C5 Respiration

Subexperiment C5.1 Our lungs
Subexperiment C5.2 Large and small air sacs

1 Main question

The following questions underlie the subexperiments and guide the activities:

- What structures are necessary for our respiration and how are they designed?
- How does our respiratory system work?
- How does air get into our lungs and where does the gas exchange take place?
- To what extent is the design of the structures critical for their function?
- Why are there air sacs in our lungs?

2 Background

2.1 Relevance to the curriculum

Studying the individual organs and functional systems of the human body makes the students aware of their own bodies. They learn more about the human body and gain insight into how the organs work. In addition, the study of their own bodies provides the opportunity to look at health-related aspects. The resulting fascination and appreciation of their own bodies will encourage them to maintain their health. Subexperiment C5.2 also visually demonstrates an important principle from biology, the principle of surface area expansion, which also has many engineering and architectural applications.
The subject of respiration offers many cross-references to the environment topic of Experimento | 8+, especially the topic of air pollution. For this reason, it makes sense to work on these two topics in succession.

Topics and terms

Air sac, bronchial tubes, carbon dioxide, diaphragm, gas exchange, lobe, lung, lung surface, oxygen, negative pressure, (over)pressure, surface, trachea, volume

2.2 Skills

The students will ...

- develop a better understanding of the human functional systems, especially respiration.
- become aware of how important the human respiratory system is.
- become more confident in following scientific-technical processes, such as taking measurements and reading variables.
- nurture their understanding of physics.
- expand their modeling skills.

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

4 Conducting the experiment

Note: The listed materials are designed to allow **one** group of maximum **five** students to conduct the experiment.

4.1 Subexperiment C5.1 Our lungs

4.1.1 Required materials

Material	Quantity
Electrical tape	20 cm
Empty plastic bottle, 1.5 liters	10
Modeling clay	1 piece (approx. 1 small spoonful)
Red balloon	2
Scissors	1
Thin tubing	10 cm
Y-shaped tubing connection	1
Zipper storage bag, 200 x 300 mm	1

4.1.2 Organizational aspects

Facilities	At a simple table in the classroom or outdoors
Time required	Approx. 45 minutes
Safety instructions	See the “Safety instructions on the topic of health” in the guidebook.
Cleanup	If there are enough materials, you can let the students take the models home. Otherwise, the models should be disassembled again at the end of the subexperiment: Balloons that have been blown up should be disposed of for hygiene reasons. The Y-shaped pieces and tubing are put away. The modeling clay can be collected and also reused. The plastic bottles should be recycled.

4.1.3 Explaining the subexperiment in the teaching context

The students will work with the structure and functioning of the human respiratory system. Based on the homemade model, they will be able to draw conclusions about their own bodies and gain valuable knowledge about negative pressure and volume.

Technical background

Schoolchildren (8 – 10 years old) breathe about 20 times a minute. As people age, they breathe less frequently. Nevertheless, we rarely think about the incredible feat constantly performed by our lungs. Our bodies cannot store much oxygen, which is why we continually breathe. The brain stem, or more precisely, the medulla oblongata, controls breathing. That’s why failure of this structure, for example, due to injury to the upper cervical spine, leads to death.

The breathing process at a glance

During inhalation, our diaphragm contracts and thus moves lower. The intercostal muscles also contract and expand the chest: The volume of the chest increases. This creates negative pressure and air follows this suction force through the oral cavity, trachea, and bronchial tubes until it reaches the air sacs. The gas exchange takes place in the air sacs; the inhaled oxygen is transferred to the blood and is distributed to all organs and cells via the blood vessels. During exhalation, the diaphragm and intercostal muscles are relaxed so that the volume of the chest decreases, thereby increasing the pressure and pushing the exhaled air out.

The expansion of the chest through the intercostal muscles cannot be represented in this respiratory system model, but the important lowering of the diaphragm can be.

4.1.4 Ask about the students' prior knowledge and ideas

The students should be familiar with the structure of the respiratory tract and the path air takes through the body. If the content should be new, you can discuss the figure in the student instructions with the students. The students are usually familiar with the individual structures, or at least with the names of the structures.

As far as the breathing process is concerned, the students have probably not dealt with it much, apart from attempts to hold their breath for as long as possible. However, this experience is enough to discuss the automatic nature of breathing. Have them remember the last time they submerged themselves under water. They all know that after a certain point, they can no longer hold their breath. The urge to finally inhale continues to increase.

If they have any idea at all, the students might think that air pushes into their lungs by itself, but by working with the respiratory system model, the students will learn how the lungs actually work. The terms negative pressure and overpressure do not have to be used. You can speak of suction force instead of negative pressure and simply pressure instead of overpressure. However, the students are familiar with the principle of negative pressure and overpressure, for example, from sucking on a drinking straw or from using a pipette.

