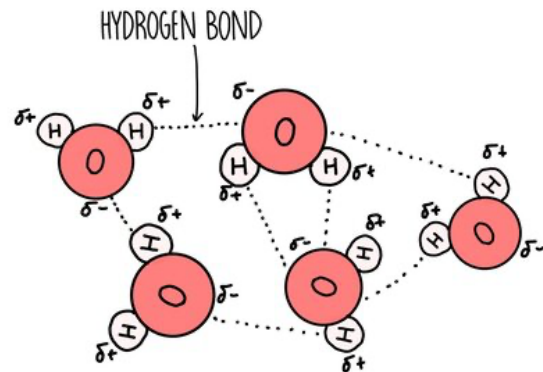


# Module 2: Foundations in Biology

## Biological Molecules

### Water and transport

Water is a **polar** molecule - this means that the electrons are shared unequally within the bonds that hold a water molecule together. Oxygen is greedy for electrons so pulls the electrons that make up the single covalent bond closer towards it (it is **electronegative**). This gives oxygen a slight negative charge and hydrogen a slight positive charge.



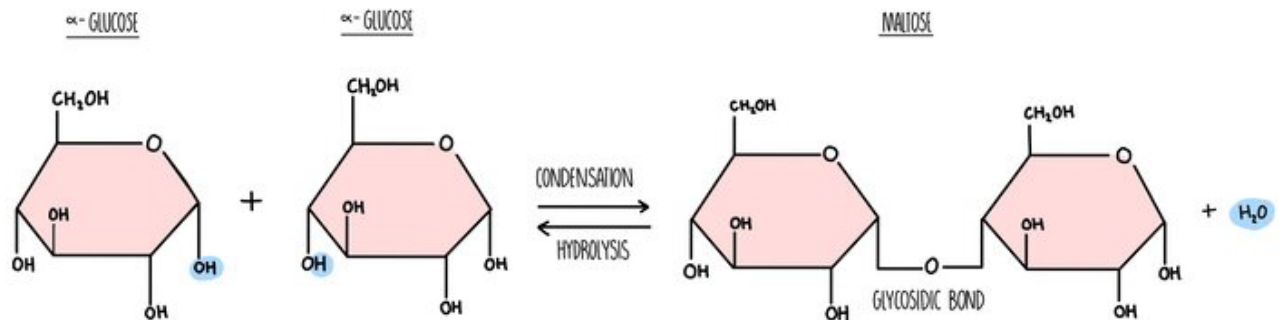
A **hydrogen bond** forms between the slightly negative oxygen atom of one water molecule and the slightly positive hydrogen atom on another molecule. The ability of water molecules to hydrogen bond gives it some special properties:

1. **It is an excellent solvent:** water is a good solvent because it can form hydrogen bonds with other polar molecules or charged ionic compounds. Water dissolves more substances than any other liquid so it is referred to as the '**universal solvent**'. This is handy for humans, since our **blood** consists mostly of water which is able to dissolve **hydrophilic molecules** such as glucose, ions and some amino acids.
2. **It has a high latent heat of evaporation** - this means that a **lot of energy** is used to convert water from a **liquid to a gas**. This is why we feel cooler when we **sweat**, since the evaporation of water from our skin's surface takes a lot of **heat energy** with it.
3. **It has a high specific heat capacity** - all those hydrogen bonds within water are great at absorbing energy, which means you have to **add a lot of it to heat water up**. This is really useful for marine life since it means that bodies of water are fairly **resistant to changes in temperature**, making it a **stable habitat** in which to live.
4. **It is cohesive** – water molecules have a tendency to **stick to other water molecules** (cohesion) because the slightly positive hydrogen of one water molecule attracts the slightly negative oxygen on another water molecule. Cohesion helps water to flow, making it a **good transport medium**.
5. **It can insulate large bodies of water** – solid water (ice) is **less dense** than liquid water because the water molecules in ice are **held further apart**. This is because each water molecule forms **four hydrogen bonds**, connecting it in a **lattice shape**. This means that in

the colder months, ice forms an insulating layer so that the water beneath doesn't freeze, allowing aquatic organisms to survive.

