# B3 Air pollution

Subexperiment B3.1 A combustion process needs oxygen
Subexperiment B3.2 Air pollution

## 1 Main question

The following questions underlie the subexperiments and guide the activities:

- Which conditions are necessary for a combustion process to take place?
- How are combustion processes related to air pollution?
- What is soot?
- What happens when a substance is burned?
- What substances contribute to air pollution?

## 2 Background

### 2.1 Relevance to the curriculum

Air is seldom consciously perceived as an essential part of our existence. Reasons for this lack of perception are rooted in the fact that air is invisible. Children normally explore their environment using all senses. They “grasp” their world, in two meanings of the word: They deal with colors and shapes, smells, and tastes. They perceive, observe, and feel. When it comes to the topic of air, children’s power of imagination reaches its limits, which is why air is often “nothing” for children. By dealing with the topic of “air pollution” in a playful, research-based way, the students will determine that we can find air pollution almost everywhere. In addition, they will become familiar with some causes of air pollution: combustion, exhaust gases, particulate matter, and pollen. They will learn that fresh air is essential for well-being.

#### Topics and terms

Air, air pollution, breathing air, carbon dioxide, combustion process, exhaled air, fire, flame, health hazard, oxygen, oxygen deficiency, particulate matter, pollen, smoke, soot

### 2.2 Skills

The students will ...

- understand that air is not “nothing,” but rather a mixture of substances made up of various gases.
- grasp the necessity of fresh air for animals and plants.
- be capable of identifying visible and invisible air pollutants.
- be informed about the possibilities for reducing air pollution.

## 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 B3.1 A combustion process needs oxygen

### 4.1.1 Required materials

| Material | Quantity |
|---|---|
| Balloon | 1 |
| Covers for jars, for example, small plates | 2 |
| Flat fireproof base, for example, a baking tray or large porcelain plate | 1 |
| Jars<br>▪ of various sizes, labeled with numbers and volume indication*, for example, with a waterproof pen<br>▪ same size as one of the previous jars | <br>3<br><br>1 |
| Matches | 1 package |
| Stopwatch | 1 |
| Tea light | 2 |

* If jars with the volume indicated are not available, the information can be written on them using a waterproof pen. Or the students can determine the volumes themselves by filling the jar with water and then pouring the water into a measuring cup, reading the volume, and labeling the jar.

### 4.1.2 Organizational aspects

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| **Facilities** | In the classroom or outdoors without wind, at a simple table.<br>The teacher must be present. |
| **Time required** | Approx. 60 minutes (together with B3.2, 90 minutes) |
| **Safety instructions** | See the “Safety instructions on the topic of the environment” in the guidebook.<br>▪ The two subexperiments must not be conducted without supervision. The teacher must monitor the burning of the candle and keep a fire extinguisher, fire blanket, or similar item on hand.<br>▪ Children with long hair must tie it back, and scarves, etc., must be taken off. |
| **Cleanup** | ▪ The tea lights must be completely cool before they are put away.<br>▪ If the jars are going to be used for another purpose afterwards, the waterproof labeling can be easily removed using dish detergent or a brush. The jars should be washed before they are used again.<br>▪ The balloons are disposed of for sanitary reasons. |

### 4.1.3 Explaining the subexperiment in the teaching context

Based on two subexperiments that build upon each other, the students will learn that a combustion process requires oxygen to be maintained and that the more oxygen is available, the longer the combustion process lasts. They will learn that combustion processes need fresh air, thus oxygen-rich air, just like people need the oxygen in the air to breathe.

