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# Too Sweet to be True

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**Abstract.** Dealing with biological topics in school can be challenging for both teachers and students despite a direct connection to their daily lives and existing pre-knowledge. This applies to carbohydrates, which can be treated in biology with regard to health education, making it possible to combine the conveyance of knowledge with the practical example of sugars and sweeteners. Carbohydrates are required for energy production by both animals and plants. Their general molecular construction, however, is similar. Sugars are also carbohydrates with the most important simple ones being Glucose and Fructose (monosaccharides). Due to their natural sweetness there are used in foods, but since obesity and diabetes have increased dramatically in the western countries, the discovery of synthetic sweeteners was a great success. When developing synthetic sweeteners, factors such as toxicity, stability and cost aside from taste have to be considered. This article aims at giving necessary, yet simple background knowledge needed for holding a thorough lesson or even teaching unit on the topic of carbohydrates as exemplified by sugars. It is rounded off by suggestions how to conduct the teaching with concrete experiments, for each of which a worksheet is provided at the end.

**Keywords:** teaching unit; experiments; synthetic sweeteners; chemistry; biology

## 1. Background

This section will focus on the basics of carbohydrates and sugars before presenting specific examples of sweeteners that are commonly found in everyone's life.

### *1.1 Carbohydrates*

Carbohydrates play an important role in our lives at all levels (Gibbs, 1970, p. 164). Both plants and invertebrates rely on them for structural materials as plants reserve carbohydrate as starch and higher animals have something similar, namely glycogen. It supplies energy for muscular activity and is stored in the liver. Carbohydrates have twice as many hydrogen as oxygen atoms in their molecules, which is depicted in the general formula Cx (H2O)y,. The molecules also have the property to form rings which can be extended to build other sugars. Most importantly, we have pentoses with five carbon atoms and hexoses with six carbon atoms. (Gibbs, 1970, p. 164).

Monosaccharides are carbohydrates that cannot be broken down in simpler sugars. Examples for monosaccharides would be ribose or xylose for the group of pentoses and glucose, mannose and galactose for the hexoses. Disaccharides, accordingly, give two molecules of monosaccharides when hydrolysed; examples are sucrose, maltose and lactose. Raffinose is a trisaccharid, thus consisting of three monosaccharides. Every carbohydrate of more than three molecules of monosaccharides is called a polysaccharide, such as cellulose for instance. (Gibbs, 1970, p. 164).

Fructose is the sweetest of the hexoses and found along glucose in honey. The hydrolysis of cane sugar yields glucose and fructose (Gibbs, 1970, p. 165), whereas glucose is only manufactured by hydrolysis of starch (ibid., p. 166). Sucrose, the most common disaccharide (Bruice, 2010, p. 963), is ordinary sugar (also called table sugar) and exists solely in one form as opposed to glucose, for example, which can be present as either α- or β- modifications (Gibbs, 1970, p. 168). Since sucrose crystallizes out of solution extremely well, it was discovered quite early in A.D. 640 (ibid., p. 169). This kind of sugar is obtained from sugar beets and sugar cane, with the annual worldwide production amounting to 90 million tons (Bruice, 2010, p. 963).

The glucose stores in plants and animals, starch and glycogen respectively, are "polycondensation products of α-glucose with 1,4-linkages" (Gibbs, 1970, p. 169); the amylose-part of starch (about 20%) consists of linear molecules while the amylopectin-fraction (about 80%) of starch is made up of branched molecules, just like glycogen (ibid.). Starch is a major component of flour, potatoes, rice, beans, corn and peas (Bruice, 2010, p. 964). The mixture of amylose and amylopectin makes it a product of two different polysaccharides (ibid.). As living cells oxidize glucose "in the first of a series of processes that provide them with energy" (Bruice, 2010, p. 965), glycogen is the result of converting excess glucose in that kind of polymer in order to store it. Plants basically do the same, but convert the excess glucose to starch (ibid.).