## Carbohydrates

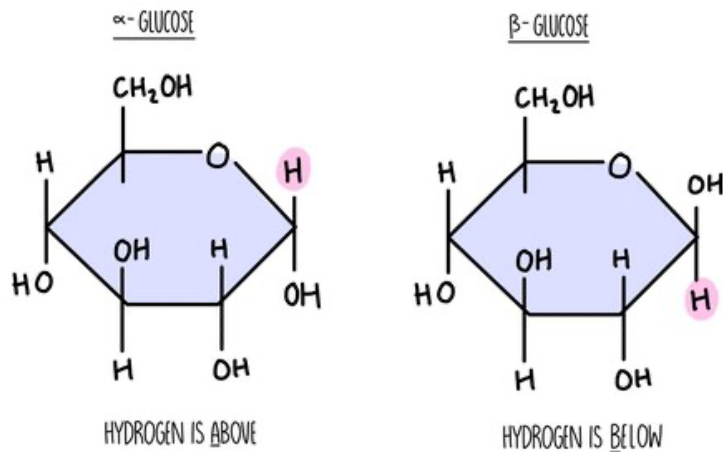
Carbohydrates are long chains of **sugar** molecules (the technical term is '**polysaccharides**') formed from lots of individual sugar molecules (**monosaccharides**) joining together. When two monosaccharides react to form a **disaccharide**, a **condensation reaction** occurs. During the condensation reaction, a molecule of water is removed (from a hydroxyl group on one sugar and a hydrogen on another) and a **glycosidic bond** forms. When polysaccharides are broken down during digestion, a **hydrolysis reaction** occurs in which a water molecule is added to break the glycosidic bond.



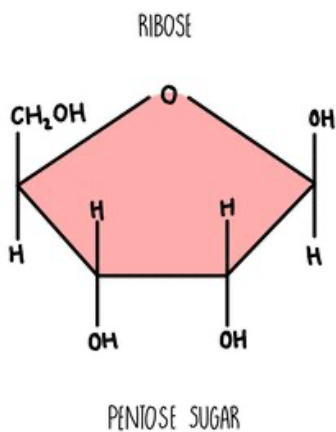
Carbohydrates are made up of **carbon, hydrogen and oxygen only**. Monosaccharides such as glucose and fructose consist of a **ring structure** with the general formula CH<sub>2</sub>O. Glucose is a **hexose sugar**, which means it is made up of six carbon atoms. It can exist as two different forms, **alpha and beta** which differ in the position of the hydrogen and hydroxyl groups on the right-hand carbon. An easy way to tell the difference between them is:

**Alpha** - the hydrogen atom is **above** the carbon.

**Beta** - the hydrogen atom is **below** the carbon.



Ribose is another example of a **monosaccharide** - it's a component of **RNA** molecules. It is a **pentose sugar** with five carbon atoms in the ring.