**Technical background**

In general, the combustion of substances in the presence of oxygen (oxidation) is called a combustion reaction. If you combust carbon or hydrogen, the combustion product is carbon dioxide ($CO_2$) or water ($H_2O$). These combustion products are also produced in the combustion of organic compounds (for example, glucose ($C_6H_{12}O_6$), butane ($C_4H_{10}$), or alcohol ($C_2H_5OH$)). These two products also form during cellular respiration in the human body, during which glucose is oxidized. In contrast, if you burn nitrogen or sulfur, nitric or sulfur oxides are formed.
Gases other than oxygen, such as carbon dioxide, will not keep a flame burning during combustion. Therefore, combustion processes are dependent on the constant supply of oxygen. This oxygen is then removed from the ambient air around the fire and replaced with carbon dioxide. Combustion processes like those that take place in large power plants, in cars, or during slash-and-burn clearing are significantly responsible for global warming. This is because the carbon dioxide produced in combustion processes amplifies the natural greenhouse effect and results in warming of the Earth. That's why carbon dioxide is also referred to as a "greenhouse gas" in everyday language. Many measures to reduce greenhouse gases (which, besides carbon dioxide, include methane, ozone, nitrous oxide) have been passed since the Kyoto Protocol of 1997. Among other things, the measures pertain to carbon dioxide emissions, since the causes of this are well known and therefore measures to reduce emissions can be derived. As a matter of fact, global greenhouse gas emissions in 2013 reached their highest level so far.
Carbon dioxide is heavier than air and flows down when it is poured. If you enrich the air surrounding a flame with carbon dioxide, this gas smothers the flame and the flame goes out. Parallels can be drawn to breathing: In an atmosphere of carbon dioxide, living organisms that depend on oxygen would suffocate.

### 4.1.4 Ask about the students' prior knowledge and ideas

For this topic, teachers can expect that students have ample prior knowledge or have already made observations. Fire and flames are very fascinating and some of the students will have already looked closely at candle flames. The lessons also deal with fresh and stale air, for example, airing out the classrooms between classes.
The students could be asked to comment on the following items:

- Appearance of a fire or flame, for example, candles or a campfire.
- Conditions for starting a flame and maintaining its stability: enough air, no draft, continuous supply of combustible material and air.
- Reasons for a flame going out.
- "Fresh air": contains the oxygen vital for our respiration.
- "Stale air": contains a high amount of carbon dioxide, the substance that we exhale.

If necessary, point out that fire is neither a substance nor an element, but represents light and heat energy.

### 4.1.5 The research cycle

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

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| **Recognizing the problem/phenomenon** | This experiment is about the phenomenon that every fire needs oxygen. As the teacher, you could also use the example of a fire blanket that you place on the source of a fire to smother the fire. |
| **The research question** | The following alternatives to the research question stated in the student instructions are possible:<br>▪ When does a candle burn, and when not?<br>▪ Why does a forest fire grow larger when the wind is strong? |
| **Collecting ideas and guesses** | Some possible guesses:<br>**Related to the research question**<br>▪ "Because the flames then have more room."<br>▪ "Because this creates a draft that carries the flames along."<br>▪ "Because then a lot of oxygen reaches the fire. The fire needs oxygen."<br>**Related to the experiments**<br>▪ "The candle under the biggest jar burns the longest because it has the most air."<br>▪ "The flame under the biggest jar is also taller."<br>▪ "The jars turn black."<br>▪ "The candle burns down."<br>▪ "The flame is smothered in the exhaled air."<br>▪ "The candle no longer burns."<br><br>Segue from the guesses to the experiment. |

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| **Experimenting** | **Subexperiment 1 setup:**<br>▪ Prepare three jars with different volumes for each group of students. It would be best to number the jars from 1 to 3 from smallest to largest volume using a waterproof pen. In addition, each jar can be labeled with its respective volume. This trains the students' understanding and estimation of volumes. In addition, the students can guess, for example, whether a candle will burn twice as long if it has double the air volume.<br>▪ Point out that the tea light cup can be hot.<br><br>**Subexperiment 2 setup:**<br>With the help of a balloon, have the students pour the air enriched with carbon dioxide, their exhaled air, into a jar with a tea light.<br><br>**Conducting subexperiment 1:**<br>▪ The students will observe the flame's appearance and investigate the burning time of a tea light depending on the available air volume.<br>▪ They will use a stopwatch to measure their observations. Provide assistance with this, if necessary. Also point out that the starting conditions should be identical in all three stages, that is, the flame must always be similarly tall and stable at the beginning.<br><br>**Conducting subexperiment 2:**<br>▪ Teamwork is required in this experiment since the jars must be covered immediately after they are filled with the exhaled air.<br>▪ Because the objective here is only to observe that the candle with the normal air burns longer, it is not necessary for the students to use the stopwatch to measure the burning time.<br>▪ Care must be taken when the exhaled air is poured in the jar:<br>If the air flows in too quickly, the candle will go out.<br>▪ In addition, the exhaled air will settle to the bottom of the jar since carbon dioxide is heavier than oxygen. So the tea light might go out very quickly anyway. |
| **Observing and documenting** | **Most important observation in subexperiment 1:**<br>▪ The tea light burned the longest in the biggest jar. The values entered in the table will vary depending on the sizes of the jars used.<br>▪ In addition, the students may observe that, as the burning time increases and thus the oxygen content in the jar is reduced, the flame becomes shorter and less bright until it finally goes out.<br><br>**Most important observation in subexperiment 2:**<br>▪ The tea light in the jar with the exhaled air does not burn as long as the tea light in the other jar.<br>▪ In addition, the students may observe that the gas really does flow downward, provided that the carbon dioxide content is reasonably high, and the candle goes out right when the gas is poured in. |

