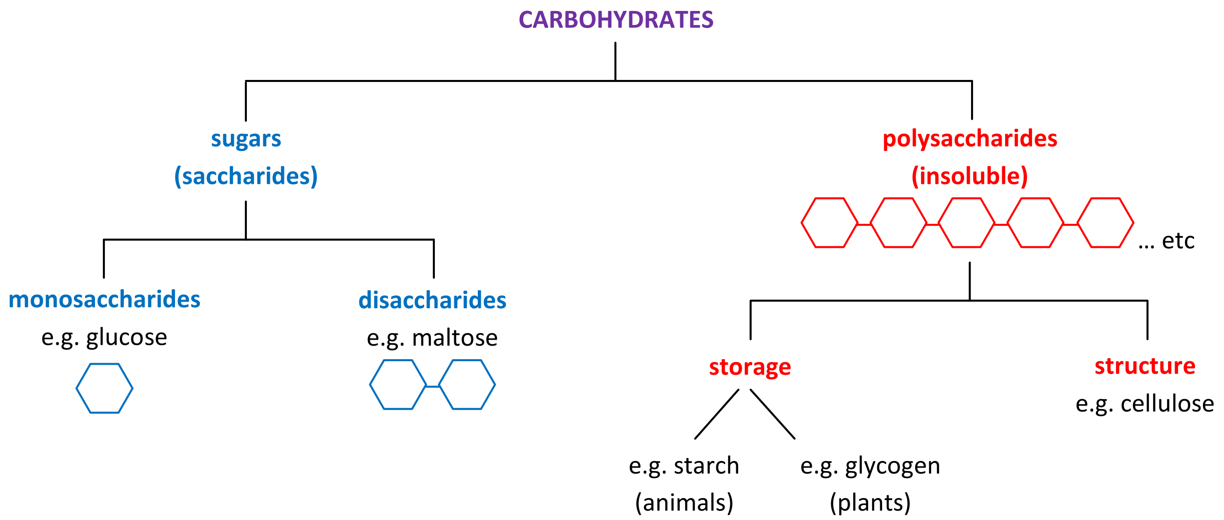
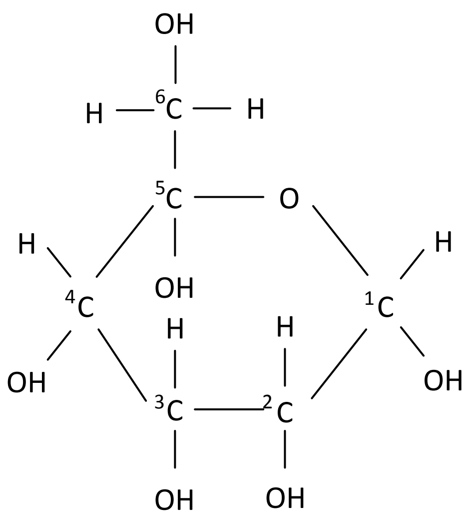
3.2 CARBOHYDRATES

Carbohydrate sugars, energy and storage; monosaccharides and polysaccharides

A **carbohydrate** is made up of *carbon*, *hydrogen* and *oxygen* atoms. Carbohydrates make up approximately one tenth of organic material inside a cell. They have the general chemical formula of **$C_x(H_2O)_y$** and have three primary functions. They are mainly used as an **energy source** (released from glucose during respiration) or as **energy storage** (e.g. starch). They also have **structural** uses, such as *cellulose*.



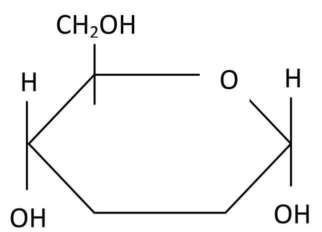
The simplest **sugars** are the **monosaccharides**. A monosaccharide is a **monomer** (single unit). One of the most common monosaccharide is **glucose**. This has the molecular formula $C_6H_{12}O_6$ and is the first product of photosynthesis, and the most commonly-used respiratory substrate.



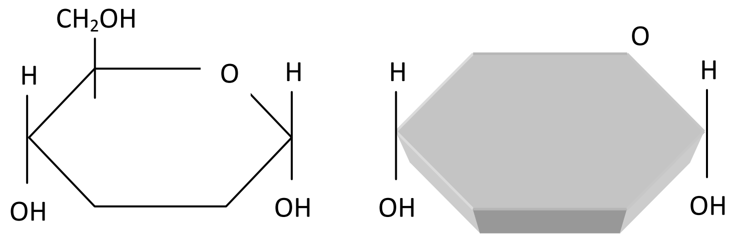
The diagram shows glucose drawn as a *ring structure*. The glucose molecule shown consists of a ring of five carbon atoms and one oxygen atom. Oxygen atoms make *two* bonds, carbon atoms make *four* bonds and hydrogen atoms make *one* bond. This can be seen in this structure. The carbon atoms are numbered to make them identifiable.