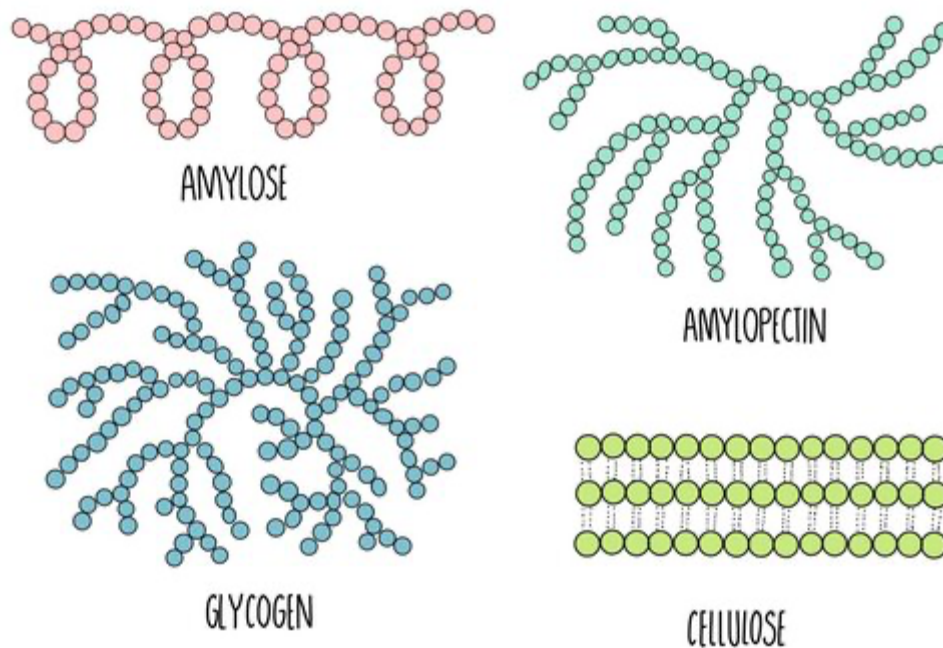


## Polysaccharides

The polysaccharides found in **plants** are **starch** and **cellulose**. Starch is broken down by the plant when it needs **energy** and cellulose is the major component of plant **cell walls**. Starch exists in two different forms: **amylose** and **amylopectin**. In animals, the energy storage carbohydrate is **glycogen**.

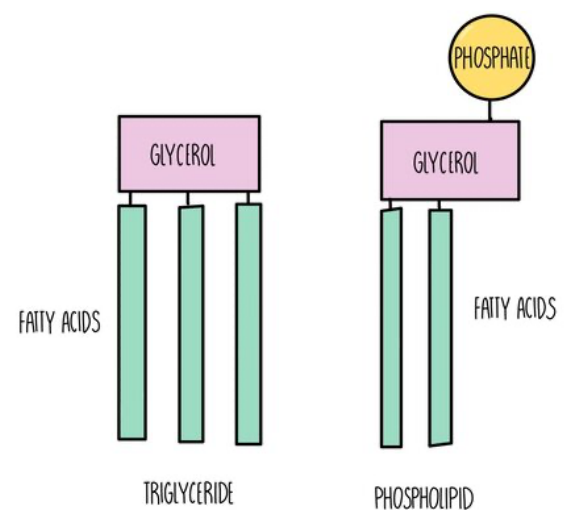
- **Amylose:** unbranched spiralling chains of **alpha-glucose** molecules. Its coiled structure means that it is very **compact** so lots of amylose can be packed into a cell.
- **Amylopectin:** branched chains of **alpha-glucose** molecules. Its branches increase its **surface area** which means that enzyme can quickly **break it apart** when glucose is needed for respiration.

- **Cellulose:** long unbranched chains of **beta-glucose** molecules. Multiple chains are linked together by **hydrogen bonding** to form **strong** structures called **microfibrils**. The strong microfibrils in the cell wall help to give plant cells their shape and structural support.
- **Glycogen:** branched chains of **alpha glucose**, similar to amylopectin but with more side-branches. This gives it a **large surface area** for enzyme action to release glucose when energy is needed. It is more **compact** than amylopectin, which means more can be stored in a cell.

