

Topic 15 : Carbohydrates

Revised March 2002

Carbohydrates are compounds which contain Carbon, Hydrogen and Oxygen.

Example :

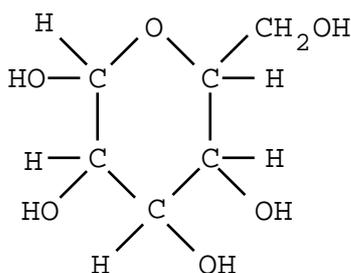
Name	Molecular formula
Glucose	$C_6H_{12}O_6$
Fructose	$C_6H_{12}O_6$
Sucrose	$C_{12}H_{22}O_{11}$
Maltose	$C_{12}H_{22}O_{11}$
Starch	$C_{600}H_{1000}O_{500}$
Cellulose	$C_{6000}H_{10000}O_{5000}$

Glucose, Fructose, Sucrose and Maltose are sugars : they are sweet and dissolve in water. Glucose, Fructose and Maltose are all **reducing sugars** : they turn Benedict's solution from blue to orange on heating. Sucrose is a non-reducing sugar : it has no effect on Benedict's solution.

Starch and Cellulose are not sweet and do not dissolve in water. When added to water, Starch forms little clumps of molecules which 'hang' in suspension. A beam of light passing through this mixture is scattered by the particles (the beam can be seen). Light beams are not scattered by sugar solutions. A suspension of one substance in another is called a **colloid**. All colloids scatter light (the 'Tyndall' effect).

Glucose and Fructose are isomers : they have the same molecular formula but a different structure (do not try to remember these structures).

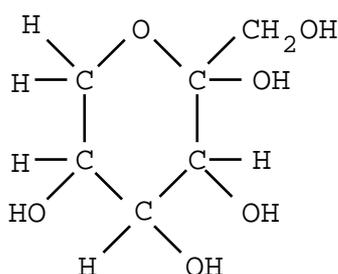
GLUCOSE



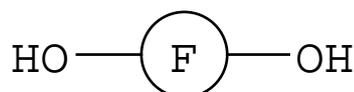
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to



FRUCTOSE



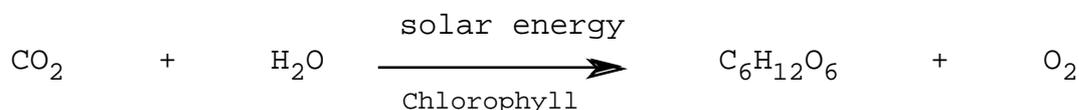
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Similarly, Sucrose and Maltose are isomers.

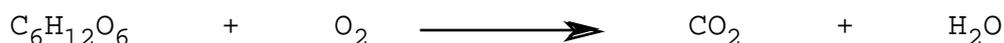
Photosynthesis

All carbohydrates are manufactured in plants. Glucose is formed by a reaction called photosynthesis : in the leaves Carbon dioxide and Water react together, in the presence of the green plant pigment Chlorophyll and using energy from the sun, to form Glucose and Oxygen. The reaction is endothermic : Chlorophyll absorbs the energy required from the sun-light and makes it available for the reaction :

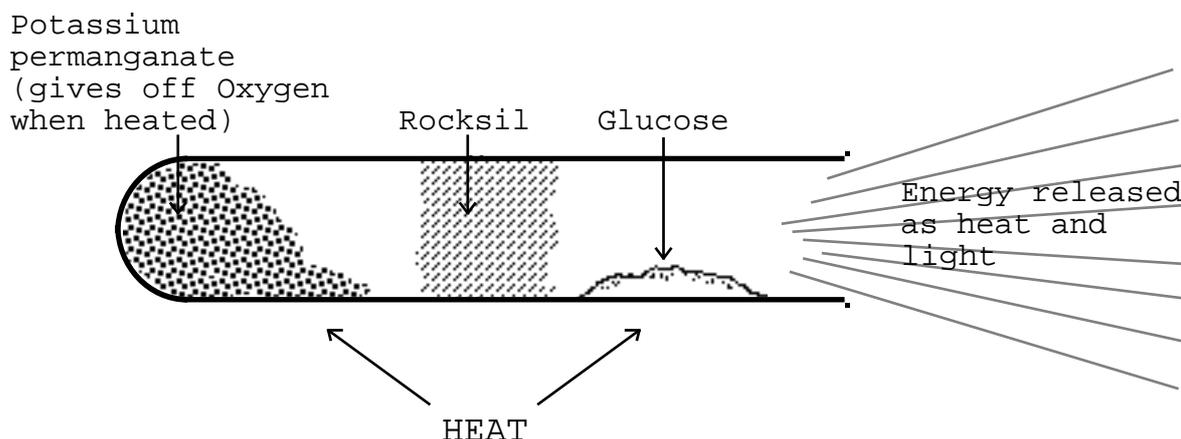


Once the Glucose has been formed it can be used by the plant to make all the other carbohydrates.