### *1.2 Taste*

The human taste sensory system makes for a great deal of quality in our lives (Saulo, 2005, p. 1). Already infants favour sweetness when they get to choose from all the basic tastes and this preference remains throughout the whole life, which is why "sweet foods are by far the most popular treats" (ibid.).
"For a molecule to taste sweet, it must bind to a receptor on a taste bud cell of the tongue" (Bruice, 2010, p. 970). This then causes nerve impulses and the perception of sweetness (ibid.). Every synthetic sweetener has an individual structure, which shows that the "sensation of sweetness is not induced by a single molecular shape" (Bruice, 2010, p. 972). Additionally, the sensation is a result of a complex cascade whose individual events have not been entirely understood yet (Portmann & Kilcast, 1996, p. 291).

The sensation of taste relies on chemoreceptors, which bring about neural signals once they bind to particular chemicals in the environment (Sherwood, 2005, p. 175). Next to taste (gustation), also smell (olfaction) influences the flow of digestive juices and a person's appetite greatly (ibid.). Actually, these two "chemical senses provide a 'quality control' checkpoint for substances available for ingestion" (ibid.).

Coming to the mechanism of tasting, the chemoreceptors are packages in taste buds (see Figure 1), of which there are 10,000 in the oral cavity and the throat in total; most of them, however, are placed on the upper surface of the tongue (Sherwood, 2005, p. 175). A taste bud is made up of about 50 taste receptor cells, which are accompanied by supporting cells (ibid.). Taste receptor cells "are modified epithelial cells with many surface folds (microvilli)" (ibid., p. 177), so that there is an increased surface area available to oral contents (Sherwood, 2005, p. 177). The plasma membrane of the microvilli contains receptor binding sites for certain chemical molecules, which, after all, only react to chemicals in solution, so either liquids or solids dissolved in saliva (ibid.). In order to allow for contact between fluids and the receptor cells, every taste bud has a small opening, called taste pore (ibid.). Due to permanent contact to the environment, taste receptors only live for about 10 days (ibid.).

