Teacher information regarding the experiments “Carbohydrates in food”

In addition to fat and proteins, **carbohydrates** are – volume-wise - one of the most important nutrient groups. We will see that this group is comprised of a huge variety of substances, such as sweet compounds (glucose), fructose and sucrose (i.e. the sugar extracted from sugar beets or sugar cane, commonly used in households) which are all generally called “sugar”. Among the members of this group, we also find one of its smallest representatives, glycerol, a sugar alcohol. It can be found in wine, and can also be used as a frost protection agent. Green plants use the sunlight to produce glucose, the most abundant sugar, from carbon dioxide (CO_2) and water (H_2O), synthesising them just like in a small chemical plant. However, plants also like to store these sweet little treats as energy reserves. For this reason, they link up the sugar residues into long chains, such as starch, that form little grains in the plant cell. If necessary these reserves can be mobilised. If the plant has a different construction plan, it will take the same glucose components, but connect them in another way to build cellulose. Cellulose is the world’s biggest synthetic product: Plants produce about 2×10^{11} t per year as they utilise cellulose as a supporting and structural substance for their unique cell walls. Unfortunately, humans cannot utilise cellulose, however cows can - using bacteria in their paunches (a partial stomach that ruminants have). The micro-organisms that contribute to breaking down cellulose are part of the cow’s nutrition; they are transported together with the degraded plant material through the digestive tract and supply additional protein.

Correct nutrition: The importance of carbohydrates for a balanced diet

A balanced nutrition is a prerequisite for a healthy and effective organism. It is important to take in the necessary energy together with all vital nutrients. Carbohydrates, fats and proteins are the energy sources in the food. It is recommended that carbohydrates supply 50-55% of the energy demand, fats 30% and proteins 10-15%. In addition to nutrients that supply energy, i.e. fats, carbohydrates, and proteins, nutrients that do not supply any energy - such as vitamins, minerals, as well as other trace elements, dietary fibres, and water - are also important.

For the ingestion of carbohydrates it is important that the proportion of mono- or disaccharides, i.e. sugary food products, is not too high (if possible it should not exceed 10% of the total nutritional energy). Instead, it is better to ingest starchy food products, such as cereals, potatoes and vegetables. In addition to carbohydrates, these products have a higher content of vitamins and minerals. At the same time, they are fibre-rich and enhance bowel functions. In contrast to quickly digestible sugary food products, they remain in the digestive tract for a longer time. Carbohydrates linked to them are broken down more slowly, resulting in a longer-lasting feeling of satiation and a more constant blood-sugar level. Therefore we should eat less energy-rich food products, such as jam, sweets and cakes, and eat more vegetables, potatoes and whole-grain products.

Similar to the fat consumption, the same applies to the ingestion of carbohydrates: excess carbohydrates will be mainly stored as body-own depot fat.
There is also proof that eating sugary food significantly contributes to caries. Caries is a food-related chronic disease of the teeth. This disease does not have only one

cause, but is the result of several factors that coincide to lead to a carious tooth. How tooth-damaging (cariogenic) sugary food is, also depends on how long it stays in the mouth. This means that a sticky chewing sweet is highly cariogenic. We should not eat sweets here and there all day long, but rather concentrate the consumption of sweets to only a few occasions. Dental care is essential too of course.
As the common types of sugar damage the teeth, non-cariogenic artificial sweeteners are used.

How does caries develop?
Micro-organisms form bacterial plaque on the tooth's surface. The bacteria in the plaque break down the carbohydrates - mainly sucrose in the food and produce acids. These acids can attack the surface of the tooth, eventually forming a little hole in the tooth. This is particularly problematic for children as the enamel on their newly-formed teeth is especially vulnerable.