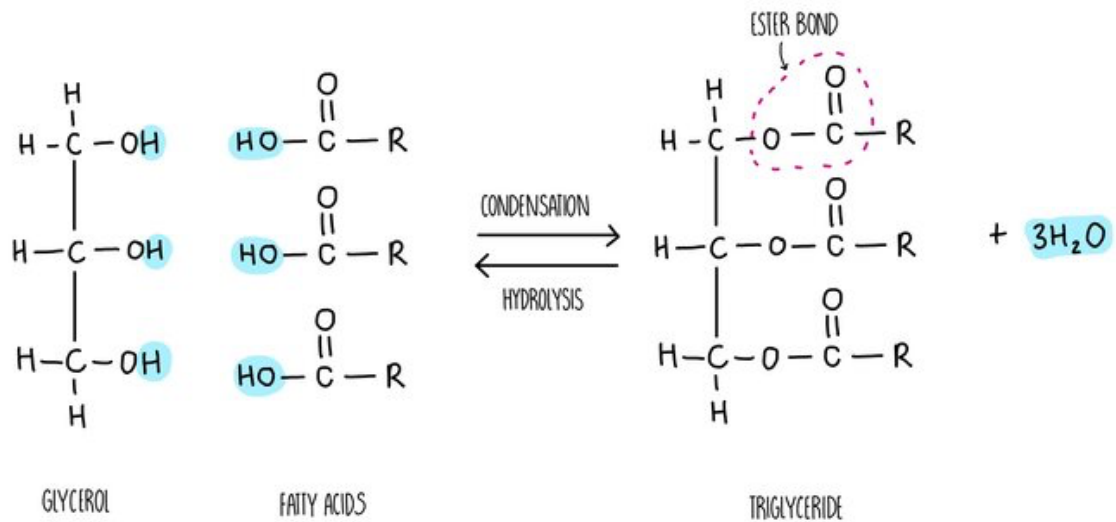


## Lipids

**Triglycerides, phospholipids** and **cholesterol** are all types of lipid. Triglycerides and phospholipids have similar structures as they are both made up of **glycerol** connected to **fatty acids** molecules through **ester bonds**. However, triglycerides contains **three fatty acid** 'tails' whereas phospholipids only have **two**. Phospholipids also possess a **phosphate group** which is absent in triglycerides. The fatty acid tails of triglycerides or phospholipids can be **saturated** (only single carbon-carbon bonds) or **unsaturated** (contain at least one double carbon bond).



The synthesis of a phospholipid or triglyceride from glycerol and fatty acids involves the formation of an **ester bond**. Just like we saw for the formation of a glycosidic bond, the synthesis of ester bonds is a **condensation reaction** in which a water molecule is released. Breaking apart a triglyceride or phospholipid involves the addition of water in a **hydrolysis reaction**.



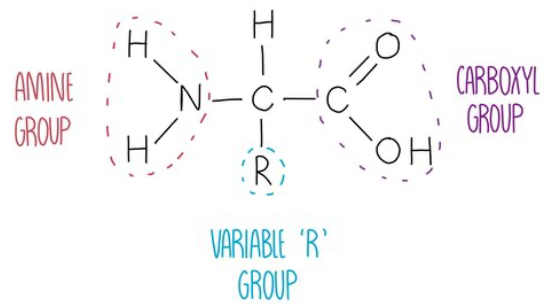
Different types of lipids have **different functions** in living organisms:

- **Triglycerides:** used as an **energy store**. A lot of energy is released when the ester bonds are hydrolysed - around twice as much compared to the breakdown of carbohydrates. Inside cells, triglycerides group together into **lipid droplets** where the hydrophobic tails face inwards and the hydrophilic heads face outwards. These insoluble droplets make good energy storage molecules since they do not affect the **osmotic potential** of the cell.
- **Phospholipids** are the main component of **cell membranes**. They form a **phospholipid bilayer** with the hydrophobic tails facing each other and the hydrophilic heads facing outwards, forming a **barrier** to prevent any polar molecules from entering or leaving the cell.
- **Cholesterol** is also found in **cell membranes** and helps to strengthen the membrane. Cholesterol pushes the hydrophobic tails of phospholipids closer together, making the membrane **more rigid**.

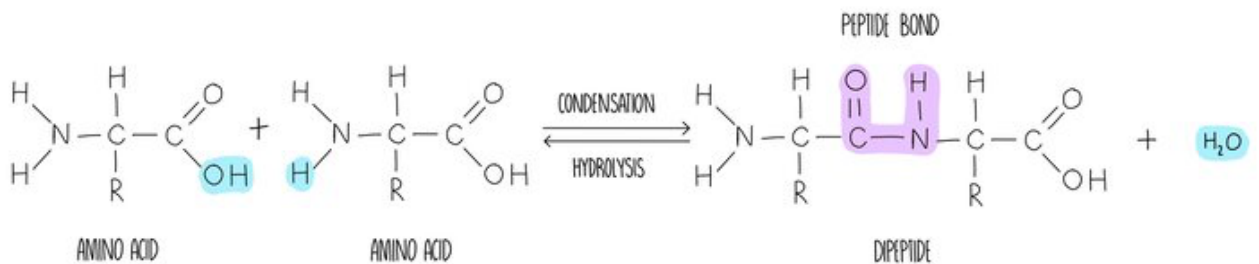
## Proteins

Proteins are polymers of **amino acids** joined together by **peptide bonds**. There are 20 different amino acids that our body needs to stay healthy, all of which have the same general structure. They consist of a **central carbon atom** attached to four different groups: an **amine group**, a **hydrogen atom**, a **carboxyl group** and an **'R' group** which is **different** in each amino acid.