Photosynthesis is therefore very important to life on Earth as carbohydrates are an important food for animals. Fruits, root vegetables and sugar cane all contain sugars ; cereal crops and potatoes contain Starch ; grass and leaves contain Cellulose. The animal first converts the Carbohydrate into Glucose then obtains the energy it requires to move, grow and keep warm by burning Glucose, an exothermic reaction known as respiration :



This can be demonstrated as follows :



Notice that this experiment shows that carbohydrates contain Carbon (the Carbon in the Carbon dioxide could only have come from the Glucose) and Hydrogen (the Hydrogen in the Water could only have come from the Glucose).

Apart from making carbohydrates, photosynthesis also takes in Carbon dioxide and releases Oxygen and thus maintains the balance between these two gases in the atmosphere. Extensive clearing of forests reduces the amount of photosynthesis possible and therefore endangers this balance.

Other Carbohydrates Made from Glucose by the Plant

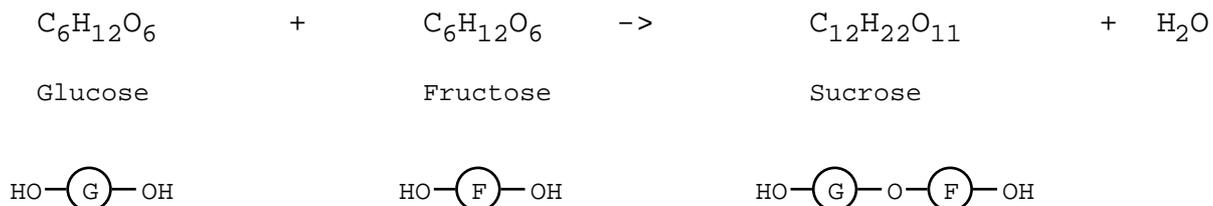
Fructose

Made by slight rearrangement of the atoms in the Glucose molecule.

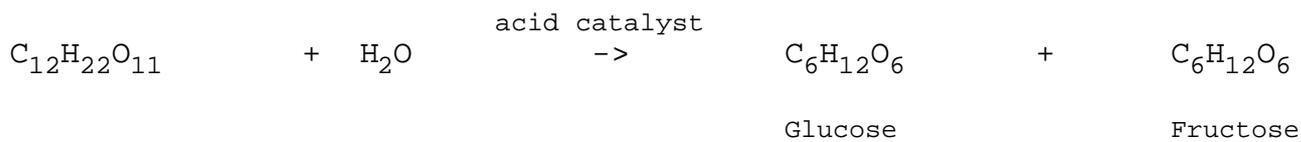
Sucrose (table sugar)

Made by a condensation reaction between Glucose and Fructose.

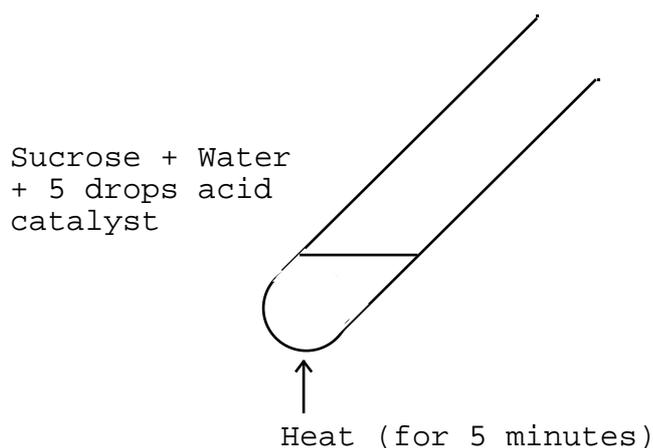
A **condensation reaction** is one in which a new bond is formed as a result of the elimination of a small molecule - usually Water.