4.1.5 The research cycle

Important aspects and information regarding the individual process steps of the research cycle during the experiment for students:

Recognizing the problem/phenomenon	This experiment is about becoming familiar with the functioning of lungs.
The research question ?	The following alternatives to the research question stated in the student instructions are possible: ▪ How does lung respiration work? ▪ Why is respiration vital for life?

Collecting ideas and guesses	Some possible guesses: **Related to the research question:** ▪ "The air flows into my lungs." ▪ "My lungs suck in the air." ▪ "My mouth/nose sucks in the air." ▪ "Opening the mouth lets air into my body." **Related to the experiment:** "I push the air from outside into the balloon." Segue from the guesses to the experiment.
Experimenting	**Experiment setup:** The students will learn or review the structure of the human respiratory organs based on the figure in the student instructions. Allow them to trace the path of the air with their fingers; this makes them aware of the path of air in the respiratory system model. The students are generally familiar with the term "bronchial tubes" from respiratory tract illnesses, such as bronchitis. All the balloons should be inflated and then deflated before they are pulled onto the Y-shaped piece. This makes them more elastic so that they respond even when not much air is drawn in, as in the case of the red balloons. **Conducting the experiment:** The students will build their own model of the respiratory system and use it to work through the functioning of the human respiratory system. They will exchange ideas while making the model and discuss the finished product.
Observing and documenting	▪ The students are encouraged to match the parts of the model to the structures in their bodies (body parts). ▪ Based on the model, they will learn which processes are crucial for human respiration to work. ▪ They will have the opportunity to simulate breathing, allowing them to learn how the lobes work.

<table>
<tr><td></td><td>The most important observations:
▪ Comparison of respiratory system model and body:
<table>
<tr><th>Part in the respiratory system model</th><th>Body part</th></tr>
<tr><td>Bottle</td><td>Chest</td></tr>
<tr><td>Bottle opening</td><td>Mouth</td></tr>
<tr><td>Tubing</td><td>Trachea</td></tr>
<tr><td>Y-shaped tubing connection</td><td>Bronchial tubes</td></tr>
<tr><td>Two balloons inside</td><td>Two lobes</td></tr>
<tr><td>Zipper storage bag bottom</td><td>Diaphragm</td></tr>
</table>
▪ When the students tug on the zipper storage bag, the balloons inside fill with air through the piece of tubing. When they push the bag into the bottle, the air flows out of the balloons again.</td></tr>
<tr><td>Analyzing and reflecting</td><td>The students will recognize that the diaphragm (zipper storage bag at the bottom of the bottle in the model) plays a key role in breathing.
It must be elastic to allow the volume to change. This results in negative pressure/suction, which pulls air into the lungs. If this negative pressure is not present, exhalation occurs.

Result to be expected (answer to the cloze test):
When I pull down on the zipper storage bag at the bottom of the bottle, the space (the volume) of the bottle becomes larger. This creates suction and the red balloons fill with air via the tubing. When I push the bag back into the bottle, the space (the volume) becomes smaller again. This creates pressure on the red balloons and the air escapes again via the tubing.

Reference to the story to get the students thinking about the topic:
Now you know why it is very difficult to hold your breath. Because negative pressure builds up in the lungs when you breathe, it acts like suction and you have to inhale. You can’t help it.</td></tr>
</table>

4.1.6 Further information

In the student instructions

Doing further research	If people can no longer breathe on their own due to an illness or due to intensive medical care (for example, a coma), ventilators are necessary. There are two possibilities for this: Either expansion of the chest is regulated externally (keywords: iron lung, biphasic cuirass ventilation), resulting in alternating negative pressure and overpressure. Or air is pressed into the lungs by means of overpressure. Have the students discuss how machines could be used to supporting breathing.

4.2 Subexperiment C5.2 Large and small air sacs

4.2.1 Required materials

Material	Quantity
Adhesive tape	1
Construction paper (two different colors)	4 sheets
Ruler or tape measure	1

Material for the additional experiment	Quantity
Clear drinking glass	2
Effervescent tablet	2
Water	Approx. 2 x 200 ml

4.2.2 Organizational aspects

Facilities	In the classroom or outdoors
Time required	Approx. 45 minutes
Experimental variations	A visualization of the total surface area for the small cylinders would be nice. Perhaps you could work outdoors and use chalk to mark the total area on the ground so that you can get a good idea of the surface area even without the pieces of construction paper. You can also mark the surface area on the floor using masking tape.
Safety instructions	See the "Safety instructions on the topic of health" in the guidebook.
Cleanup	Remove the tape completely or cut off the portion that hangs over the edge of the paper. The pieces of construction paper can be reused.

4.2.3 Explaining the subexperiment in the teaching context

By spreading out a model of air sacs, the students will understand that many small geometric objects, such as the air sacs, have a much larger surface area than one large geometric object with the same volume.