Chemical structure of carbohydrates

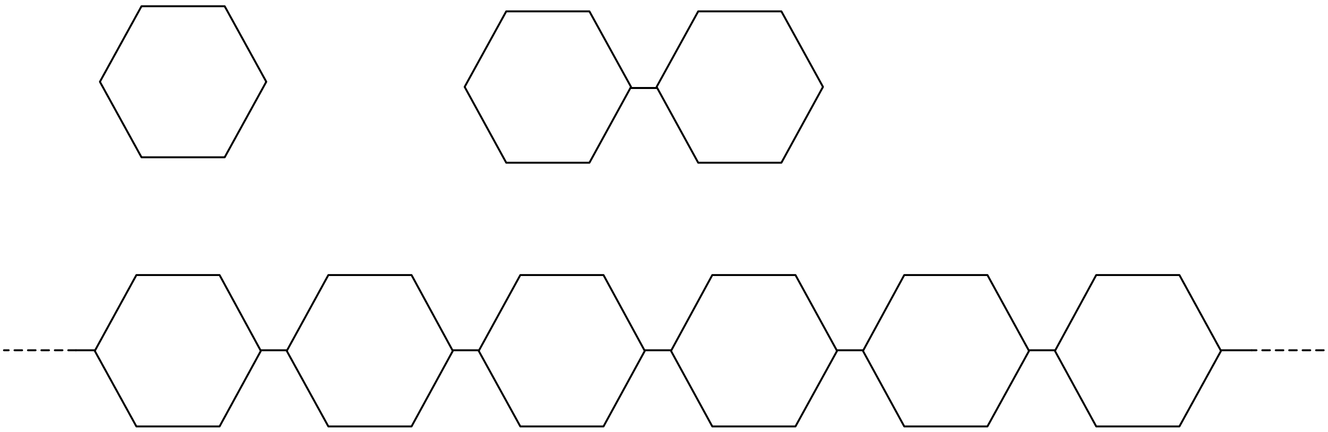
Don't worry! – Talking about the chemical structure here means to underline what all carbohydrates have in common and why they are called carbohydrates. The previously mentioned fats and proteins also follow a particular construction principal, but theirs is different from the one of carbohydrates. The structure or composition on the molecular level also determines the visible characteristics and behaviour of a substance – where a huge amount of molecules is accumulated at one place (for 1 g of glucose we talk about 3.5×10^{21} molecules!). Therefore chemists look at the structure of one molecule as a representative of the substance.

What do different carbohydrates have in common and what distinguishes them from each other? In the name, we find carbon (C) - the most important component of all organic matter - and hydrate, for water (H_2O). The combination of the two results in carbohydrate $C(H_2O)$. We have already mentioned that all carbohydrates originate from plants using photosynthesis to produce them from such simple inorganic sources as carbon dioxide and water. In addition to glucose, they also produce oxygen (O_2), which comes in handy for us. Without any special knowledge in chemistry, we can see how this calculation makes sense: $CO_2 + H_2O \rightarrow O_2 + C(H_2O)$. For glucose, we then only need 6 units of each ingredient and arrive at our photosynthesis equation:

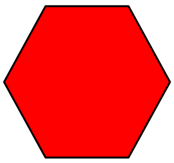
$$6\ CO_2 + 6\ H_2O \rightarrow 6\ O_2 + C_6H_{12}O_6.$$

$C_6H_{12}O_6$ is also the molecular formula of glucose. In glucose, all components are strongly linked and do not solely exist next to each other. Therefore the total number of each of the individual atoms (C, H, O) is noted bottom right as an index. The notation also means, for instance, that water consists of 2 hydrogen atoms and one oxygen atom that are linked to each other. Only through this link, a so-called **compound**, can we get a new substance with new characteristics. For example, bricks only become a house if we join them together with mortar according to a specific construction plan. Otherwise they just remain bricks.

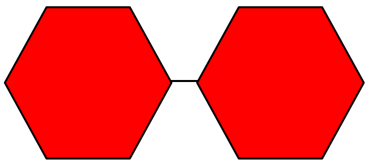
Glucose and the previously mentioned fructose are the most simple sugar components that can be – similar to beads – made into smaller or larger chains. This is also the case for proteins where these components are called amino acids. However, it is a special feature of carbohydrates that they can be linked in many different ways. Therefore the image with the beads might be slightly misleading as beads are round. A better image would be hexagons that can be linked up via (approximately) each corner. If you make a drawing of that and allow your imagination to run free, you can create on paper a large amount of different carbohydrates.