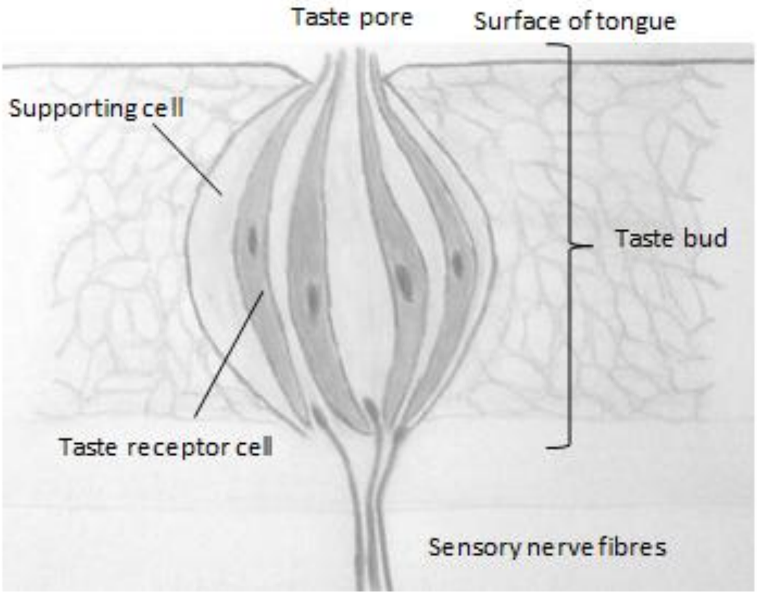


**Figure 1: Sketch of a taste bud (based on Sherwood, 2005, p. 171).**

The taste sensation is brought about by a taste-provoking chemical, the tastant, which produces a receptor potential as soon as it is bound (Sherwood, 2005, p. 177). This, in turn, initiates action potentials in afferent nerve fibres that lead to the brain stem and the thalamus, before it reaches the cortical gustatory area in the parietal lobe (ibid.). Taste signals are also sent to the hypothalamus and the limbic system in order to evoke affective dimensions such as 'pleasant' or 'unpleasant' taste and to process behavioural associations (ibid.). Even though taste buds are able to discriminate among thousands of different taste sensations, they are actually all just combinations of the four primary tastes salty, sour, sweet and bitter (Sherwood, 2005, p. 177). A salty taste is provoked by chemical salts like NaCl (ibid.). Sour, on the other hand, is caused by acids, such as citric acid (ibid.). Sweetness is induced by the special configuration of glucose (Sherwood, 2005, p. 177). Besides glucose, other organic molecules with a similar structure (e.g. sweeteners) can interact with those particular receptor binding sites (ibid.). A bitter taste is made for by numerous chemical groups, for example, alkaloids or poisonous substances, which functions as a protection mechanism (ibid.). The ability to distinguish between different tastes is based on the receptor cells' response of varying degrees to all four primary tastes (ibid.). Recently, a fifth modality of taste has come to be known as "umami", which resembles a "meaty, mouth-filling taste of L-amino acids such as glutamate" (Pocock et al., 2013, p. 226). As they are especially responsive to a particular taste, subtle differences in stimulation patterns of the taste buds result in a distinct taste (Sherwood, 2005, p. 177).

### *1.3 Sweeteners*

Sugars differ in their degree of sweetness, as glucose is set to be 1.00; compared to that, sucrose has a sweetness degree of 1.45 and fructose the highest one with 1.65 (Bruice, 2010, p. 970). When it comes to developing synthetic sweeteners, there are also factors such as toxicity, stability and cost aside from taste (ibid., p. 971). In order to be acknowledged as an alternative sweetener, the substance has to share the taste quality of sucrose. "This implies […] a clean sweet taste, with a quick onset and a minimum persistence" (Portmann & Kilcast, 1996, p. 291).
Among sweeteners, it is important to differentiate between nutritive and non-nutritive sweeteners, with the former ones providing energy and the latter ones only providing little to no energy (Shwide-Slavin et al., 2012, p. 104). A feature of non-nutritive sweeteners is their high degree of sweetness, which can be a several hundred to several thousand times as much as sucrose (ibid.). Even though they are incredibly sweet, they do not really provide any calories as they are used in such small doses (ibid.).

Saccharin was the first sweetener to be discovered and is 300 times sweeter than glucose. It carries only little caloric value, which is why it has come to be recognized as a substitute for sucrose. Due to its characteristics, it might help prevent western-world problems that are caused by the overconsumption of sugar like obesity, heart diseases and dental decay. It has also proven useful to people with diabetes (Bruice, 2010, p. 971). Being the only non-caloric sweetener to be prepared from sucrose, saccharin is also special since it was the first sweetener to be found a century ago (Saulo, 2005, p. 5). Constantin Fahlberg produced the sweetener in 1885, which made the "sweet taste affordable to poor people" (Ahmed et al., 2010, p. 377). As a result of the commercial success of synthetic sweeteners, sugar and sweetener industries try to prevail (ibid.). Saccharin was a great advantage during the two world wars, when sugar supply in Europe was short (Saulo, 2005, p. 5). Due to recent development and progress in food industry, blends of saccharin with other sweeteners are commonly found to compensate for weaknesses of individual sweeteners (Mukherjee & Sarkar, 2011, p. 407).

Polysols are also known as “sugar alcohols” and have a reduced amount of caloric value (Saulo, 2005, p. 1). In order to achieve the appropriate degree of sweetness, it is sometimes combined with other sweeteners and is commonly found in sugar free cookies and candies, baking goods, toothpastes and pharmaceuticals (ibid.). Even though they are available from fruits and beverages, they are made commercially “from other carbohydrates, such as starch, sucrose, and glucose” (ibid., p. 2). Due to their incomplete absorption by the small intestine into the bloodstream, polysols have only minor effects on blood glucose levels as compared to sucrose or glucose (ibid.). Metabolisation to energy happens with little or no production of insulin (ibid.).

Another sweetener is Tagatose, a white, crystalline powder prepared from lactose, which is “especially suitable as a flavour enhancer at low doses” (Saulo, 2005, p. 2). Another advantage of this sweetener is its reduced taste of bitterness, whereas sweetness spreads rapidly (ibid.). Tagatose is mostly used in chewing gums and mints, and also provides creaminess in dairy products (ibid.).