The oxygen atom in the ring has two bonds (with two C atoms). Four of the carbon atoms in the ring have four bonds, two with another two C atoms, one with an H atom and one with a **hydroxyl group**. A hydroxyl group is just an oxygen and hydrogen group. The fifth carbon atom also has four bonds: one with a C atom in the ring, one with an O atom in the ring, one with an OH hydroxyl group and another with a C atom outside the ring. This carbon atom has its own four bonds, as seen. It is an **alcohol group**. An alcohol group is a carbon atom attached to two hydrogen atoms and one hydroxyl group.

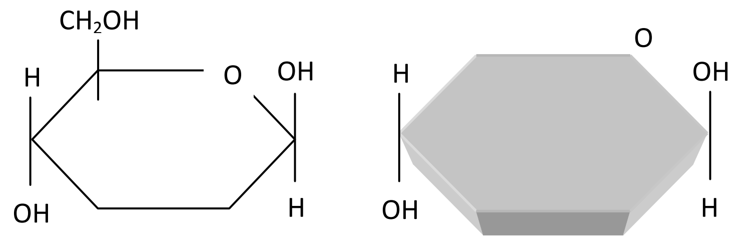
Alternatively, the molecule can be drawn as shown to the right. This version shows the ring containing the oxygen, and the carbons are assumed, but not written in. Carbon ^{2} and Carbon ^{3} are ignored, as they are thought to be unimportant. The alcohol group is written as CH_2OH to simplify it.



There are two forms of glucose. The diagram below is drawn to represent a 3D molecule. In this form of glucose, the Carbon ^{1} bonds with a hydrogen on top and the hydroxyl group below. This is called **α-glucose**.



In the other form of glucose, the hydroxyl OH group of the Carbon ^{1} is *above* the plane of the carbon ring and the hydrogen is below. However, the Carbon ^{2}, Carbon ^{3} and Carbon ^{4} remain the other way round. This is called **β-glucose**.



POLYMERISATION

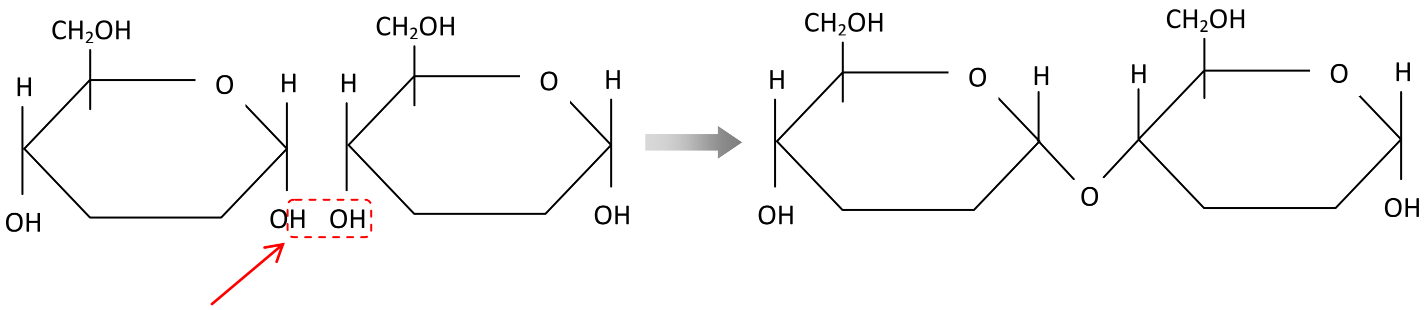
When α-glucose **polymerises** it becomes either *starch* (plants) or *glycogen* (animals). When β-glucose polymerises it becomes cellulose. Two monosaccharides will join together in a **condensation reaction** to form a **disaccharide**. Two glucose molecules join together to produce **maltose**. The two molecules are held together by a covalent bond called a **glycosidic bond**.