The identity of the R group will influence how the amino acid **interacts** with other amino acids, therefore influencing **protein folding**. For example, lysine has a charged R group and is able to form ionic bonds with negatively charged amino acids.

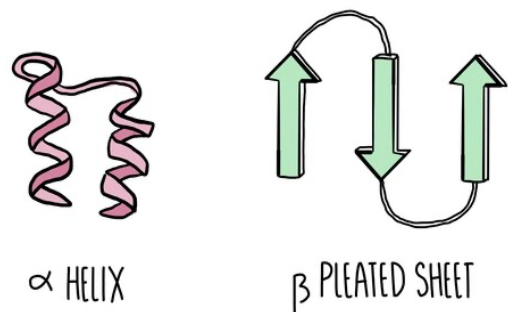


Peptide bond formation involves the removal of water in a **condensation reaction**. The water is formed by removing a hydrogen atom from the amine group and a hydroxyl (-OH) group from the carboxylic acid. What's left behind is a **peptide bond** (-CONH) which can be broken with the addition of water in a **hydrolysis reaction**.

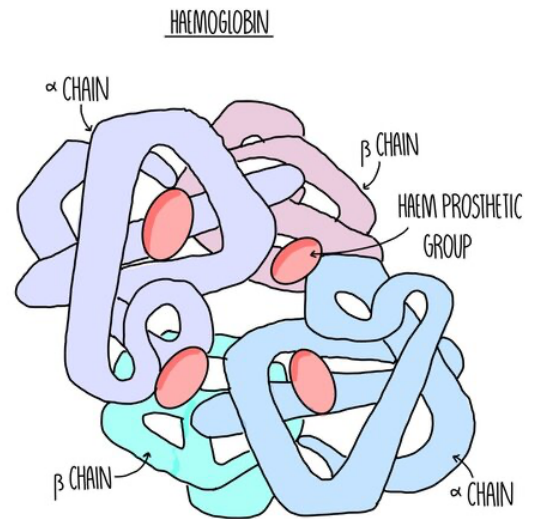


Once a long polypeptide chain is synthesised from the formation of numerous peptide bonds between adjacent amino acids, the polypeptide undergoes multiple stages of **folding**. These stages of protein origami are defined as the **primary**, **secondary**, **tertiary** and **quaternary structures** which describe a protein from its most unravelled to its final compact structure.

- **Primary structure:** peptide bonds have formed between amino acids to form a long, straight chain (polypeptide).
- **Secondary structure:** hydrogen bonds form between nearby amino acids (from the amine group on one amino acid to the carboxyl group of another) to form either an **alpha helix** or a **beta pleated sheet**. Proteins which form neither of these two structures will form a random coil.

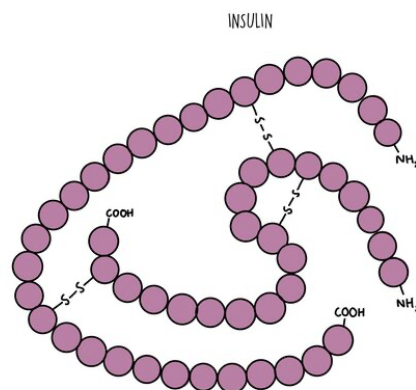


- **Tertiary structure:** more bonds form between the different **R groups** to give the protein a **3D structure**. R-group interactions involve **hydrogen bonds, disulfide bonds, ionic bonds and polar interactions**. If proteins are made of a single polypeptide chain, this is their final overall structure.
- **Quaternary structure:** this is the structure formed from the **interaction of multiple polypeptide chains** held together by bonds. Haemoglobin is an example of a protein with quaternary structure. It consists of four polypeptide chains (two alpha chains and two beta chains) bonded together. Each chain surrounds an iron-containing haem group. The haem group is referred to as a *prosthetic group* - non-protein components which are required for protein function.