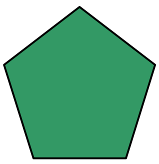
There is more than just glucose. In order to distinguish the monosaccharides from each other, we use different colours: Lactose, for instance, consists of galactose (**blue**) and glucose (**red**). Beet or cane sugar (sucrose) consists of glucose (**red**) and fructose (**green**). And fructose is here represented as a pentagon. If we link them up, we create so-called disaccharides - which basically means double sugar.



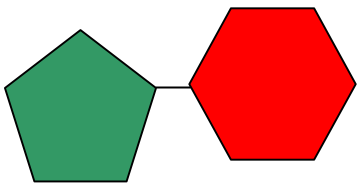
Glucose



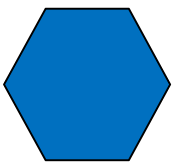
Maltose



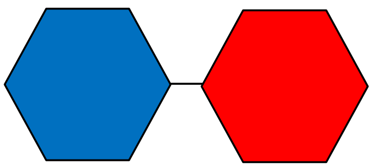
Fructose



Sucrose



Galactose



Lactose

Reality is slightly more complicated though. The compounds of pentagons and hexagons are not found on the paper level we have drawn, but rather point up- and downwards. From a spatial perspective, this means we can build even more structures, e.g. a threadlike (cellulose) or a spiral molecule (starch). But this is what a good construction kit – be it Lego, Fischer-Technik or a molecule kit – is made of: we want to come up with as many alternatives as possible. And a good molecular kit can do that too.

And if we continue with our construction work, via oligosaccharides ("multiple sugars") we finally arrive at polysaccharides. And these polysaccharides do not only consist of long chains, but can also have branches, such as amylopectin in starch. They can consist of a single type of components, such as starch or cellulose, or of two or more different ones, such as pectin – which has a very complex composition.

Carbohydrates in food and other everyday products

After this introduction into the architecture of carbohydrates, we want to mention a few important representatives of this group of substances. Some were already mentioned, above all glucose.

Glucose is an important energy supplier for us, but also for animals and plants. It quickly enters the blood stream and can be directly absorbed by the body. This is why athletes or students take Dextro Energy directly before a competition or test, respectively. Dextrose is another name for glucose or grape sugar.
As we cannot have an arbitrary amount of glucose in our blood our body regulates the blood sugar level. If that does not work properly, we are diabetic and have to eat sugar substitutes. These too partially belong to the carbohydrates, such as fructose and even glucitol (sorbitol), and provide us with energy. As opposed to this, sweeteners such as saccharin, cyclamate or aspartame are not carbohydrates and are extremely sweet only by coincidence.

Fructose is - similar to glucose - found in sweet fruit and honey and is used as sugar substitute for diabetics. With a larger number of fructose components we can build fructans. Among them, there is **inulin** which is called pre-biotic and is supposed to help our intestinal flora. Inulin can be found in chicory; it is added to pre-biotic yoghurt or can be used in low-fat margarines to bind water thus giving the margarine a fattier consistency.

Sucrose is produced from sugar cane or sugar beets. In European countries, we mainly use sugar beets. The sugar is extracted with hot water from beets that have been chopped into small pieces. During this process, also other ingredient substances will dissolve. Over several sophisticated steps, these substances begin to precipitate and eventually nice white sugar crystallizes. It is often stated that these processes involve bleaching, but that is far from the truth. Refined sugar is probably the purest compound we can buy in grocery stores. The so-called brown raw sugar is simply still heavily contaminated by substances produced during the boiling of the beet juice.
In the intestines, enzymes quickly break down sucrose into glucose and fructose which then can be immediately reabsorbed.

Lactose is the sugar in the milk. This is also where the name comes from. It consists of galactose and glucose. Lactose does not taste as sweet as the above mentioned types of sugar. If we would organise them according to their sweetness, we would arrive at the following order: fructose > sucrose > glucose > lactose.

