Carbohydrates

Carbohydrates (also called **saccharides**) are molecular compounds made from just three elements: carbon, hydrogen and oxygen. Monosaccharides (e.g. glucose) and disaccharides (e.g. sucrose) are relatively small molecules. They are often called **sugars**. Other carbohydrate molecules are very large (polysaccharides such as starch and cellulose).

Carbohydrates are:

- a source of energy for the body e.g. glucose and a store of energy, e.g. starch in plants
- building blocks for polysaccharides (giant carbohydrates), e.g. cellulose in plants and glycogen in the human body
- components of other molecules e.g. DNA, RNA, glycolipids, glycoproteins, ATP

Monosaccharides

Monosaccharides are the simplest carbohydrates and are often called single **sugars**. They are the building blocks from which all bigger carbohydrates are made.

Monosaccharides have the general molecular formula $(CH_2O)_n$, where *n* can be 3, 5 or 6. They can be classified according to the number of carbon atoms in a molecule:

n = 3	**trioses**, e.g. glyceraldehyde
n = 5	**pentoses**, e.g. ribose and deoxyribose ('pent' indicates 5)
n = 6	**hexoses**, e.g. fructose, glucose and galactose ('hex' indicates 6)

There is more than one molecule with the molecular formula $C_5H_{10}O_5$ and more than one with the molecular formula $C_6H_{12}O_6$. Molecules that have the same molecular formula but different structural formulae are called **structural isomers**.

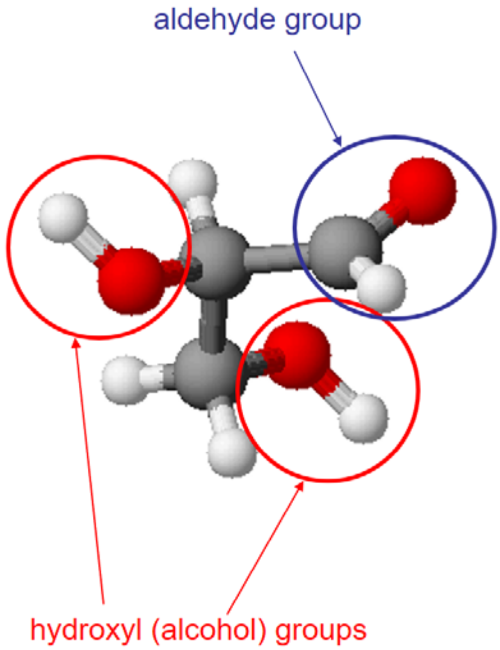
Glyceraldehyde's molecular formula is $C_3H_6O_3$. Its structural formula shows it contains an aldehyde group (-CHO) and two hydroxyl groups (-OH). The presence of an aldehyde group means that glyceraldehyde can also be classified as an **aldose**. It is a reducing sugar and gives a positive test with Benedict's reagent.

$CH_2OHCH(OH)CHO$ is oxidised by Benedict's reagent to $CH_2OHCH(OH)COOH$; the aldehyde group is oxidised to a carboxylic acid and Benedict's reagent is reduced (Cu^{2+} to Cu^{+}).

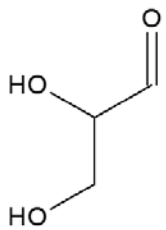
Glyceraldehyde, $C_3H_6O_3$

Glyceraldehyde is a triose because there are three carbon atoms in each molecule

It is also called an aldose because of the presence of an aldehyde group in the molecule