Trehalose, which can normally be found in honey, mushrooms, and shrimps, and is even produced by the body, is half as sweet as sucrose (Saulo, 2005, p. 3). It “provides sustained energy, and elicits a very low insulin response” (ibid.). The disaccharide consisting of two glucose molecules is, for example, used in fruit juices, nutrition bars and dehydrated fruits and vegetables (Saulo, 2005, p. 3). A very intense sweetener with 200 times the degree of sucrose is acesulfame potassium, also referred to as “Ace-K” (Saulo, 2005, p. 3). It provides no lingering aftertaste and is used in baking and dairy products, and also in alcoholic beverages (ibid.).

About the same level of sweetness is contained in Aspartame, a nutritive sweetener (ibid., p. 4). Broad usage implies enhancing fruit and citrus flavours (ibid.). It probably was the most prominent sweetener for the past two decades and facilitated the enormous growth of the low- and reduced-calorie market (ibid.). Proven to be helpful for diabetic patients, it is also valuable with regard to weight control (ibid.).

Neotame has the property of being nearly 8,000 times as sweet as sucrose and “is used in many cooking and baking applications” (Saulo, 2005, p. 4). Sucralose maintains exact sugar-like taste, despite being 600 times as sweet as table sugar (Saulo, 2005, p. 5). Due to its favourable features being preserved even after long storage and heating, it acts more and more as a replacement for sugar in several products (ibid.). True for any low-calorie sweetener presented so far is that they pass “quickly through the body relatively unchanged and [are] not converted to energy” (Saulo, 2005, p. 5). They are neither recognized as a sugar or a carbohydrate by the body (ibid.).

## 2. Teaching Unit

The suggested teaching activities should be seen as a tool box from which you might pick the appropriate components suitable for your class and background, but not necessarily as a complete and all-embracing teaching unit ready for application. In order to introduce the topic “sugars and sweeteners”, a “sugar exhibition” can be done to show the huge quantity of products that are used to sweeten foods. Depending on the age of the class, it has to be focused on the nutritional value of different carbohydrates, always with the aim of staying sensitive about this topic since you might have obese or even anorexic students to teach.

If you want to go further into human physiology, it would be advisable to draw the connection of sugar consumption and the increase or decrease of the blood sugar level. Diabetes is a good, reality-related topic for that purpose. The students should be willing to engage in further research as they might be directly or indirectly affected.

Especially with younger students it is your duty to inform them about the relation of sugar consumption and state of health, as health education constitutes a big part of the biology lessons particularly in primary schools. This might include practicing reading ingredient lists on the product packaging and trying to determine which and how much sugar the food actually contains.
In case this topic is to be taught in year eight to ten, the students could first be occupied with extracting general information from the background information text of this article. Of course, it has to be modified before giving it to the students. Instead of taking notes, however, they should be able to present the essential facts in a diagram, which highlights common properties and the hierarchy or order plus relationships between carbohydrates in general, and then doing the same for sugars and sweeteners.

Since there are many opportunities how to put together this teaching unit, it might also provide a good basis for a project day centred around the topic of nutrition, diet and health. This will be especially suitable if otherwise not enough lessons for conducting at least some of the fascinating experiments and at the same time giving sufficient background information can be provided. The suggestions presented in this article show an interest in easy experiments for students where they get more insight into chemical working and the relationship between everyday life and chemistry as such. As the experiments are not interconnected, you can use the method of market place learning, provided there is adequate support by teachers or other instructed people. In the following, a short overview of the supplied worksheets (see Appendix) is given; they also contain explanations and solutions to some steps (printed in blue italics), which should be of help for the teacher, but of course needs restructuring of the worksheet as such once it should be given to the students.