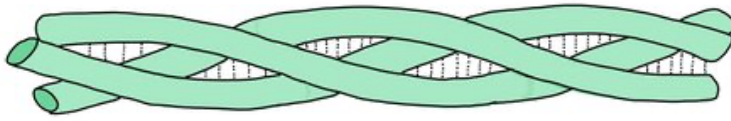
## Globular vs fibrous proteins

All proteins can be organised into one of two broad categories: **globular** proteins and **fibrous** proteins. Globular proteins are **spherical** and arranged with their **hydrophobic amino acids tucked inside** and the hydrophilic amino acids exposed on the outside. This means globular proteins are **soluble** and can be transported easily from one part of the cell to another. They perform **functional roles** and include things like **enzymes** (such as amylase), **hormones** (such as **insulin**) or proteins like **haemoglobin**. Globular proteins unravel and **denature** when the temperature or pH deviates from optimum levels. Globular proteins with prosthetic groups attached (such as haemoglobin) are referred to as **conjugated proteins**.



**Fibrous proteins** are long and thin and their primary structure consists of a repetitive sequence of amino acids. They perform **structural roles** so they are **strong** and **insoluble**. Examples of fibrous proteins include **collagen, keratin** and **elastin**. Collagen consists of **three polypeptide chains** wrapped tightly around each other to form a stable quaternary structure held together by numerous **hydrogen bonds**. Collagen is found in **connective tissue**, such as skin, muscle and bone. Fibrous proteins tend to be **less sensitive** than globular proteins to **changes in temperature and pH**.

COLLAGEN



## Inorganic ions

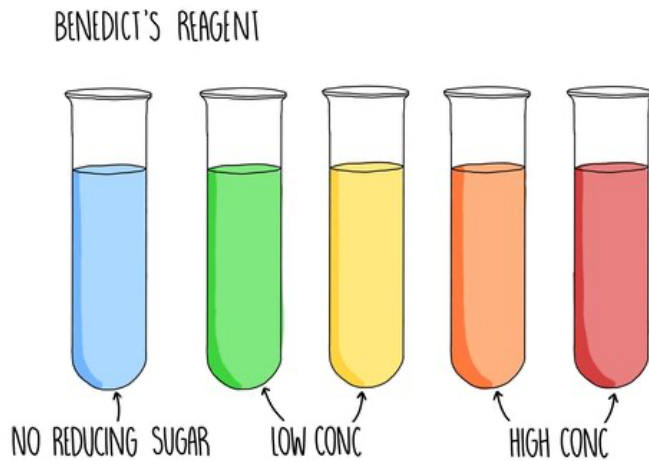
There is an array of **cations** (positive ions) and **anions** (negative ions) which are necessary for many biological processes:

- **Calcium ions,  $\text{Ca}^{2+}$** : required for the transmission of **action potentials**, the formation of **bone**, the release of **insulin** from the pancreas and as an enzyme **cofactor**.
- **Sodium ions,  $\text{Na}^+$** : required for the generation of **action potentials**, **muscle contraction** and for maintaining **blood pressure**.
- **Potassium ions,  $\text{K}^+$** : required for the generation of **action potentials**, **muscle contraction**, maintaining **blood pressure** and for **activating photosynthesising enzymes** in plants.
- **Hydrogen ions,  $\text{H}^+$** : important role in **respiration** and **photosynthesis** reactions and influences **pH** of a cell by increasing acidity.
- **Ammonium ions,  $\text{NH}_4^+$** : an important part of the **nitrogen cycle**. It is absorbed by plants and incorporated into amino acids for protein synthesis.
- **Nitrate ions,  $\text{NO}_3^-$** : an important part of the **nitrogen cycle**. It is absorbed by plants and incorporated into amino acids for protein synthesis.
- **Hydrogencarbonate ions,  $\text{HCO}_3^-$** : maintains constant pH in the blood by acting as a **buffer**.
- **Chloride ions,  $\text{Cl}^-$** : maintains **constant pH** in the blood through the process of '**chloride shift**' and acts as a **cofactor** for the enzyme amylase.
- **Phosphate,  $\text{PO}_4^{3-}$** : used to synthesise biological molecules such as **nucleic acids** and **phospholipids** and is added to enzymes and other proteins to regulate their **activity**.
- **Hydroxide,  $\text{OH}^-$** : changes the **pH** of a cell by making the area more alkaline.