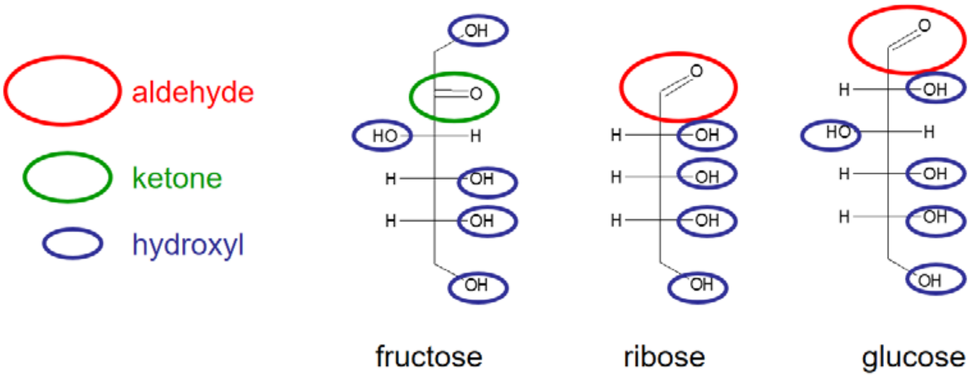


Its skeletal formula is



Pentoses and hexoses can exist in two forms: cyclic and non-cyclic. In the non-cyclic form their structural formulae show they contain either an aldehyde group or a ketone group.

Non-cyclic forms of carbohydrates

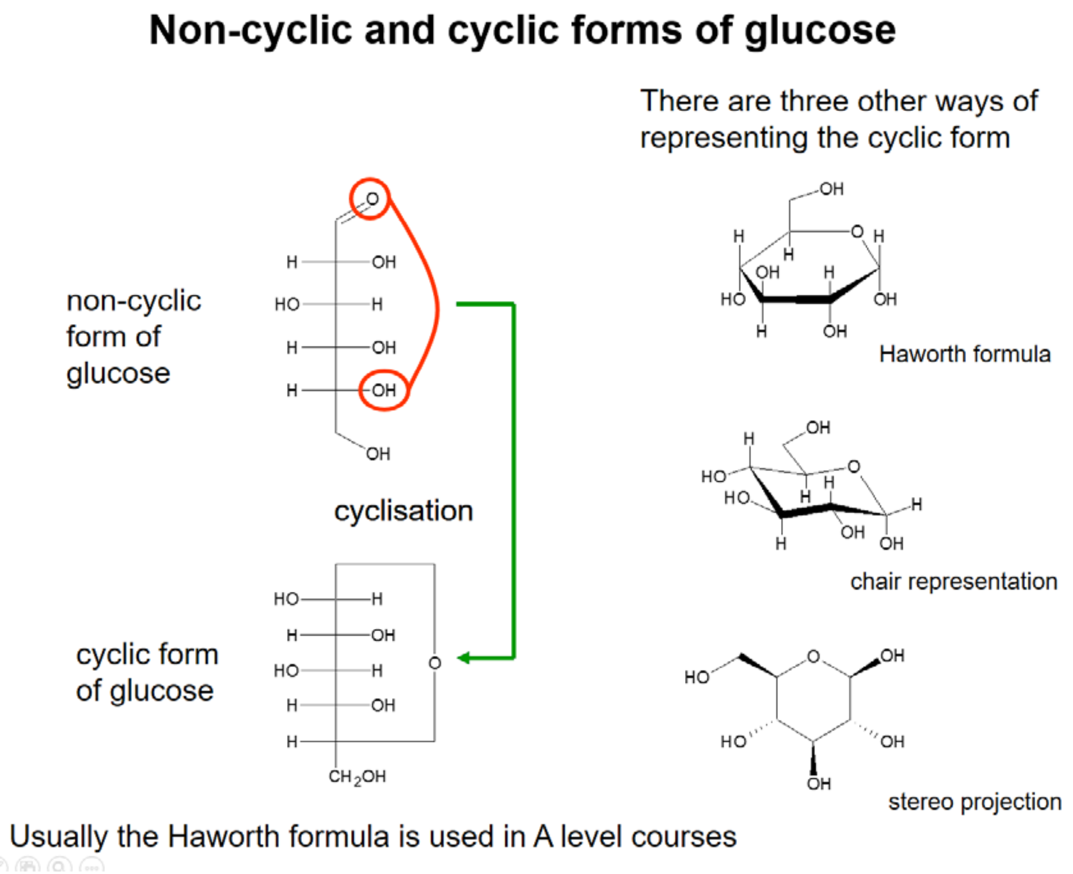


Here are the non-cyclic forms of:

- fructose (a ketose, i.e. contains a ketone group)
- ribose
- glucose

(both aldoses, i.e. contain an aldehyde group)

Monosaccharides containing the aldehyde group are classified as **aldoses**, and those with a ketone group are classified as **ketoses**. Aldoses are reducing sugars; ketoses are non-reducing sugars. This is important in understanding the reaction of sugars with Benedict's reagent.