Starch is a polysaccharide, consisting of a large number of connected glucose molecules. There are two components with different structures: **amylose** with up to 6000 glucose components being linked into a long, spiral chain (helix), and amylopectin which is branched like a Christmas tree and consists of 60,000 to 600,000 glucoses. These two components are then neatly arranged in the starch grain. With the microscope, we can nicely see- especially for potato starch – the layering of the growth rings. Starch is an important energy provider for the human body. Digestion enzymes break down starch into individual glucose components which are then used in the metabolism for energy production. Our saliva contains one of these enzymes. This is why we notice a sweet taste after chewing bread – which contains starch - for a longer time.
As plants use starch as an energy reserve, large amounts of starch are found in seeds or other storage organs, such as in potatoes. The main starch suppliers are potatoes, corn and wheat. Similar to beet sugar, corn starch is one of the purest, most uniform substances that we can buy in the grocery store. In contrast to flour which also has starch as the main component, corn starch no longer contains any minerals or proteins. We use starch mainly because of its thickening effect (soups, sauces) or for the production of solid gels (pudding). Starch can also be used for gluing (starch glue). Secondary starch products are also widely used, in paper production for instance.

In addition to starch and **cellulose**, there are several other polysaccharides that are used as thickeners in food products, such as **pectin**, **locust bean gum** (galactomannan) or **xanthan gum**.

How do we know what food is sweet and what food products contain sugar or starch? As previously mentioned, it is very important for our body to ingest the correct nutrients. As it is difficult to see from the outside what substances they contain, we need methods to figure that out. Only by knowing the composition of our food, can we combine foods for a balanced diet. Using the following experiments, we want to illustrate some of the detection methods.

Now let us take a closer look at the individual experiments:

Explanation regarding the experiment “Evidence of starch”

Starch is commonly composed of 70-80% amylopectin and 20-30% amylose. In the hollow spaces of the amylose helix, different substances can be included; they only have to have the correct form to properly fit in the hollow spaces.
We use an iodine solution to detect starch. Starch and iodine form an inclusion compound (iodine sits on the inside of the chain, in the interior of the helix) resulting in a strong blue colour. The iodine atoms (symbol for iodine = I) take each other by their hands and form a long chain in the amylose tunnel. In this manner they become highly excitable and can swallow (absorb) the colour orange from the white sunlight – which the human eye then perceives as blue-violet (this is the remaining mix of the rainbow spectrum after the colour orange is absorbed). The iodine solution itself is

brown. You might know that from iodine tincture that is commonly used to disinfect wounds.

The widely branched amylopectin can only form short helical sections that can then only accommodate comparatively short iodine chains. Therefore it produces only a slightly red colour.

If we drop iodine solution directly on food the stain looks almost black - in the case of a positive reaction. We can only see the actual colour shade if we add iodine solution to a starch solution or dispersion and, if necessary, dilute the solution with water until we clearly see the blue-violet colour against the light.

Conclusion: It is the amylose that causes the dark blue shade of the brown iodine.

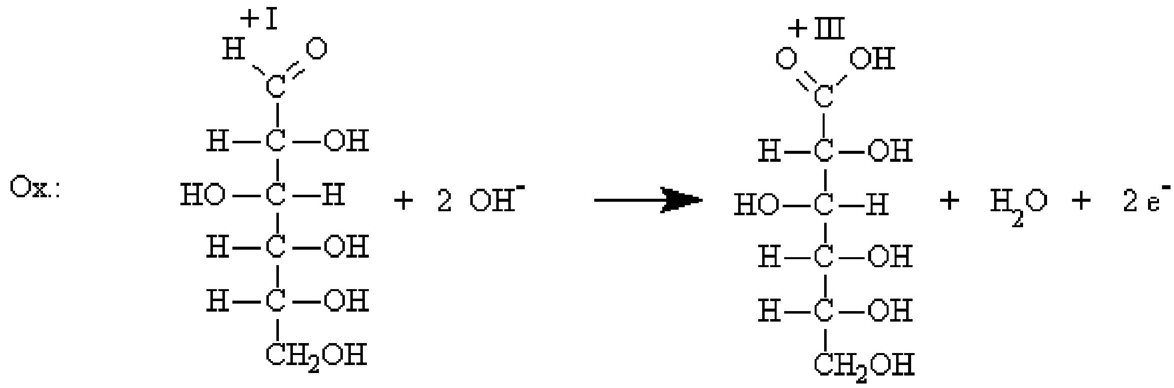
Explanation regarding the experiment
"Evidence of sugar"