## Testing reducing sugars using Benedict's solution

A **reducing sugar** is any sugar that can act as a reducing agent because of its aldehyde or ketone group. All **monosaccharides** are reducing sugars, along with some disaccharides (such as **maltose** and **lactose**). If the sugar you are testing is a reducing sugar, it will change colour from **blue** to **green/yellow/orange/brick red**, depending on the **concentration** of sugar you are testing. **Low** concentrations of reducing sugar will cause a **green or yellow** precipitate to form whereas a reducing sugar of **higher concentration** will appear **orange** or **brick red**.



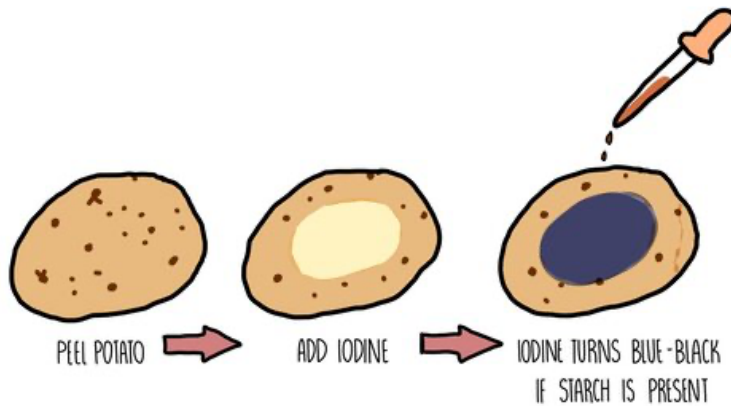


If the test for reducing sugars is negative and you want to confirm the presence of a **non-reducing sugar**, such as **sucrose**, you need to break down the sample into **monosaccharides** using **hydrochloric acid** which **breaks the glycosidic bonds**. The sample is neutralised with **sodium hydrogencarbonate** and the Benedict's test can be carried out. Since sucrose will have been broken down into glucose and fructose (both reducing sugars), you should now see a **positive result** if your original sample contained sucrose.

If you want to accurately measure the amount of reducing sugar in a sample, you can use **calorimetry**. Calorimetry works by measuring **how much light is able to pass through** the solution. The **less light** that passes through, the **higher the absorbance** of the sample and the **higher the concentration**. Before measuring the unknown sample, you first need to measure the absorbance readings of a series of solutions of a **known concentration**. You would plot a **calibration curve of absorbance against concentration** then measure the absorbance of the sample of **unknown concentration**. You can **read off your graph** to find the concentration which corresponds to this particular absorbance reading.

## Testing for starch using iodine

Starch is the storage carbohydrate in plant cells. If you want to test a part of a plant (such as a potato) for starch, you need to add **iodine** dissolved in **potassium iodide solution**. A positive result occurs when the solution changes colour from **orange/brown** to **blue/black**.



## Testing for lipids using the Emulsion test

To test for the presence of lipid in a sample, you need to add **ethanol** to a sample and mix thoroughly by **shaking**. Add an equal volume of **water** and if lipid is present a **milky white suspension** should form. If the solution remains colourless, no lipid was present in the sample.

## Testing for proteins using Biuret reagent

The Biuret test involves adding **sodium hydroxide** to a sample followed by **copper sulfate solution** (together these compounds are referred to as Biuret reagent). A colour change from **blue to purple** indicates a positive result.