However, in water pentoses and hexoses exist mainly in the cyclic form, and it is in this form that they combine to form larger saccharide molecules.

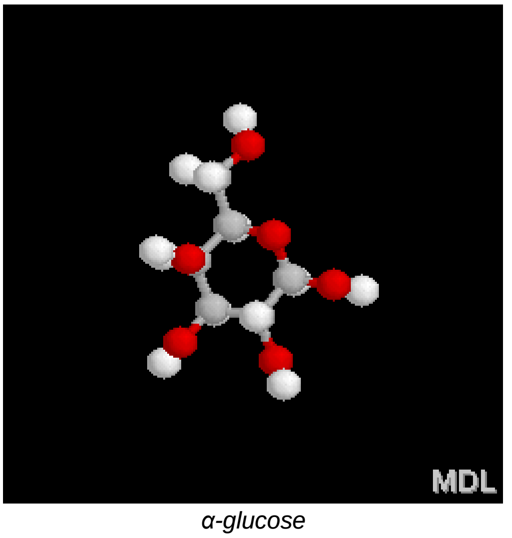
Glucose

Glucose is the most important carbohydrate fuel in human cells. Its concentration in the blood is about 1 gdm^{-3}. The small size and solubility in water of glucose molecules allows them to pass through the cell membrane into the cell. Energy is released when the molecules are metabolised ($C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$). This is part of the process of **respiration**.

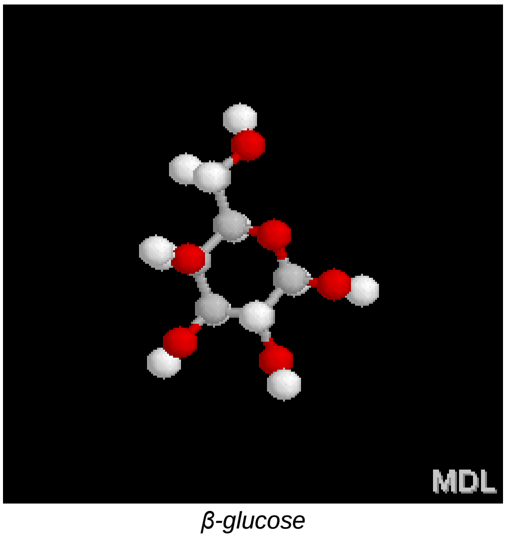
> See the topic about Respiration

> See the topic about In and out of cells

There are two forms of the cyclic glucose molecule: α-glucose and β-glucose.



α-glucose

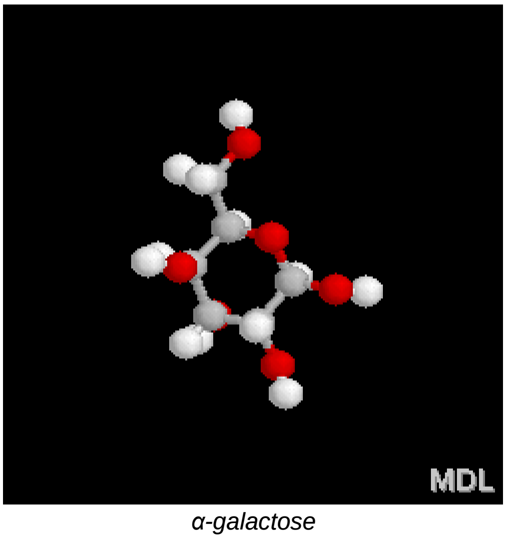


β-glucose

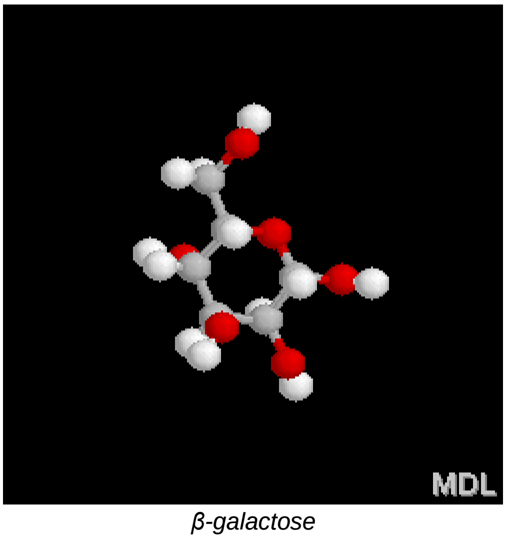
Two glucose molecules react to form the disaccharide **maltose**. **Starch** and **cellulose** are polysaccharides made up of glucose units.