This reaction is a classical detection of reducing sugars and is named after Hermann von Fehling (1811-1885), a chemistry professor from Stuttgart, Germany.
"Reducing" here means a specific chemical characteristic typical for most carbohydrates. In order to realize this characteristic, the sugar needs a (reaction) partner that can be reduced. We use copper salts that form a nice blue solution. This so-called Fehling's solution – which is mixed together prior to the experiment using two solutions – also containing several other ingredients that create an appropriate reaction medium, e.g. an alkaline pH-value (opposite of acid). If we add some heat, the glucose will reduce the blue copper (II) ions (Cu^{2+} ions) to copper (I) ions (Cu^{+} ions) that are no longer soluble and form an orange-red precipitation. And of course the glucose does not get off scot-free. It will oxidise.

Conclusion: With an orange or red precipitation we can detect the presence of sugar.

As opposed to this, sucrose does not show any reaction as glucose and fructose are linked up in a way that prevents this reaction. If we briefly heat sucrose with acid we get the two components that are the basis of the detection reaction.

Chemists summarize the process in the following formula:



Red.: $2\,Cu^{2+} + 2\,OH^- + 2\,e^- \longrightarrow Cu_2O\,(s) + H_2O$

Redox.: $2\,Cu^{2+} + 2\,RCHO + 4\,OH^- \longrightarrow Cu_2O + 2\,RCOOH + 2\,H_2O$

Special knowledge:

Remark: Fehling's assay uses the reducing reactivity of sugars (=aldehydes) in contrast to Cu^{2+} ions that in alkaline solutions have a weak oxidizing effect. In addition to copper ions, Fehling's solution contains tartrate ions as complexing agents that keep the copper ions in solution. Without tartrate ions, a precipitation of $Cu(OH)_2$ would form in alkaline solutions. The tartrate ions are not able to form a complex with the Cu^+ ions. Therefore the reaction from Cu^{2+} to Cu^+ due to reducing sugars results in red precipitation of Cu_2O.

Explanation regarding the experiment "Breakdown of Starch by Saliva"

Above we have mentioned that our saliva contains an enzyme (an amylase) that breaks down (hydrolyses) starch chains into their individual components. Therefore bread tastes sweet if we chew it for some time. This is the first step of the digestion of nutrients with the help of saliva.

Part B of the starch degradation experiment aims at detecting the released glucose components, Part A at detecting that starch disappears. The results of both detection experiments complement each other.

Part A of the experiment shows that saliva breaks down starch. We commonly use the iodine test to detect starch. The iodine solution colours the starch intensely blue. After the starch is broken down, the blue colour loses its intensity too. It can even completely disappear.
(Notice: The reducing sugar glucose released from starch during digestion can also consume the iodine reagent (forming iodide ions, which are colourless!). Therefore, fresh iodine must be added to check whether starch can be detected anymore. But the disappearance of the blue-violet colour is in any case an indication of starch hydrolysis, since the consumption of iodine is caused by the degradation product glucose.)

Part B of the experiment shows that starch consists of sugar components. With saliva, starch is broken down into glucose which can be detected using Fehling's reagent (orange colouring, see above). For a starch suspension without saliva, the detection fails and the solution remains blue.

Explanation regarding the experiment "Making a Sheet from starch"

Starch is not only an important source of carbohydrates for the human body, starch and its derivatives have a large number of other uses. In addition to the food industry, it is increasingly used for technical applications, such as in the paper industry.

For the production of a "starch sheet", one starch characteristic is of particular interest: starch in watery solutions forms – when drying – films. These films are rather brittle, but this can be compensated by using so called plasticisers (e.g. glycerol). Glycerol slips between the starch and prevents the formation of brittle crystalline starch. In addition, glycerol is hygroscopic, i.e. attracting water. It prevents the starch sheet from drying out completely and keeps it flexible.
Special starch sheets are used for overhead transparencies, for instance.

Regarding the experiment, please note: If several pupils work together you should prepare a larger charge in order to produce more sheet. You could also add food colourant to colour the foil. Avoid the formation of bubbles during moulding.