We can reverse this reaction in the laboratory by reacting Sucrose with Water in the presence of a few drops of Hydrochloric acid catalyst :



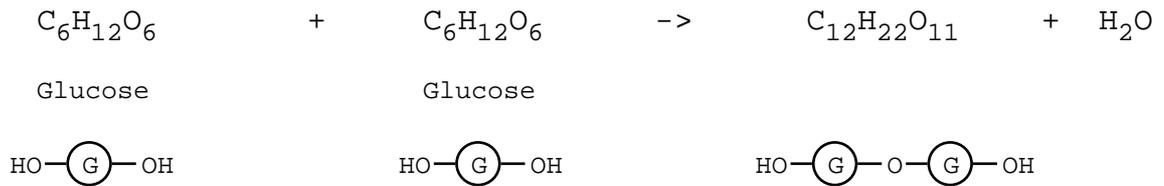
This is an example of **hydrolysis** : reaction with Water. The product of a hydrolysis reaction is called the **hydrolysate**.



After neutralising the acid catalyst in the hydrolysate with Sodium hydroxide solution a Benedict's test is positive showing that the original non-reducing Sucrose has been converted into reducing sugars.

Maltose

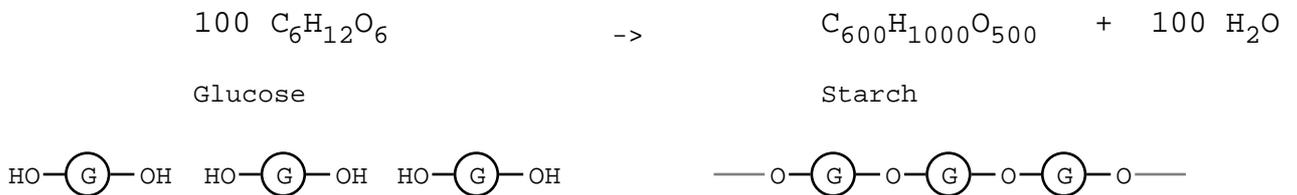
Made by a condensation reaction between two Glucose molecules.



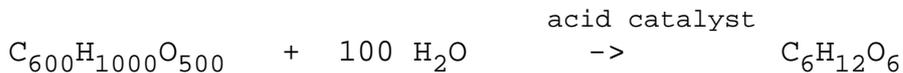
Sucrose and Maltose are often referred to as **disaccharides** (double sugars), Glucose and Fructose as **monosaccharides** (single sugars).

Starch

Made by condensation polymerisation between about 100 Glucose molecules.



Starch is therefore a natural condensation polymer made from Glucose monomers. We can reverse this reaction in the laboratory by reacting Starch with Water in the presence of a few drops of Hydrochloric acid catalyst (hydrolysis) :

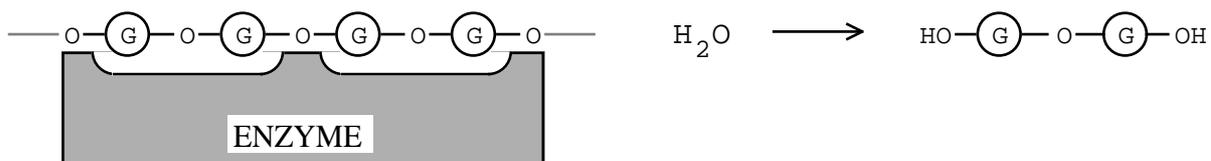


We can test whether hydrolysis *has* occurred by testing the hydrolysate either for reducing sugars (Benedict's test - remember to neutralise the acid) or for lack of Starch (Starch would turn Iodine blue/black if present).

This hydrolysis also occurs in our intestines (Digestion). The Starch molecules are broken down into smaller Glucose molecules which can pass through the gut wall. The body's catalyst is an **enzyme**, a natural catalyst. Enzymes are large, coiled-up protein molecules which have grooves on the outer surface. The Starch molecules fall into these grooves. The -O- links are strained and therefore break more easily. Water attacks. Glucose is formed.



Enzymes are highly specific catalysts. Each enzyme does ONE specific job only. There is another enzyme, in saliva, called Salivary Amylase. This converts Starch, by hydrolysis, to Maltose.



We can carry out this reaction in the laboratory by mixing a little Salivary amylase with some Starch in Water. By withdrawing a few drops every minute and testing for reducing sugars (Maltose) and lack of Starch we can time how long the reaction takes.

Cellulose

Made by condensation polymerisation of Glucose and so has a similar structure to Starch. Many more (about 1000) Glucose molecules are polymerised so the Cellulose molecule is much longer than Starch.