Galactose

Galactose molecules look very similar to glucose molecules. They can also exist in α and β forms. Galactose reacts with glucose to make the disaccharide **lactose**.



α-galactose



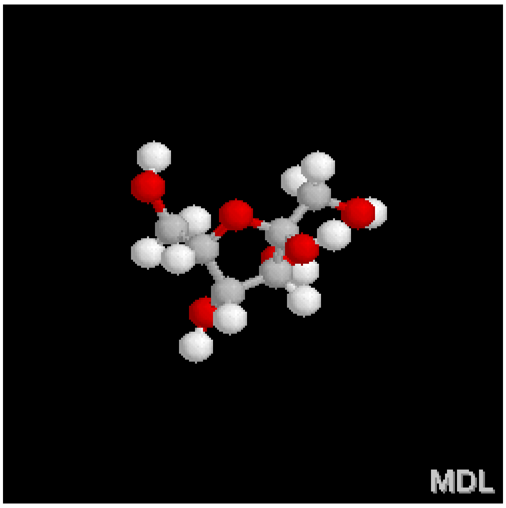
β-galactose

However, glucose and galactose cannot be easily converted into one another. Galactose cannot play the same part in respiration as glucose.

This comparison of glucose and galactose shows why the precise arrangement of atoms in a molecule (shown by the displayed formula) is so important.

Fructose

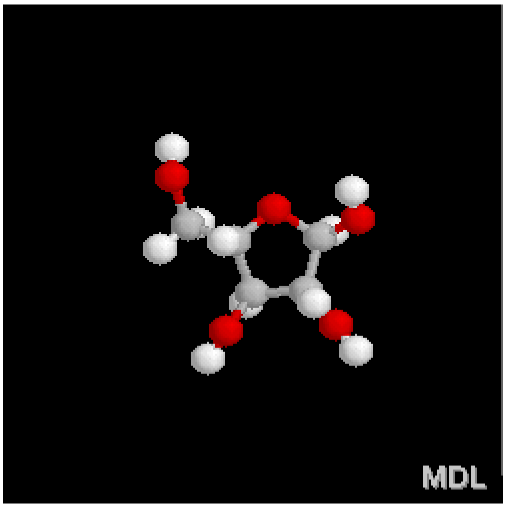
Fructose, glucose and galactose are all hexoses. However, whereas glucose and galactose are aldoses (reducing sugars), fructose is a ketose (a non-reducing sugar). It also has a five-atom ring rather than a six-atom ring. Fructose reacts with glucose to make the disaccharide **sucrose**.



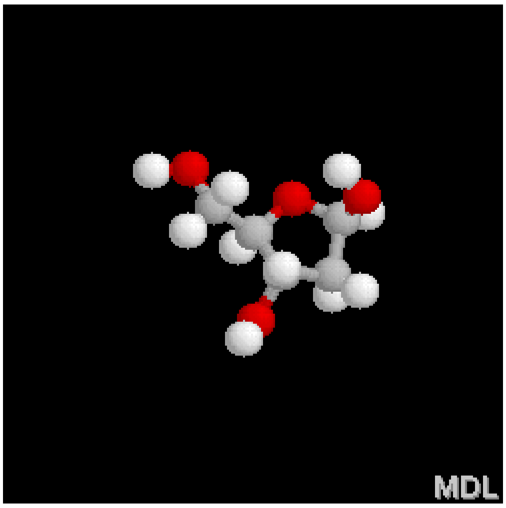
α-fructose

Ribose and deoxyribose

Ribose and deoxyribose are pentoses. The ribose unit forms part of a **nucleotide** of **RNA**. The deoxyribose unit forms part of the nucleotide of **DNA**.