### *2.1 Worksheet 1*

This first experiment deals with the detection of glucose and fructose with the help of two different reagents. It is important that the students know how to work with chemical substances and instruments already; also, safety goggles have to be used. As the background of the experiment is rather advanced, it is more suitable for secondary school students who have had some chemistry lessons before and are able to follow the content. Since the students have to work precisely and notice a colour change, make sure that all of them know what to expect and how to achieve it; otherwise, the experiment would have to be repeated all over again. As a slight extension you can have the students bring actual food and let them detect the sugar in them in a way that relates to the usage of Fehling's solution as done before (second experiment on worksheet 1). This will be especially interesting for them as it suggests a practical application of a chemical technique.

### 2.2 *Worksheet 2*

In order to show the students how exactly sugar is obtained, this experiments focuses on the extraction of sugar from sugar beets. Probably the students did not even make the connection between those two products, which would result in all the more a great introduction as you can use the student's fascination and surprise. Once you prepared all the materials necessary, the experiment will take approximately 30 minutes. However, you have to consider another one to two days until you can really see sugar crystals. Still, it is a nice introductory experiment, particularly since there are no dangerous reagents or the like in use, the setup rather reminds you of working in a kitchen. This will be very helpful to get the students accustomed to working scientifically, which should at all times be related to writing or filling in a test protocol.

### 2.3 *Worksheet 3*

The distinction of sugars and artificial sweeteners is of concern in this experiment. It joins together all the background knowledge given earlier in this article. As suggested above, detailed study of that topic is not very fruitful until approximately class ten. But once features of carbohydrates and sweeteners plus their similarities and differences are clear and glucose or fructose have already been detected in foods, this experiment will still take them a step further as the chemical differences are also revealed in reality. But exactly this is why the necessary background has to be established first; otherwise the conduction and explanation of the experiment will be far too difficult. Due to the materials used, the wearing of safety goggles is prescribed.

### 2.4 *Worksheet 4*

This experiment is really fun and probably most suitable for primary school children up to class six. It does not really take much time, but depends of course on the students and how they work. Talking about different taste zones of the tongue is quite interesting since you taste different aromas only on certain areas of the tongue, but actually a very broad taste sensation is achieved. In order to make the students name and find different taste areas on the tongue, you have to provide suitable liquids that preferably have only one taste and not a mixture of several. As a means of recording their findings, the students should highlight the region of a particular taste on the tongue-map on the worksheet. In the anchoring phase you could make them combine all of them by drawing one big image and denoting the different tastes in various colours. Even if you do this experiment with older students, they will enjoy this activity as an introduction to the topic; you could then deepen their understanding of the issue by working on chemical processes happening during ingestion.

## 3. Conclusion

The topic of synthetic sweeteners relates to everyone's life and is therefore particularly well suited to be treated in a teaching context. It is a great chance to sensitise pupils with regards to their diet and it will be fun for them to learn about a serious issue with the help of experiments. Due to the variety of worksheets provided in this article, teachers can use them as a whole or modify sections of them and create their own teaching unit about sweeteners taking into consideration the essential background knowledge which is presented at the beginning.

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## Appendix: Worksheets

### Worksheet 1: Detection of Glucose and Fructose

Experiment: ~ 15 min

Safety note: Due to the strong basicity of the detection reagents which will be heated together with the sample in a water quench, you have to wear safety goggles (risk of splashing)!

Materials: 5 test tubes, droppers, water quench, Bunsen burner, glucose, fructose, distilled water, Fehling's solution, Benedict's reagent

Conduction:

a) Detection of Glucose and Fructose with Fehling's solution

A spatula's tip of fructose and glucose are to be resolved in 1 ml distilled water each. Add 1 ml Fehling's solution drop by drop to each solution. After that, both solutions are carefully heated in a water quench until a change of colour occurs.

b) Detection of Glucose and Fructose with Benedict's reagent

Prepare a glucose- and fructose-solution like you did in Experiment a). Then, mix both solutions with each 1ml Benedict's reagent dropwise and heat carefully in the water quench until a distinct change of colour is detectable.