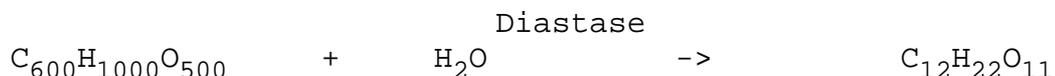
Starch and Cellulose are often referred to as **Polysaccharides** (many sugars)

Alcohols

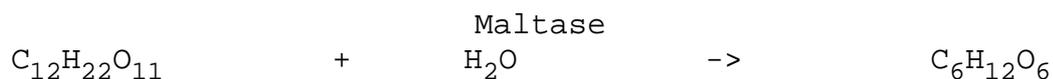
Alcohol can be regarded as a food, drug or poison. It makes us feel good. It can lead to aggressive behaviour. It slows down our reaction times and can lead to accidents. It destroys the liver and kidneys. It can become addictive and it can kill.

Alcohol can be made from any fruit or vegetable which is a source of Starch or sugars. The type of alcoholic drink depends on the source of carbohydrate. Wine can be made from grapes and other fruit. Whisky can be made from barley :

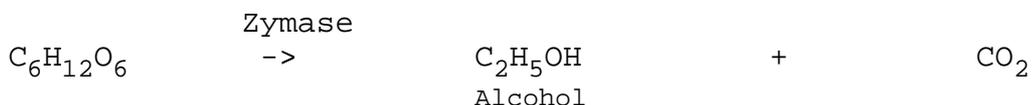
1. The barley is allowed to sprout when an enzyme, Diastase, present in the barley, catalyses the hydrolysis of Starch to Maltose.



2. Yeast, a living plant, is added to the Maltose solution. The enzyme, Maltase, present in the yeast, catalyses the hydrolysis of Maltose to Glucose.



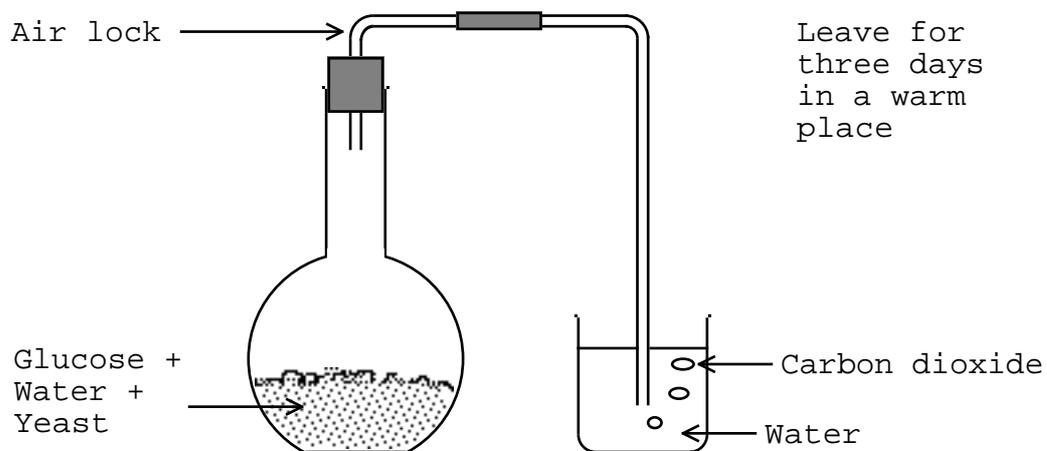
3. The enzyme, Zymase, present in the yeast, catalyses the conversion of Glucose into alcohol and Carbon dioxide, a reaction called **fermentation**.



To enable the enzymes to work properly the following conditions should be met :

1. The pH should be around 7 ; enzymes are attacked by acids or alkalis.
2. The temperature should be around 30-40 °C ; enzyme molecules break down at higher temperatures.