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| **Analyzing and reflecting** | **Results to be expected: Summary**<br>1. The larger the jar and the associated volume of air, the longer the tea light burns.<br>2. The flame goes out faster with exhaled air.<br>3. The candle goes out when the oxygen content necessary for combustion becomes too low.<br><br>The firefighter's statements and tips on behavior in the event of a fire serve as a summary and segue to establishing an analogy with oxygen consumption and carbon dioxide production through respiration.<br>▪ The more fresh air that reaches a fire, the longer the combustion process lasts. (true)<br>▪ The less fresh air that reaches a fire, the longer the combustion process lasts. (false)<br>▪ You must close windows and doors in the event of a fire. Otherwise, too much fresh air will reach the fire, causing it to grow bigger and burn longer. (true)<br>▪ The more carbon dioxide that the air contains (exhaled air), the longer the fire burns. (false)<br>▪ The more oxygen that the air contains, the better the fire burns. (true)<br>▪ A combustion process needs oxygen, just like people do. (true)<br>▪ Carbon dioxide is produced in the combustion process. (true)<br><br>**Reference to the story to get the students thinking about the topic:**<br>After the experiment and the explanation from the fireman, Ben understands why he should close windows and doors in the event of a fire. This prevents the fire from spreading. |

### 4.1.6 Further information

**In the student instructions**

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| **Doing further research** | Now you can discuss the various possibilities for extinguishing a fire. Show the students the following objects or pictures thereof:<br>▪ Fire extinguisher (with powder or foam)<br>▪ Fire sand<br>▪ Fire blanket<br>Ask whether the students are familiar with any of the extinguishing methods and if so, from where. Discuss as a group the types of fires that can be best extinguished using each method.<br>Many fire extinguishing methods aim to deprive the fire of oxygen. When water is used, the fire is not extinguished because it was deprived of oxygen, but because the temperature was lowered. Small household fires are fought by covering and beating them.<br>**Important:** Never use water to extinguish a grease fire since the sudden vaporization of water will splatter the hot grease and spread the fire. |

**Miscellaneous**

In many counties, emissions of the greenhouse gas carbon dioxide are not being curbed but continue to reach new heights. Discuss the processes that are responsible for increased carbon emissions with the students.
Help them if they have problems understanding.
The students should then come up with possible solutions for reducing their own carbon dioxide emissions. Solutions concerning one's own behavior are easier to formulate than those concerning others' behavior. One example:

- Problem: Exhaust gases from cars contain carbon dioxide.
- Answer: Cover short distances on foot or by bicycle, travel longer distances with public transportation (own behavior). Design electric cars (others' behavior).

For global solutions, the students will probably mainly suggest bans.
Allow some time for this important topic.