Ribose



Deoxyribose

Disaccharides

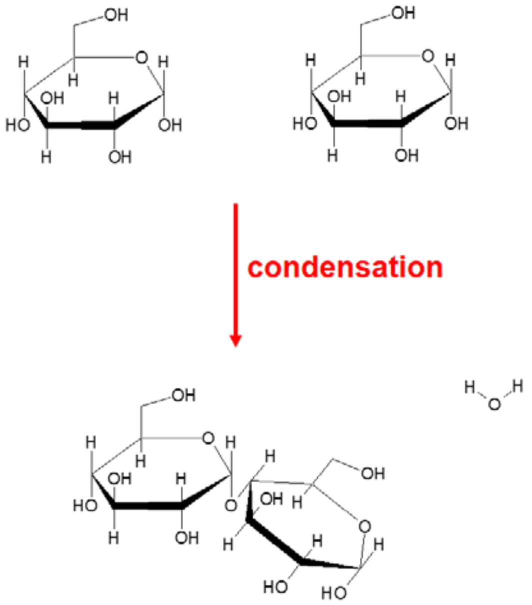
Monosaccharides are rare in nature. Most sugars found in nature are disaccharides. These form when two monosaccharides react.

Maltose – a disaccharide

A maltose molecule is formed from two α-glucose molecules

A water molecule splits out – this is a condensation reaction …

… and the two glucose units are linked by a glycosidic bond (or link)



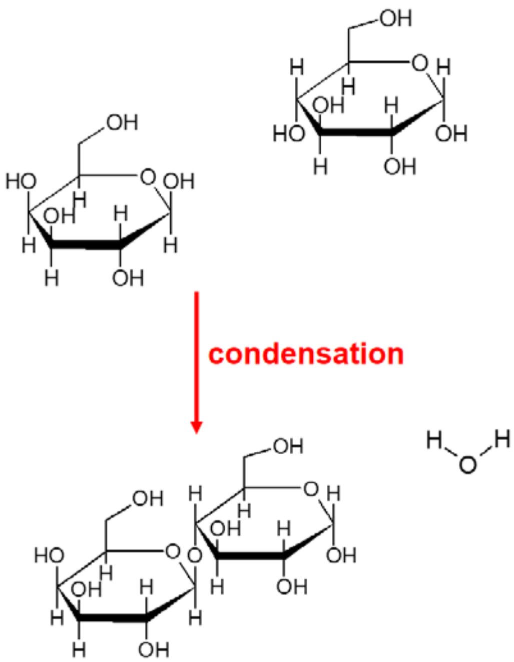
A **condensation reaction** takes place releasing water. This process requires energy. A **glycosidic bond** forms and holds the two monosaccharide units together.

Lactose – a disaccharide

An α-lactose molecule is formed from one β-galactose molecule and one α-glucose molecule

A water molecule splits out – this is a condensation reaction …

… and the two monosaccharide units are linked by a glycosidic bond (or link)



The three most important disaccharides are **sucrose**, **lactose** and **maltose**. They are formed from the a forms of the appropriate monosaccharides. Sucrose is a non-reducing sugar. Lactose and maltose are reducing sugars.

Disaccharide		**Monosaccharides**
sucrose	from	α-glucose + α-fructose
maltose	from	α-glucose + α-glucose
α-lactose *	from	α-glucose + β-galactose

* Lactose also exists in a beta form, which is made from β-galactose and β-glucose

Disaccharides are soluble in water, but they are too big to pass through the cell membrane by diffusion. They are broken down in the small intestine during digestion to give the smaller monosaccharides that pass into the blood and through cell membranes into cells.

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

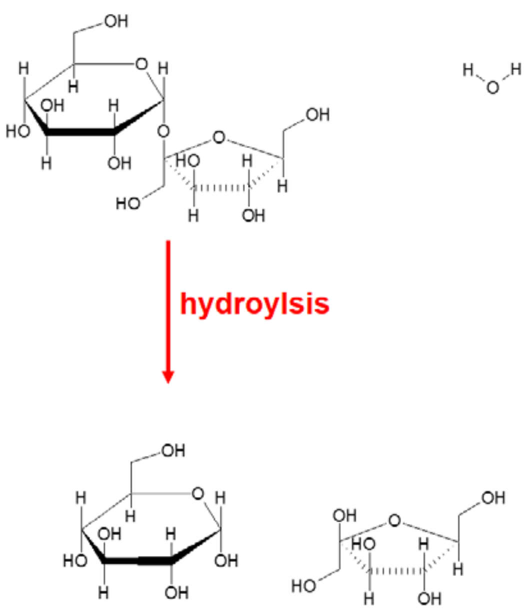
This is a **hydrolysis reaction** and is the reverse of a condensation reaction. It releases energy.