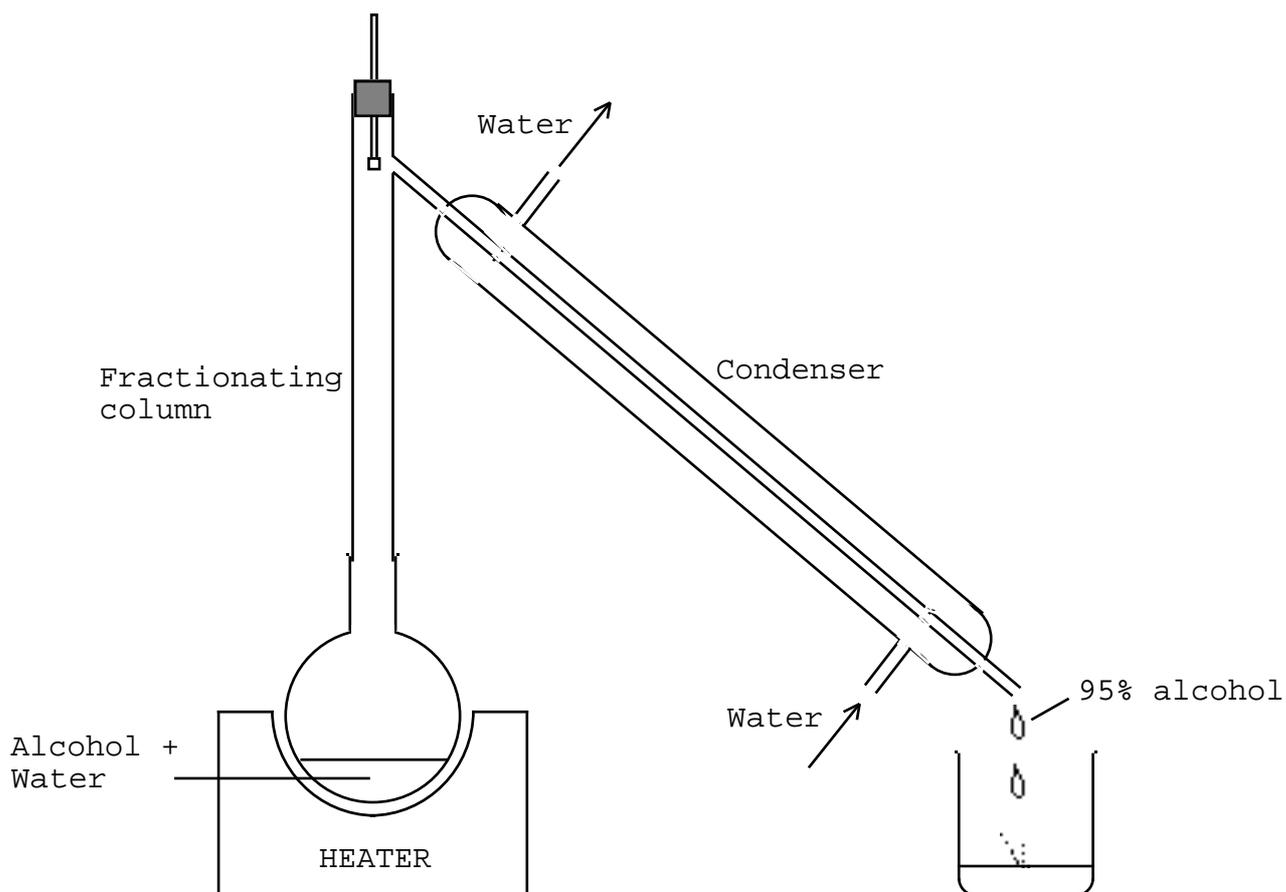
The fermentation of Glucose can be carried out in the laboratory :



The air lock is necessary to keep out Oxygen (Alcohol reacts with Oxygen to form vinegar, a dilute solution of Ethanoic acid)

The fermentation stops when the alcohol concentration reaches about 7%. This is because, at this concentration, the alcohol kills the yeast. The alcohol solution we obtain is therefore mostly Water !

The concentration of alcohol can be increased by distillation :



As the mixture boils, both alcohol and Water vapourise. The vapour contains more alcohol than Water since alcohol has the lower boiling point (78 °C). As the two fractions begins to rise up the fractionating column and begin to cool, the Water, with the highest boiling point (100 °C), condenses first and drops back into the flask. As the vapour moves further up the column it becomes more and more enriched in alcohol. When it reaches the top the vapour is 95% alcohol. It then enters the condenser, cools and becomes a liquid. The thermometer reads 78 °C until all the alcohol has been distilled then begins to rise.

Alcohol content of drinks

Cider, Babycham	2-7 %
Beer	3-6 %
Sherry	20 %
Spirits (Whisky, Gin etc)	30-60%

Other alcohols

The alcohol produced by fermentation is Ethanol. Ethanol is the second member of the alcohols (alkanols) homologous series :

Name	Molecular formula
Methanol	CH ₃ OH
Ethanol	C ₂ H ₅ OH
etc.	