## 4.2 Subexperiment B3.2 Air pollution

### 4.2.1 Required materials

| Material | Quantity |
|---|---|
| Adhesive tape | 1 x approx. 7 cm |
| Cotton swab | 1 |
| Damp towel for cleaning the test object | 1 |
| Flat fireproof base, for example, a baking tray or large porcelain plate | 1 |
| Magnifying glass | 1 |
| Matches | 1 package |
| Tea light | 1 |
| Test tube | 1 |
| Test tube clamp | 1 |

### 4.2.2 Organizational aspects

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|---|---|
| **Facilities** | In the classroom or outdoors, at a simple table.<br>The teacher must be present. |
| **Time required** | Approx. 20 minutes (together with B3.1, 90 minutes) |
| **Safety instructions** | See the “Safety instructions on the topic of the environment” in the guidebook.<br>▪ The teacher must monitor the burning of the candle and keep a fire extinguisher, fire blanket, or similar item on hand.<br>▪ Children with long hair must tie it back, and scarves, etc., must be taken off. |
| **Cleanup** | The tea lights must be completely cool before they are put away. |

### 4.2.3 Explaining the subexperiment in the teaching context

The students will learn that combustion processes can contribute to air pollution. They will learn that the starting substances do not disappear in the combustion process, but that combustion results in products (in this case, soot, and steam) that are released into the air.

#### Technical background

Combustion proceeds all the more completely and longer when more oxygen is available.
The more oxygen that is present, the taller and more brightly the flame burns.
In contrast, if a combustion reaction is incomplete due to a lack of oxygen, soot particles are produced. The combustion of these soot particles produces a yellow flame.
This is the reason why a candle flame appears yellow when the gaseous wax burns. If soot particles and other solid particles are in the air, this is referred to as smoke.
Soot is elementary carbon in powder form that also contains oily residue from the combustion reaction. This is easy to understand when you rub soot between your fingers. Soot is considered particulate matter; the particles are so extremely small that they can cause lasting damage to a person’s respiratory tract in the event of frequent and prolonged exposure. Soot itself could be carcinogenic to humans. Depending on the starting substance that is burned, soot can also contain

other components that are definitely carcinogenic, for example, polycyclic aromatic hydrocarbons. Combustion processes therefore play a significant role in air pollution and adverse health effects. A combustion process always has one gaseous starting substance, oxygen, and two gaseous ending substances, carbon dioxide and steam. For this reason, many people have the impression that starting substances disappear, when actually the ending substances simply leave the reaction and enter into the air. This conversion of matter follows the “Law of conservation of mass in a closed system” that applies to chemical reactions. This means that substances do not disappear, but only undergo a conversion. Therefore, the mass of the starting substances (reactants) must equal the mass of the ending substances (products).

### 4.2.4 Ask about the students’ prior knowledge and ideas

The students are likely to be familiar with some combustion processes, such as fire, flame, and smoke development. Ask them about the products of the combustion processes and about observations they can make depending on the type of substance burned. Students also often know that the color of the flame can change, for example, when different types of paper are burned, especially glossy paper. Many of them have experienced campfires and have been confronted with all the properties of a fire: It burns yellow to orange, it is hot, a typical odor is produced, smoke with particles that irritate the respiratory tract is produced, and combustible material must be added.

### 4.2.5 The research cycle

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

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|---|---|
| **Recognizing the problem/phenomenon** | This experiment is about detecting pollutants in the air that are often not visible with the naked eye. |
| **The research question** | The following alternatives to the research question stated in the student instructions are possible:<br>▪ How can air be polluted?<br>▪ Why are air pollution levels higher in cities than in the country? |
| **Collecting ideas and guesses** | Some possible guesses:<br>**Related to the research question**<br>▪ “It is smoke, which disappears into the air.”<br>▪ “Soot is found in smoke.”<br>▪ “The snow turns black from the cars.”<br>▪ “Exhaust gases from cars make the snow black.”<br>▪ “There is soot in exhaust gases.”<br>**Related to the experiment**<br>▪ “The test tube begins to glow.”<br>▪ “The test tube is singed.”<br>▪ “The test tube burns.”<br>▪ “I see dust on the adhesive tape.”<br><br>Segue from the guesses to the experiment. |

