C4 pH value of beverages – How acidic is it in the stomach?

This is a typical introductory experiment. The experimentally acquired finding that “humans can tolerate extremely acidic beverages” leads to the conclusion that “it must be very acidic in the stomach”. The question is “why?”. This automatically introduces us to the topic of the digestive tract and digestion. Depending on the age group, the teacher can and must deal with the topic in more detail. Apart from the topic of digestion in biology lessons, students’ basic knowledge of acids and bases can be put to excellent use in the experiment in chemistry lessons. The materials supplied allow eight groups of students to conduct the experiments simultaneously.

1 Main question

Notwithstanding the eye-catching heading, the real question is what significance the pH value has in the digestive organs of the body. The pH value of beverages is appropriate for an experimental introduction to this topic. The origin of various symptoms of illness can be understood with a knowledge of the acid-base balance in the body and the function of the digestive organs. The experiment can also motivate students to favor certain beverages or reduce their consumption of others in the light of their (high or low) acid content.

2 Integrating the experiment into the teaching context

2.1 Basic principles

The digestive tract consists of a series of consecutive organs. These include the oral orifice, the pharynx, the esophagus, the stomach, and the intestine. The excretory ducts of the pancreas and gall bladder open into the first section of the small intestine, the duodenum. The duodenum is followed by the colon, which has one rising, one transversal, and one descending section. At the end of this latter section, the feces are collected in the rectum and expelled through the anus.
Different pH values prevail in various regions of the body. pH is the abbreviation for potentia hydrogenii (power of hydrogen) and is a logarithmic measure for the concentration of protons (H^+ or H_3O^+) in an aqueous solution. The more protons there are in a solution, the lower the pH value is. Acids therefore have a pH value of 0 – 7 and bases a value in the range from 7 – 14. A pH value that provides a generally good basis for the functioning of the internal organs in the body is in the slightly alkaline range (blood is at about 7.4). The pH value can also be measured in the urine or on the skin. However, the values measured there vary to a fairly high degree, depending on the time of day and the food or drink consumed, or due to the effect of soap.
Thorough chewing of food is of particular importance for digestion. The food is thereby mixed with saliva, which is usually neutral or slightly alkaline with a pH value of 7.0 – 7.1. Saliva contains amylase, an enzyme for digesting carbohydrates that splits starch down into maltose.
During the subsequent process of swallowing, the food pulp (bolus) passes the pharynx into the esophagus and then through the sphincter muscle between the esophagus and stomach (esophagus sphincter) into the stomach. The bolus is mixed thoroughly with the gastric juice and then passed on in small portions into the small intestine. Microbes are killed off by the strong hydrochloric acid content of the gastric juice. The pH value of the gastric acid is between 1 and 3, making it the most acidic substance in the human body. The hydrochloric acid together with the enzyme pepsin is also responsible for the enzymatic degradation of proteins into peptides. With the aid of this acidic fluid, the stomach is also capable of liquefying very solid food constituents. The nature of the food ingested therefore influences the time it spends in the stomach (it can be

"heavy" or "light" on the stomach). In order to protect itself against the aggressive gastric acid, the stomach's mucous membrane must have intact protective mechanisms. These include an unbroken "acid-resistant" mucus layer (mucosal barrier) and a good supply of blood to the mucus membrane.
Reflux of the stomach contents (and acid), the so-called acid reflux disease, occurs when the esophagus sphincter does not close the stomach properly, enabling stomach acid to come into contact with the mucus membrane of the esophagus. Unlike the stomach, though, the esophagus is not equipped with the necessary protective mechanisms (see above) to withstand the acid. This results in a burning feeling in the chest area, acidic regurgitation (heartburn), and pain when swallowing. It is imperative that the reflux disease be treated in order to avoid secondary diseases such as cancer of the esophagus.
The body has a number of control mechanisms for the stomach to prevent hyperacidity in the small intestine following the stomach:

- The hormone gastrin stimulates the production of stomach acid.
- The hormone secretin inhibits the production of stomach acid.
- The vagus nerve is responsible for peristalsis and emptying of the stomach.
- Peristalsis and emptying of the stomach are influenced by factors such as the smell and taste of food and the state of fullness of the stomach.