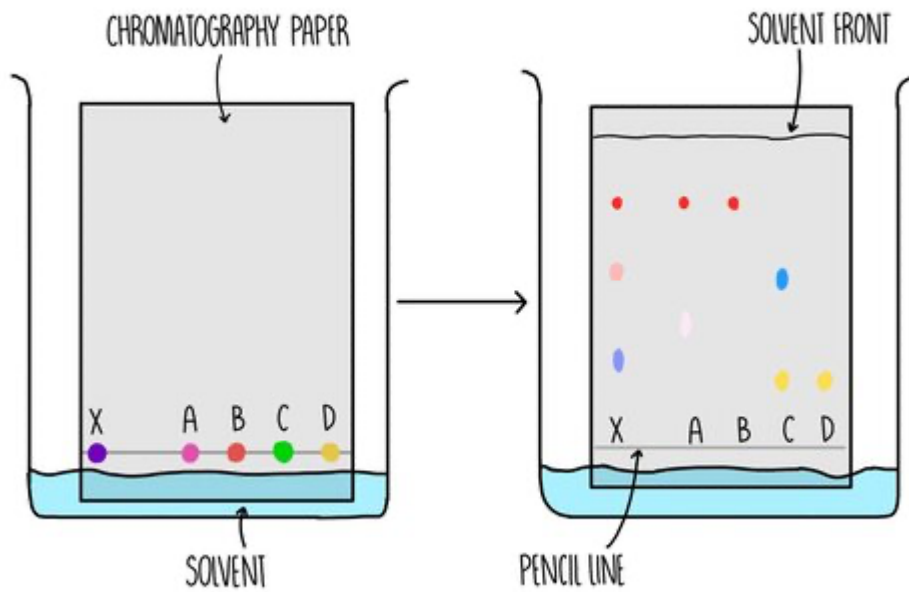
## Biosensors

A **biosensor** is an analytical device that is used to detect the **presence of a chemical**. It uses **biological molecules** (e.g. an enzyme) to produce a **chemical signal**, which is converted into an **electrical signal** by a **transducer**, which is then processed.

For example, glucose biosensors are used to determine the concentration of glucose in a solution, using the enzyme glucose oxidase. **Glucose oxidase** catalyses the **oxidation of glucose** at the **electrodes**, creating a **charge**. The electrodes (the transducer) convert the charge into an electrical signal which is processed to determine glucose concentration.

## Chromatography

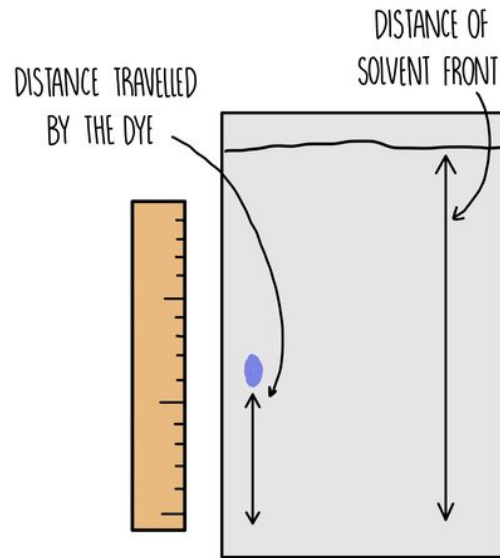
Paper chromatography is used to separate a mixture of **soluble substances**, such as different amino acids in a mixture. It involves a **stationary phase** (the part of the equipment which doesn't move) which is a sheet of paper and a **mobile phase** (the thing which moves) which is the solvent.



A **line** is drawn near to the bottom of the piece of paper - this is the starting line where the **amino acid mixture will be placed**. It is important that the line is drawn in **pencil** because the ink from pens will also dissolve in the solvent and cause a mess.

- The paper is placed in a **tank** containing some **solvent** and a **lid** is placed on top of the tank to **prevent evaporation** of the solvent. The solvent need to be **below the starting line** so that the mixture does not dissolve in the solvent before they can move along the paper.
- As the paper absorbs the solvent, the **solvent moves further up the stationary phase**. The amino acids are carried up the paper along with the solvent with different dyes moving up the paper to different extents. The total distance travelled by the solvent is the **solvent front**.
- An **Rf value** is calculated for each amino acid using the equation:

$$\text{Rf} = \frac{\text{distance travelled by dye}}{\text{distance travelled by solvent}}$$



$$R_f \text{ VALUE} = \frac{\text{DISTANCE TRAVELLED BY THE DYE}}{\text{DISTANCE TRAVELLED BY THE SOLVENT}}$$

Because **different compounds** have **different Rf values**, we can use chromatography to **identify** the compounds present by comparing their Rf value to the published values in a **data book**.