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| **Experimenting** | **Experiment setup:**<br>The two experiments teach the students how to discover air pollution – once directly at the source and once indirectly in the environment.<br>**Conducting subexperiment 1:**<br>▪ The students will hold a test tube just above or in the candle flame and discover in the process that soot is produced in the immediate vicinity of the flame.<br>▪ Keep in mind that the test tube can be hot where it is heated.<br>▪ In addition, the soot should not be swirled up and inhaled.<br>▪ To keep from touching the soot with their fingers and then spreading it around, the students can use a cotton swab to remove the soot from the test tube. In doing so, they will recognize the powdery structure. Otherwise, the students could think that their observation is black discoloration or a burn.<br>▪ An attempt to brush off the soot fails because the soot is too oily.<br>**Conducting subexperiment 2:**<br>▪ The surface of the test object should not be painted, or else the paint could peel off with the adhesive tape.<br>▪ The smooth surface of the test object is cleaned with a slightly damp towel. The surface must not be wet.<br>▪ The "harvest" takes place on the next day: The students should touch only the ends of the sticky side. |
| **Observing and documenting** | **Most important observations:**<br>▪ Bottom of the test tube: A black substance was produced on the bottom of the test tube.<br>▪ Sticky side of the adhesive tape: Many different particles, for example, dust, pollen<br>▪ Tip: Beautiful images of pollen taken with a scanning electron microscope exist. Show images to the students so they recognize that these small particles have many different structures. |
| **Analyzing and reflecting** | **Results to be expected:**<br>1. The substance is soot. Soot is black and consists of very fine powder. It seems oily.<br>2. Burned food, a used match, campfire, exhaust pipe, smoking oven, old steam locomotive, etc.<br>3. Dirt from the air, pollen, etc., is found on the adhesive tape.<br>**Reference to the story to get the students thinking about the topic:**<br>Now you know why the snow near the curb is totally black: It is due to the exhaust gases from cars that drive there. The black soot is produced through the combustion of gasoline and deposited on the white snow. |

### 4.2.6 Further information

**In the student instructions**

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|---|---|
| **Doing further research** | Low-emission zones are found throughout Europe, mainly in large cities. In everyday life, the students may have seen the traffic signs for low-emission zones or the emission stickers on car windshields.<br>Low-emission zones have been created to reduce particulate matter and thus keep the air we breathe clean.<br>In large cities, road traffic is viewed as a main source of particulate matter. A substantial portion is soot from diesel vehicles, trucks, and buses. Additional sources are tire and brake dust as well as the swirling of dust on the road. Heating systems that use fossil fuels also contribute to particulate matter pollution.<br>In Germany, for instance, only cars with a gasoline engine and a regulated catalytic converter or a diesel vehicle with exhaust emission standard Euro 4 receive the green sticker and are allowed to be driven downtown (further information about this is available, for example, from the German Federal Environment Agency). In other European countries, often it is only diesel vehicles and trucks that are affected by the low-emission zone regulation.<br>The purpose of this research project is to familiarize the students with the signs/stickers for low-emission zones and to sensitize them to the topic of keeping air clean in all areas of life. The topic does not need to be worked out in greater detail for these age groups since the discussions on the topic of “particulate matter” are highly controversial. |

**Miscellaneous**

Rain helps clean the air, which means many air pollutants end up on the ground.

- Sometimes we can even see this, for example, when cars and streets are covered with a sticky pollen layer after a downpour overnight. On the other hand, the air is clean. Allergy sufferers are especially happy about this. For healthy people, too, the inhaled air feels fresher and cleaner. These correlations are important for an understanding of the tiny particles in the air. Talk with the students about this phenomenon.
- Depending on their level of interest, you can also discuss the fact that the dirt that is washed out of the air can also have negative consequences on the Earth’s surface (keyword: acid rain. Nitric oxides and sulfur dioxide in the air react with rainwater and oxygen to form nitric acid and sulfuric acid, respectively).

### 4.2.7 Reference to values

**What is your opinion?**

In the discussion about values for this experiment, the teacher can provide a prompt or tell a story in which a problem is posed. Both actions lead to a discussion based on reflections. What's important is that the reference to values can be established in the experiment. The discussion can focus either on learning-process-related values (for example, working reliably in groups) or on object-related values (for example, handling paper as a resource). The student instructions for **B3.2 Air pollution** address object-related values.