Observation: What did you see?
*A brick-red precipitate is formed in all the test tubes after heating.*

Analysis:
*The reducing effect of the aldehyde (glucose) and the hydroxyl groups of an adjacent carbonyl group (fructose) cause the reduction of the complex-bound copper(II)-ions to red copper(I) oxide in Fehling's solution and Benedict's reagent.*

(Blume, 1994, p. 32)

Experiment: In order to check which kinds of foods contain sugar, you will dissolve different foods in water and add Fehling's solution.

Safety note: Due to the strong basicity of the detection reagents which will be heated together with the sample in a water quench, you have to wear safety goggles (risk of splashing)!

Materials: 8 test tubes, droppers, water quench, Bunsen burner, 2 beakers, Fehling's solution

Conduction: Try to dissolve the following foods in different test tubes:

- A tip of a spatula of honey in 2-3 cm water (in a test tube)
- A little piece of a dextrose tablet in 2-3 cm water.
- Put a sweetener tablet into the test tube and add some water.
-In another beaker, dissolve candy in water and pour about 2-3 cm of the solution into the test tube.
- Put some jam in a test tube and add water.
- Dissolve some ketchup in water (in a beaker) and filtrate the solution through a pleated filter before pouring 2-3 cm of the solution into a test tube.
- Dissolve biscuit crumbs in water.
- Dissolve salt in water.

While mixing the solutions, you should not forget to label the test tubes! Before adding a good splash of Fehling's solution to all of the test tubes, shake them gently to ensure dissolution. Then put them into the water quench one by one, heat carefully and observe attentively.

Observation: Observe what happens to every solution in the test tubes and note down your findings in the table beneath.

| **Food sample** | **Observation** |
|---|---|
| Honey | |
| Dextrose tablet | |
| Sweetener tablet | |
| Candy | |
| Jam | |
| Ketchup | |
| Biscuit | |
| Salt | |

(Agnes-Pockels-Labor, TU Braunschweig, 2010)

**Worksheet 2: Extraction of sugar from sugar beets**

Experiment: ~30 min

Materials: beaker (500 ml), beaker (200 ml), knife, grater, glass blender, sieve, test tubes, filter-device, water quench, Bunsen burner, tripod
Sugar beet, activated carbon, water

Conduction:
Peel the sugar beet and chop it with the grater. Make it boil in a 200ml-beaker and let the beet slices dry out for 5 minutes in boiling water. After that, divide the beet slices from the juice with a sieve. The juice has to be condensed to syrup under constant stirring in a smaller beaker.
Dilute a sample of the syrup with water in a test tube, then shake it out with activated carbon and filter it in another test tube. The filtrate is again condensed in the water quench and eventually air dried. After 1-2 days the purified, white sugar crystallises.

Analysis:
*The sugar that is contained in the beets is extracted with water and the beet slices are detached with a sieve. The contaminations are adsorbed by the activated carbon and sugar (saccharose) remains in a crystallized form due to the evaporation of water.*

(Blume, 1994, p. 33)

**Worksheet 3: Distinguishing between sugars and sweeteners**

Experiment: ~ 30 min

Safety note: In some parts of the experiment, Fehling's solution, potassium hydroxide and hydrochloric acid are heated. It is absolutely necessary to wear safety glasses (risk of splashing!).

Materials**:** test tubes, droppers, water quench, tripod, Bunsen burner
Glucose, saccharin, Fehling's solution, cerammonium-nitrate, potassium hydroxide, concentrated hydrochloric acid, indicator paper, distilled water

Conduction: With a tip of a spatula of each (Glucose, Sorbit and Saccharin) conduct the following three experiments:

a) Dilute the samples in test tubes in 1 ml distilled water. After that, mix them dropwise with 1 ml Fehling's solution each. Carefully heat the test tubes in a water quench for about 5 minutes and observe.
b) Dilute the samples in test tubes in 1 ml distilled water. Mix the solutions with cerammonium-nitrate-reagent abundantly.
c) Add to the samples in test tubes 1-2 potassium hydroxide- platelets. Heat the tubes with a Bunsen burner. During heating place indicator paper at the testing tube mouth. The molten baths are resolved and filtered in distilled water, once they are cooled off. Add a few drops concentrated hydrochlorid acid to the filtrates and heat gently. After that, check the smell by fanning with the hand.