Hydrolysis of sucrose

A sucrose molecule reacts with a water molecule to form one α-glucose molecule and one α-fructose molecule

The glycosidic bond is broken in the reaction …

… and the two monoaccharide units are formed



Monosaccharides are used very quickly by cells. However, a cell may not need all the energy immediately and it may need to store it. Monosaccharides are converted into disaccharides in the cell by condensation reactions. Further condensation reactions result in the formation of **polysaccharides**. These are giant molecules which, importantly, are too big to escape from the cell. These are broken down by hydrolysis into monosaccharides when energy is needed by the cell.

Polysaccharides

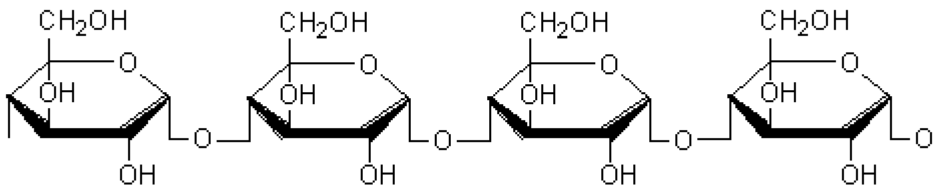
Monosaccharides can undergo a series of condensation reactions, adding one unit after another to the chain until very large molecules (polysaccharides) are formed. This is called **condensation polymerisation**, and the building blocks are called **monomers**. The properties of a polysaccharide molecule depend on:

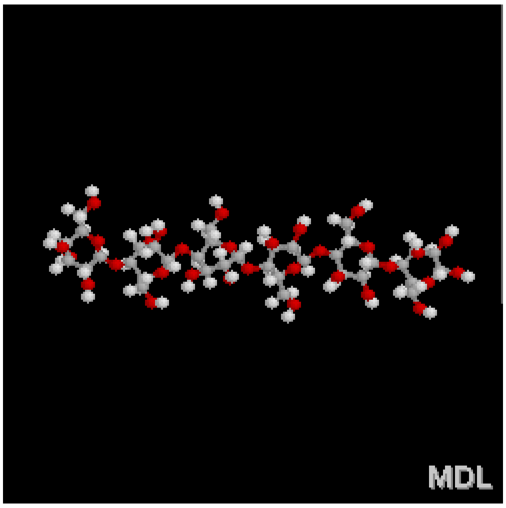
- its length (though they are usually very long)
- the extent of any branching (addition of units to the side of the chain rather than one of its ends)
- any folding which results in a more compact molecule
- whether the chain is 'straight' or 'coiled'

Starch

Starch is often produced in plants as a way of storing energy. It exists in two forms: **amylose** and **amylopectin**. Both are made from α-glucose. Amylose is an unbranched polymer of α-glucose. The molecules coil into a helical structure. It forms a colloidal suspension in hot water. Amylopectin is a branched polymer of α-glucose. It is completely insoluble in water.