**Object-related dilemma:**
An object-related dilemma can be integrated in the discussion of the values "sustainability," "environmental awareness" (treating the environment carefully), and "acceptance of responsibility" at the end of the student instructions. The students should express their opinions about it.

**Dilemma related to a birthday ride:** It's your best friend's birthday and he lives just a few blocks away from you. You and your brother have been invited. You're running late. Your brother suggests, "Let's ask Mom if she can drive us over!"

*Think about it:* How you do see things?

**Possible statements by the students for and against the car ride:**

| Reasons for the car ride | Reasons against the car ride |
|---|---|
| ▪ The children will otherwise arrive too late.<br>▪ The mother has an electric car. | ▪ The car pollutes the environment due to exhaust gases.<br>▪ For a short distance, you can get there just as fast on a bicycle. |

**Objective:**
The students should reflect upon how they can handle the environment sustainably, responsibly, and in an eco-friendly manner. The values of sustainability, environmental awareness, and acceptance of responsibility are addressed.

**Alternatives:**
Statements or questions as prompts related to the story told in the student instructions are also suitable for encouraging discussion. The values remain the same.

- **Image for discussion:** Exhaust gases from a car
- **Question for discussion:** Where does polluted air come from?

**Notes:**
The students should reflect on values and express their opinions. It may turn out that several values are addressed.

### 4.2.8 Reference to technology

Given the increasingly strict car exhaust emission regulations that are visibly displayed for everyone through stickers on cars, the students may already be familiar with the topic of air pollution and keeping air clean.

**In the student instructions**

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|---|---|
| **Tracking down technology** | Two photos are shown in the student instructions:<br>▪ As a reference to everyday life: **vacuum cleaner with filter bag**<br>▪ As other ideas: **vacuum cleaner with centrifugal separator** (cyclone system) and **diesel particulate filter of a diesel car**<br>The students should grapple with how a vacuum cleaner with a filter bag functions, recognize the importance of filters, and discuss additional technologies that are used to separate dirt out of the air. |

Most students will be familiar with the **vacuum cleaner** with a paper filter bag. There are probably some students whose families use a **bagless vacuum cleaner**. The principle of this technology (cyclone technology) is based on centrifugal force. Many students have probably already ridden on a swing ride or roller coaster. Or they have been pressed against the side of a car or bus when the vehicle has driven around a sharp curve. These examples can be used to transfer an understanding of how dust particles behave in a spiral airflow. Maybe the students have also seen a whirlwind in nature or have heard a report about a tornado and know that soil is swirled up as a result. In meteorology, tropical whirlwinds are also referred to as cyclones, which is where the name cyclone technology comes from.

The students are likely familiar with the **emission control systems of cars**. However, few of them will know exactly how such a system works. The teacher should first explain the difference between a catalytic converter and a filter.

- The automotive catalytic converter removes unwanted components from the exhaust gas by means of a chemical reaction that converts incompletely burned gasoline or diesel residues into water and carbon dioxide. (Carbon dioxide is a greenhouse gas, but it is less damaging than incompletely burned fuel.)
- It should be explained why a diesel particulate filter has a honeycomb structure (this is also the case for metal diesel particulate filters). The honeycomb structure ensures that the exhaust gas flows through as uninhibited as possible. Due to the large surface area, the walls of the honeycomb trap an especially high number of soot particles as they pass through. As the filter traps more and more soot, it will eventually become clogged. In order to prevent this, the filter is automatically cleaned from time to time. When the car is driven fast and the exhaust gas and therefore the honeycomb filter are particularly hot, additional fresh air is blown through the filter. This causes the soot to burn. The diesel particulate filter may possibly be coated with a catalyst that burns the soot at lower temperatures. (By the way, the same catalyst is used in self-cleaning ovens in households.)

You will find the answers to the questions in the student instructions on the answer sheet in the guidebook. For technical information about the bagless vacuum cleaner and the diesel particulate filter technologies shown here, refer to the information sheet or the link list on the Siemens Stiftung Media Portal. There you will also find the work assignment as a prepared worksheet.