be transported efficiently (except non-polar molecules which are hydrophobic). Thus, many metabolic chemical reactions also take place in the body through water.
    - Excrements such as excess salt, urea, and water are removed from the body by dissolving in water. Clears the digestive pathway and protects the gut from stomach ulcers.
    - It is a major component of blood & tissue fluid, & allows the transport of dissolved substances around the body such as products of digestion, hormones, etc.
    - Water is the main component of sweat, which has a cooling effect on the body upon evaporation.
    - Because water requires a large amount of heat energy to raise the temperature, it helps to maintain a constant body temperature providing suitable habitats. It also allows for constant temperatures within bodies and cells to be maintained (this ensures enzymes have the optimal temperatures).
    - Protein molecules form colloidal solutions with water. E.g.
      Egg white (85% water + 15% albumin)
      Cytoplasm (80% water)
    - Fats and oils do not dissolve in water. They form emulsions with water in the presence of bases.
- Source: fresh fruits such as watermelon, melon, strawberries etc. & vegetables such as cucumbers, spinach, lettuce, celery etc.

Why is water a polar molecule?

- Water is polar because oxygen & hydrogen have different electronegativity values.
- Oxygen has 2 lone electron pairs that repel each other & the electrons bonded to the hydrogen atoms.
- This gives the water molecule a bent shape.

- The oxygen side has a partial negative charge; the hydrogen side has a partial positive charge.

<u>The Structure of a Water Molecule:</u>

- Water is composed of atoms of hydrogen and oxygen. One atom of oxygen combines with two atoms of hydrogen by sharing electrons (covalent bonding).
- Although water as a whole is electrically neutral the sharing of the electrons is uneven between the oxygen and hydrogen atoms.
- The oxygen atom attracts the electrons more strongly than the hydrogen atoms, resulting in a weak negatively charged region on the oxygen atom ($\delta-$) and a weak positively charged region on the hydrogen atoms ($\delta+$), this also results in the asymmetrical shape.
- This separation of charge due to the electrons in the covalent bonds being unevenly shared is called a dipole. When a molecule has one end that is negatively charged and one end that is positively charged it is also a polar molecule.

<u>Important Properties of Water:</u>

<u>High Specific Heat Capacity:</u>

- The specific heat capacity of a substance is the amount of thermal energy required to raise the temperature of 1kg of that substance by 1°C. Water's specific heat capacity is 4200 J/kg°C.
- The high specific heat capacity is due to the many hydrogen bonds present in water.
- The hydrogen bonds that tend to make water molecules stick to each other make it more difficult for the molecules to move about freely.
- The bonds must be broken to allow free movement.
- Hydrogen bonding allows water to store more energy for a given temperature rise than would otherwise be possible, hence making water more resistant to changes in temperature.
- Due to the above characteristics, water can remain as a liquid within a high range of temperature.
- Also, the change of temperature in a water body is always minimized.
- It takes a lot of thermal energy to break these bonds and a lot of energy to create them, thus the temperature of water does not fluctuate greatly.
- The advantage for living organisms is that it:
  - Provides suitable habitats.
  - Allows for constant temperatures within bodies and cells to be maintained (this ensures enzymes have the optimal temperatures).

- This is because a large increase in energy is needed to increase the temperature of water.

High Latent Heat of Vaporization:

- In order to change state (from liquid to gas) a large amount of thermal energy must be absorbed by water to break the hydrogen bonds and evaporate.
- This is an advantage for living organisms as only a little water is required to evaporate for the organism to lose a great amount of heat.
- This provides a cooling effect for living organisms, for example the transpiration from leaves or evaporation of water in sweat on the skin.
- Latent heat, energy absorbed or released by a substance during a change in its physical state (phase) that occurs without changing its temperature. During melting, the ice absorbs latent heat, which is used to change the state of the water from ice to liquid water.
- Latent heat of fusion of ice is very high.
- Latent heat of vaporization of water is also high.
- Therefore, water can store a huge amount of heat.
- Water molecules tend to stick to each other by hydrogen bonds means that relatively large amounts of energy are needed for evaporation to occur, because hydrogen bonds have to be broken before molecules can escape as a gas.
- This is an advantage for living organisms as only a little water is required to evaporate from the surface of the organism in order to lose a great amount of heat energy.
- This is biologically important as it provides a cooling effect for living organisms, for example the transpiration from leaves or evaporation of water in sweat from the skin or panting in mammals.

High Latent Heat of Fusion:

- The amount of heat energy which is absorbed or released when a solid changes into liquid state at the atmospheric pressure at its melting point. This is known as latent heat of fusion.

Solvent Action:

- Water is an excellent solvent for ions and polar molecules.
- Since ions are charged, water molecules are attracted to them.
- The attraction occurs because δ- oxygen atoms of water molecules face positive ions while δ+ hydrogen atoms face negative ions.
- Non-polar molecules like lipids are insoluble in water and, if surrounded by water, tend to be pushed together by the water, since water molecules are attracted to each other.

Property	Role in Living Organisms	Reason
Solvent	Allows chemical reactions to occur. Transport medium.	Polarity in Water.
High Specific Heat Capacity	Allows water to be a suitable habitat. Optimal temperature maintained within cells & bodies.	Presence of many hydrogen bonds.
High Latent Heat of Vaporisation	Coolant	Presence of many hydrogen bonds.

<u>Water Molecules & Hydrogen Bonding:</u>

- Water is of great biological importance. It is the medium in which all metabolic reactions take place in cells. Between 70% to 95% of the mass of a cell is water.
- As 71% of the Earth's surface is covered in water it is a major habitat for organisms.
- Water is composed of atoms of hydrogen and oxygen.
    - One atom of oxygen combines with two atoms of hydrogen by sharing electrons so they are covalently bonded.
- Although water as a whole is electrically neutral the sharing of the electrons is uneven between the oxygen and hydrogen atoms.
    - The oxygen atom attracts the electrons more strongly than the hydrogen atoms, resulting in a weak negatively charged region on the oxygen atom (δ) and a weak positively charged region on the hydrogen atoms (δ^+).
    - This results in the asymmetrical shape of water molecules.
    - This separation of charge due to the electrons in the covalent bonds being unevenly shared is called a dipole. When a molecule has one end that is negatively charged and one end that is positively charged it is also a polar molecule.
- Water is a polar molecule.
- Hydrogen bonds form between water molecules.
    - As a result of the polarity of water hydrogen bonds form between the positive and negatively charged regions of adjacent water molecules.
- Hydrogen bonds are weak, when there are few, so they are constantly breaking and reforming.
- However, when there are large numbers present, they form a strong structure
- Hydrogen bonds contribute to the many properties water molecules have that make them so important to living organisms:
    - An excellent solvent – many substances can dissolve in water

- A relatively high specific heat capacity
- A relatively high latent heat of vaporization
- Water is less dense when a solid
- Water has high surface tension and cohesion
- It acts as a reagent