Observation: Fill in the table with your findings!

| | **Glucose** | **Sorbit** | **Saccharin** |
|---|---|---|---|
| **Fehling's solution** | *Red colouring* | *No colouring* | *No colouring* |
| **Cerammonium-nitrate reagent** | *Red colouring* | *Red colouring* | *No colouring* |
| **Indicator paper** (Addition KOH) | *neutral* | *neutral* | *alcaline* |
| **Smell** (Addition HCl) | *No smell* | *No smell* | *Strong smell* |

Analysis:
***Glucose*** *is an aldehyde, and in combination with Fehling's solution red copper(I)-oxide will be formed. The hydroxyl-molecule of glucose reacts with cerammonium-nitrate, which is commonly used for detecting alcohols.*
***Sorbit*** *is a sweetener and very similar to a glucose-molecule, but instead of the glucose's aldehyde-group Sorbit has another hydroxyl-group. There is no reaction when adding Fehling's solution, but since it is a hexavalent alcohol, it reacts with cerammonium-nitrate.*
*Saccharin does not bear any similarity with glucose or Sorbit. It is made of an aromatic ring, and the NH- and $SO_2$-groups can be detected via potassium hydroxide and*

*hydrochloric acid. The NH-group reacts with potassium hydroxide to form ammonia ($NH_3$). When this gas is dissolved in water, it is an alkaline solution and can be detected with indicator paper.*

$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$

*If you acidify the watery solution of the alkaline molten bath, the $SO_2$-group of the already split saccharin-molecule is released as $SO_2$-gas, which has a very strong smell.*

(Blume, 1994, p. 32)

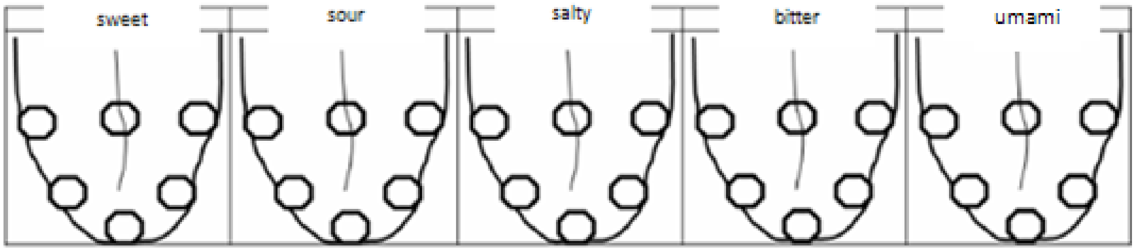
**Worksheet 4: Testing the taste zones on our tongue**

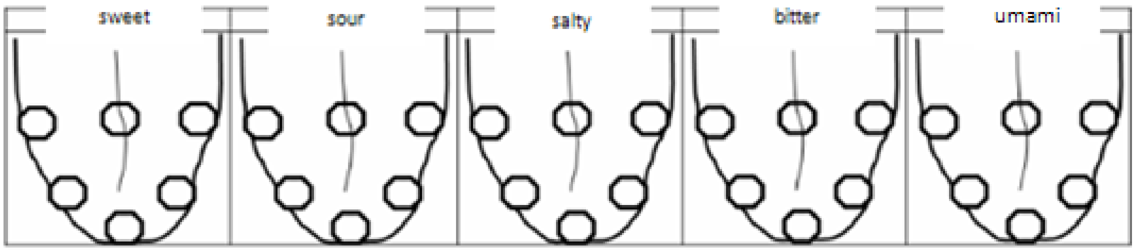
Experiment: In this experiment we want to find out which different tastes you can perceive and how they relate to the position of the taste on the tongue.

Conduction: Dab a liquid with cotton sticks onto the marked spots of the tongue. Put a cross where taste was sensed.

Important: Rinse out the mouth thoroughly with water after every flavour.

Observation:




Analysis: Draw a map of the tongue showing the different taste zones.