2 α-glucose → maltose + water

$$2C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11} + H_2O$$

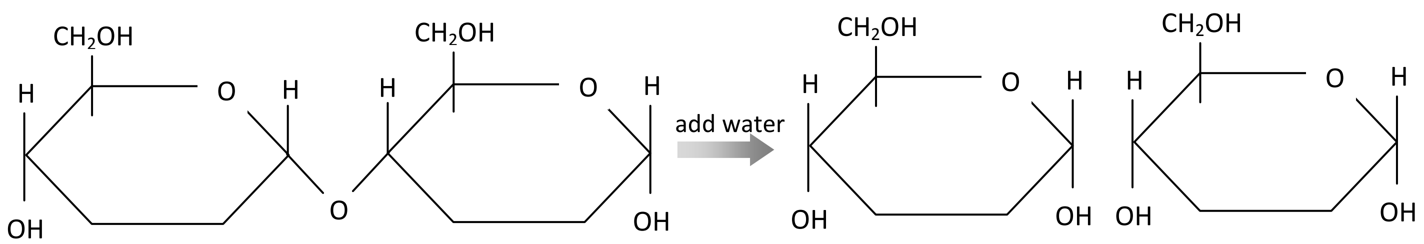
Condensation Reaction - a reaction where molecules join together which also produces water

Hydrolysis - splitting a molecule or breaking a bond by adding water



When the two molecules join, the hydroxyl group of one glucose molecule, and the hydrogen of the other bond to become water. The two molecules then join by forming a covalent *glycosidic* bond with the remaining oxygen.

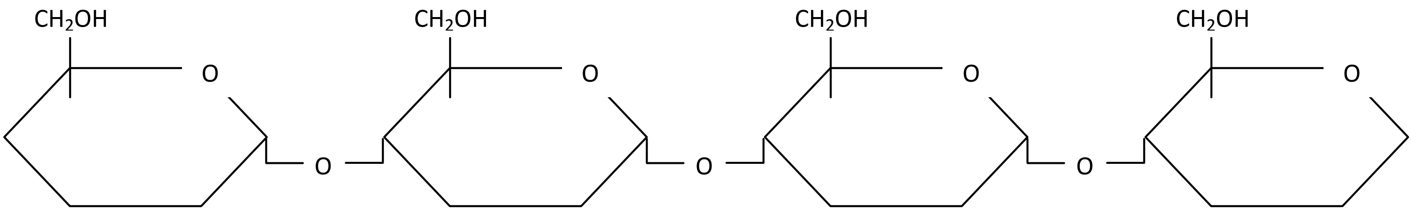
This reaction is *reversible*. A disaccharide can be split via **hydrolysis**. This is the breaking down of a bond by adding water, the opposite of the previous reaction.



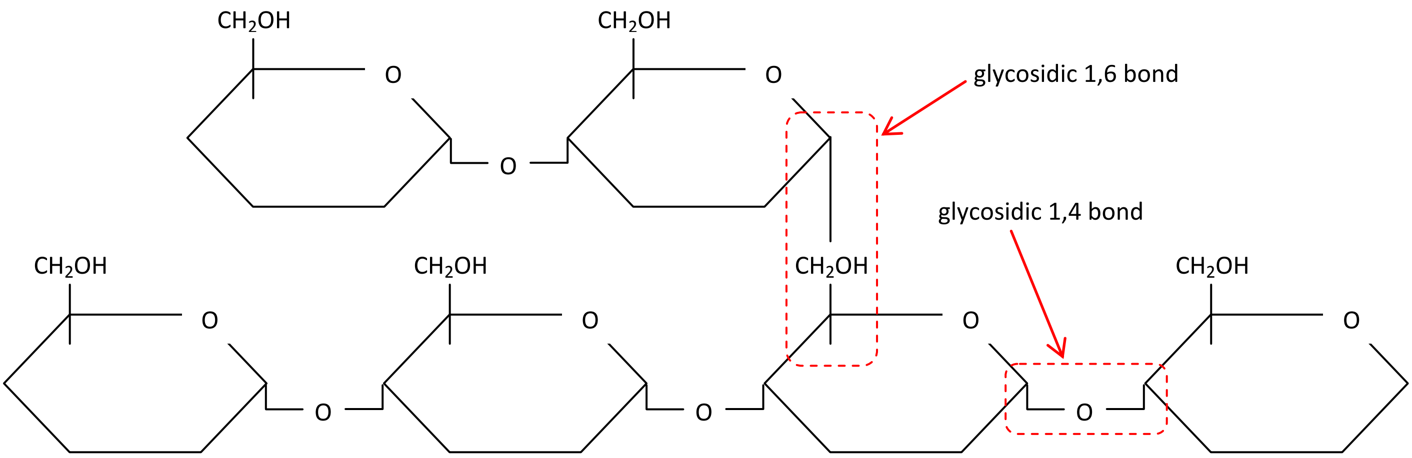
CARBOHYDRATES IN ENERGY STORAGE

Two α-glucose molecules will join together to form a disaccharide called *maltose*. When more and more of these glucose molecules join together to form a longer chain, a **polysaccharide** is formed. **Starch** is an energy store used by plants, which is a polysaccharide. It consists of two different types of molecules formed primarily of glucose…