There are many possible causes for hyperacidity of the stomach. Sometimes it can be caused by the general state of health of the person. People with mood swings and energetic people are more prone to overproducing stomach acid than quiet, laidback types. High acid levels in the stomach often revert to normal of their own accord when a quieter lifestyle is adopted. Inflammations of the mucus membrane of the stomach (gastritis) subside.
Another important factor is diet. Above all, you should avoid overeating; otherwise, the resulting overburdening of the stomach leads to permanently increased acid production. Also, you should consume only moderate amounts of food with a high acid content, for example, citrus fruits, citrus fruit juices, and sodas containing carbon dioxide and sugar.
On its way through the digestive tract, the acidic bolus passes into the small intestine, where bile and secretions from the pancreas are added. The bile liquid for emulsifying fats is slightly alkaline at pH 7.1, while the pancreas secretion (which plays a role in the further splitting of energy-providing nutrients) has a pH value of 8.0, which helps shift the pH value further into the alkaline range. This is vital to enable nutrients to be absorbed by the organism further along the small intestine. If the acid content in the duodenum rises, the pylorus (exit from the stomach) closes until the secretion from the pancreas has neutralized the acid. Only then does the pylorus admit more bolus into the duodenum. During resorption of nutrients in the small intestine, the content of the intestine has a pH value of approximately 8.0 or higher. If acid is produced in the intestine due to digestive disorders resulting from fermentation or decomposition processes, this causes diarrhea.
Finally, in the colon water is resorbed from the bolus, and beneficial bacteria produce vitamins (for example, vitamin H "biotin", vitamin K, folic acid, and small quantities of vitamin B12). Feces are then collected in the rectum and eliminated from the body.
Urine, which is produced by the kidneys, has a pH value varying from 4.8 (strongly acidic) to 8.0 (alkaline). The value is often in the acidic range. This is easily explained because excess acid is transported from the body with the urine. Slightly acidic urine is also beneficial, as it inhibits growth of bacteria in the urine and reduces the risk of cystitis. In the second half of the night, acids are excreted to an increasing extent in parallel to the activity of the liver. This normally makes urine slightly acidic in the morning. The pH value of urine in the evening should be between 6.8 and 7.4.

Variations in the pH value are therefore normal and an indication of properly functioning regulation of the acid balance in the human body.
In muscle tissue, the pH value is more commonly acidic with a value of less than 7. This is because carbon dioxide is produced in the muscle cells as a byproduct of energy production. In order to deacidify the cells, the carbon dioxide occurring is transported away with the blood and exhaled via the pulmonary alveoli.

2.2 Relevance to the curriculum

The interrelated aspects of pH values described here can be dealt with from the age of about 15 years, building on knowledge of the function of the various digestive organs that students usually acquire at the age of about 14.
Prior knowledge in the field of biology is required in order to understand the processes taking place in the digestive tract. Basic knowledge of chemistry will facilitate understanding of the interrelated aspects of the pH value.

Topics and terms: amylase, bile, blood, carbon dioxide, carbohydrates, colon, digestion, digestive enzymes, duodenum, esophagus, fats, food, gastrin, heartburn, intestine, oral cavity, pancreas, pepsin, pH value, pharynx, protein, reflux disease, secretin, stomach, urine

2.3 Skills

The students will …

- determine the pH value of various beverages.
- check their measurement results by comparison with those of the other students.
- distinguish between beverages with low and those with high pH values.
- describe the path of food through the digestive tract.
- explain the digestive processes in the different sections of the digestive tract.
- deduce the properties of the stomach on the basis of their test results.

2.4 Explaining the experiment in the teaching context

The students will determine the pH values of various beverages in this experiment. The following overview lists the pH values of different liquids.