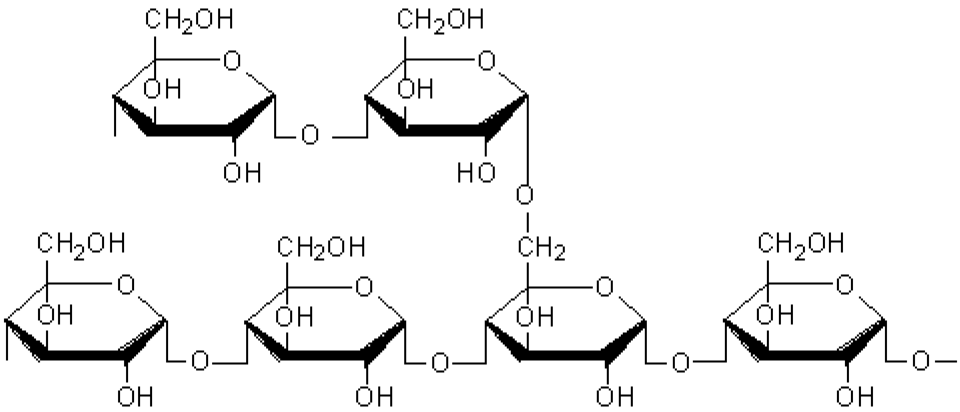
Section of the amylose molecule

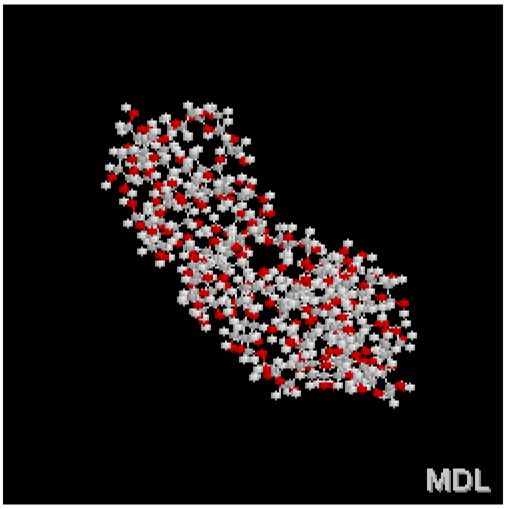




A section of the amylose molecule

Section of the amylopectin molecule





A section of the amylopectin molecule

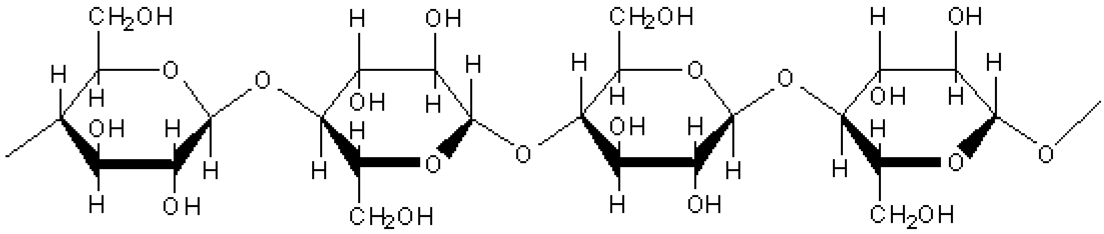
Glycogen

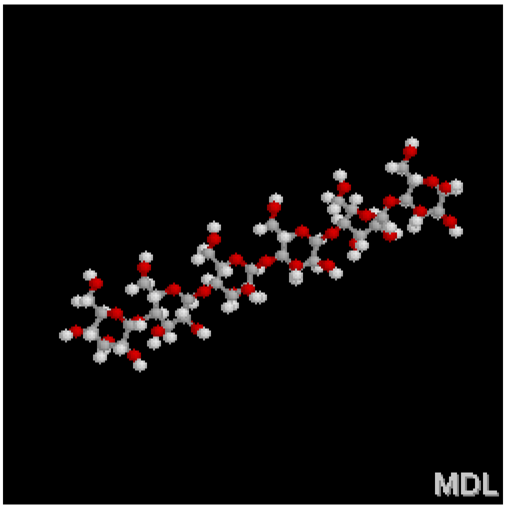
Glycogen is amylopectin with very short distances between the branching side-chains. Starch from plants is hydrolysed in the body to produce glucose. Glucose passes into the cell and is used in metabolism. Inside the cell, glucose can be polymerised to make glycogen which acts as a carbohydrate energy store.

Cellulose

Cellulose is a third polymer made from glucose. But this time it's made from β-glucose molecules and the polymer molecules are 'straight'.

Section of a cellulose molecule





Cellulose

Cellulose serves a very different purpose in nature to starch and glycogen. It makes up the cell walls in plant cells. These are much tougher than cell membranes. This toughness is due to the arrangement of glucose units in the polymer chain and the **hydrogen-bonding** between neighbouring chains.

Cellulose is not hydrolysed easily and, therefore, cannot be digested so it is not a source of energy for humans. The stomachs of Herbivores contain a specific enzyme called cellulase which enables them to digest cellulose.

Test your knowledge

Take quiz on *Carbohydrates*