The first of the molecules is **amylose**. Amylose is a long chain of α-glucose molecules joined together. Each glucose molecule is joined together by a covalent glycosidic **1,4** bond. This means they bond between the Carbon^{1} and Carbon ^{4} of adjacent molecules. Amylose is formed in a condensation reaction, and it forms a **helix** shape because of the **hydrogen bonding** in sugar molecules between the hydroxyl group.



The second molecule is **amylopectin**. This is a *branched* molecule which forms a glycosidic **1,6** bond. Structurally, the basic arrangement of amylopectin is the same as amylose, it consists of a long chain of glucose molecules bonded by the oxygen of the hydroxyl group. However, amylopectin has separate branches coming off of it which make it more 3D.



Starch is a mixture of amylose (approximately 20%) and amylopectin (80%) and is used as an energy store. It can be broken down back into glucose molecules, which can be used in **respiration** which releases energy.

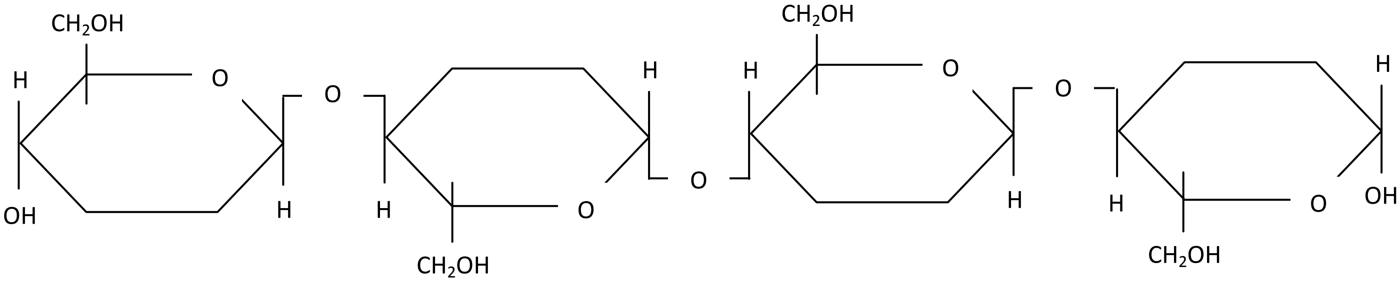
Starch is the polysaccharide product of glucose molecules in *plants*. In animals, however, **glycogen** is formed, and this is used as the energy store for animals. It is found especially in muscle cells and liver cells. The structure of glycogen (also named "animal starch") is the same as plant starch in that it is composed of α-glucose subunits, and it can also be broken down into glucose to be used in respiration to release energy. The only real structural difference with glycogen is that the glycosidic 1,4 chains are a lot shorter, and there are more branches of 1,6 bonds on each chain, so the molecule is more compacted.

Both glycogen and starch share a couple of features:

- ✓ They do not dissolve, so the stored glucose does not affect the water potential of the cell. This feature is vital in both animals and plants because glucose stored in a cell as free molecules would dissolve, reducing the water potential
- ✓ They hold glucose molecules in chains that can be easily broken (hydrogen bonds are weak) so the individual glucose molecules can be used in respiration to release energy

CARBOHYDRATES AS STRUCTURAL COMPONENTS

It is not only α-glucose molecules which can bond together. β-glucose molecules bond together in a very similar way, but instead of forming long coiled and branched chains, they form long, straight chains. The β-glucose molecules join in a series of condensation reactions.



Each alternate glucose molecule flips 180° to allow the bonding of the hydroxyl groups. This means that the CH_2OH alcohol group of every other molecule is above the carbon ring, and the others are below. When these molecules bond, the OH hydroxyl groups on Carbon[1] and Carbon[4] condense to form β1,4 glycosidic bonds. The rotation of each alternate glucose molecule means that they do not fit together like a helix, but instead remain in a straight chain.

These chains can consist of thousands and thousands of molecules. Such chains are called **cellulose** chains. Cellulose is a structural carbohydrate, which, like amylose, forms hydrogen H-bonds with each other to form **microfibrils**. Each microfibril consists of about 50 to 100 molecules. Microfibrils then bond together to form **macrofibrils** which are woven in layers to form structures, such as cell walls.