Beverage	pH value (approx.)
Apple/orange juice	3.5
Beer	4 – 5
Carbonated water	5 – 6
Coffee	2.5 – 3.5
Soft drinks (e.g., Fanta, Cola)	2 – 4
Stomach acid	1 – 3
Tap water	7 – 8
Wine	2.5 – 4
For comparison: battery acid	1.0

The pH value is a measure of the concentration of protons in an aqueous solution. Protons can significantly alter certain substances with which they come into contact (“etching agents”). Students will be familiar with this from the example of the effect of acetic acid for cleaning lime deposits in the kitchen or bathroom.
Carbonated water, which is thereby acidified, only produces a thirst quenching and refreshing effect because of the tingling sensation it gives. Carbon dioxide in water also has a preserving effect. If, for example, mineral water was not absolutely sterile when it was bottled, it still remains “fresh” thanks to the carbon dioxide. For the body or stomach, the carbon dioxide is superfluous and lowers the pH value in the stomach unnecessarily.
Humans can drink highly acidic beverages, at least in small quantities, without doing any harm. That suggests that a very low pH value is also present in the stomach.
Nevertheless, excessive consumption of acidic drinks can stress the mucus membrane of the stomach and stimulate it to activate its mucosal barrier “unnecessarily”. That is obvious to the students from their observations and previous knowledge. They will recognize that different beverages vary with regard to how stomach-friendly they are.
Important note: The value indicated on the pH test strip by the change in color corresponds to the pH value of the measured liquid only immediately after the strip is taken out of the liquid. The indicated value can change again within minutes when the strip is exposed to air.

2.5 Experimental variations

Students can conduct the experiment individually or in pairs.
As an alternative to the beverages suggested here, the teacher can ask the students, as preparation for the experiment, to bring a sample to class of all the beverages they drink during the course of a day. This will increase the size of the database. Working in small groups, the students can then arrange their beverages according to their pH values (from alkaline to acidic).

3 Additional information on the experiment

You will find additional media for preparing or for further study of this experiment on the Siemens Stiftung Media Portal:
https://medienportal.siemens-stiftung.org

You will find additional experiments on the topic of digestion and metabolism in the experiment kit: “C1 We burn sugar – Cellular respiration and respiratory chain”, “C2 Carbohydrates as providers of energy for metabolism – Starch and sugar”, “C3 How does human digestion break down fats? – Saponification of edible oil”.

4 Notes on conducting the experiment

4.1 Facilities

This experiment can be conducted in any classroom.

4.2 Time required

Preparation and execution	Analysis and questions
10 min.	20 min.

4.3 Safety aspects

The students may conduct the experiments only in the presence and under the supervision of the teacher.
The teacher is to point out to the students that the provided materials may be used only according to the respective instructions.
For this experiment, watch out for the following potential dangers and make your students aware of them:

- Make sure that no damage can occur to water-sensitive materials and apparatus.
- Point out to the students that the beverages are not suitable for consumption.

4.4 Apparatus and materials

Required materials that are not supplied:

- Paper towels or similar for wiping the hands
- Various samples of beverages (about 40 ml of each), for example, tap water, mineral water (with carbon dioxide), apple or orange juice, cola (if possible, since cola is generally extremely acidic)
- Water-soluble markers, one per group

Supplied:
The apparatus and materials supplied are sufficient to allow **eight** groups of students to conduct the experiments simultaneously.
The following materials included in the kit are needed for **one** group of students:

Material	Quantity
pH test strip, package	1x for entire class
Plastic cup, 100 ml	4x

Fig. 1: Apparatus and materials supplied for one group of students.
The pH test strips shown are for the entire class.

4.5 Cleanup, disposal, and recycling

All apparatus and nearly all materials from the kit can be reused. Therefore, after the students have completed the respective experiment, they should put the apparatus and materials back in the appropriate boxes and return them to the kit. This practice will ensure that you and your colleagues will find everything again quickly the next time the kit is used.
Apparatus that become dirty during the experiment, such as cups, bowls, spoons, and test tubes, should be cleaned before being returned to the kit. We recommend that you have the students do this immediately after they have completed the experiment.
Also make sure that the apparatus are in working order for the next time. For example, recharge used accumulators immediately. (It makes sense to charge the accumulators even if they will not be used for an extended period.)
Materials that cannot be reused, such as used pH test strips and filter paper, should be disposed of properly.
The waste that accumulates during this experiment can be disposed of in the regular trash or poured down the sink.