Technical background

The lungs contain a large number of small air sacs, called "alveoli." The vital exchange of gases between the air and the blood takes place in the air sacs. The blood receives oxygen from the air and at the same time can release the by-product carbon dioxide to the air, so that this carbon dioxide does not accumulate in toxic amounts in the body. The lungs have an estimated 300 million air sacs with a total surface area of 80 to 120 m^2. This means a very large surface area can be accommodated within the same chest volume. In this way, a large volume of oxygen can be absorbed into the blood via diffusion at the boundary between the air sacs and the vessel walls. This biological principle is called the principle of surface area expansion and it can be found in many other contexts. The total surface area is continually increased, for example, through folding or division of a larger volume into many small spaces. Another example is the folds in the inner intestinal wall: The intestinal villi ensure that many nutrients pass through the blood vessel walls and into the blood.

4.2.4 Ask about the students' prior knowledge and ideas

The students should already have gained prior experience with different shapes and solids, such as a circle versus a sphere or a square and rectangle versus a cube. They should thus be able to distinguish between surface area (two-dimensional) and volume (three-dimensional). In addition, they should be familiar with the structure of the respiratory organs.
The students should be able to measure precisely using a ruler or tape measure.

4.2.5 The research cycle

Important aspects and information regarding the individual process steps of the research cycle during the experiment for students:

Recognizing the problem/phenomenon	This experiment is about becoming familiar with the structure of the lungs with the air sacs.
The research question	The following alternatives to the research question stated in the student instructions are possible: ▪ Why are lungs divided into air sacs? ▪ What happens at the air sacs?
Collecting ideas and guesses	Some possible guesses: **Related to the research question:** ▪ "If one air sac pops, there are still a lot of other air sacs." ▪ "Because you can breathe in more air." ▪ "If you had one large air sac, the blood vessels would also have to be large." ▪ "It must have something to do with blood." **Related to the experiment:** "I will place many spheres next to each other." Segue from the guesses to the experiment.

Experimenting	**Experiment setup:** Prepare the large and small pieces of construction paper in advance for the students. Ideally, the color of the large piece of construction paper will differ from the color of the small pieces. Point out to the students that the structure they make in the experiment is just a model. Some things can be demonstrated with the model (relation of surface area to volume) and other things cannot (blood vessels, actual size). The results obtained from a cylinder model can be transferred to a sphere model. If the students are not familiar with the term “cylinder” as the geometric object that they will be making in this experiment, introduce the term by comparing a cylinder with everyday objects (for example, beverage can, advertising column, water pipe). A comparison of a cylinder with a top hat as a “hat without a brim” is also easy to remember. **Conducting the experiment:** Always make a distinction between the model and reality. Do not refer to the pieces of construction paper as “lungs” or “air sacs.”
Observing and documenting	The students will observe that the completed model of the lung containing the air sacs takes up far less space on the table than the materials that were previously placed flat on the table (or, alternatively, placed on the floor or outdoors on the ground). **Measurement results to be expected:** Lung surface area: 45 cm x 15 cm = 675 cm^2 Air sac surface area: max. 10 times 15 cm x 10 cm = 1,500 cm^2
Analyzing and reflecting	**Results to be expected:** The combined surface area of the small cylinders is greater than the surface area of the large cylinder. The students will learn that by subdividing the initial volume into smaller spaces, the combined surface area of the smaller spaces is larger than the original surface area of the large cylinder. Bring the lesson full circle by establishing a size reference to one’s own body: The surface area of a person’s air sacs totals 80 – 120 m^2. Define a visible area as a comparison, for instance, the classroom, and explain that they could “tile” 1.5 classrooms, for example, with their air sacs. Also establish a reference to the air sacs’ function. The large surface area is necessary for gas exchange. You must hold a classroom discussion so that the students transfer the findings from the model experiment to the human body. **Reference to the story to get the students thinking about the topic:** Now you know why your friend can’t breathe well. Due to his allergy, the air circulation to the air sacs is impaired. Because he cannot get the air out of his lungs due to the spasms, he cannot breathe in any fresh air. That’s why he needs an inhaler that relieves the spasms.

4.2.6 Further information

In the student instructions

Doing further research 	The students can also experience the phenomenon of surface area by comparing the dissolving of an intact effervescent tablet in water to the dissolving of a crumbled effervescent tablet. The latter will disintegrate much faster because a larger surface area comes into contact and reacts with the water.

Miscellaneous

For talented designers, you can discuss the various shapes.

- What happens if the shape of the individual air sacs is changed?
- For instance, how do angular objects behave in a lobe shaped like a sack?
  (The edges cannot be optimally filled.)

Test this out together and draw conclusions with the students about the optimum shape.