A2 Conductors and insulators

Subexperiment A2.1 What are conductors and insulators?
Subexperiment A2.2 Hot wire

1 Main question

The following questions underlie the subexperiments and guide the activities:

- How can you close and interrupt a circuit? (Subexperiment 1)
- Which substances are conductors, and which are insulators? (Subexperiment 1)
- What role do conductors and insulators play in the design of electrical devices? (Subexperiment 2)

2 Background

2.1 Relevance to the curriculum

Electrical conductivity is one of the physical properties of a substance, in addition to boiling temperature, melting temperature, color, odor, thermal conductivity, density, and taste. Knowledge of the conductivity of substances is part of the basic knowledge about current and electricity. We need this knowledge in everyday life and for understanding all electrotechnical applications.
If the students already have basic knowledge about switches, this knowledge can be transferred to experiments **A1.1 to A1.3 Simple electrical circuits**.

Topics and terms

Conductor, (electrical) conductivity, (electrical) contact, electrical circuit, insulator, interconnecting wire, metal, non-conductor, physical property, substances, switch

2.2 Skills

The students will ...

- be able to evaluate substances for their property as a conductor or an insulator.
- be able to indicate which components of an electronic device require conducting or insulating materials.
- transfer their knowledge by finding solutions to a technical question.

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

Notes:

- The listed materials are designed to allow **one** group of maximum **five** students to conduct the experiment.
- Some of the electronic components may be available as different versions, such as cables (cables with alligator clips or interconnecting wires), lamps (incandescent lamps or LEDs), and switches. Feel free to provide the students with other equivalent components as an alternative to the materials indicated in the list. The students can explore the different versions of electronic components, match them to their function, and use them properly.
- Only batteries and solar cells are used as voltage sources in Experimento | 8+. These are safe for the students due to their low direct current voltage.

4.1 Subexperiment A2.1 What are conductors and insulators?

4.1.1 Required materials

Material	Quantity
Battery	3
Battery holder	1
Cable with alligator clips	3
Conducting and non-conducting objects made of various substances (e.g., plastic spoon, metal spoon, pencil, nail, pieces of fabric, glass rod, wooden stick)	As varied as possible
Incandescent lamp, 3.5 V or 6 V	1
Incandescent lamp socket	1

Material for the additional experiment	Quantity
Measuring cup, 100 ml	1
Salt (small spoon, level)	1
Small spoon	1
Tap water	100 ml

4.1.2 Organizational aspects

Facilities	At a simple table in the classroom
Time required	Approx. 45 minutes
Safety instructions	See the “Safety instructions on the topic of energy” in the guidebook.

4.1.3 Explaining the subexperiment in the teaching context

The students will examine substances and determine whether they are electrically conductive or insulating.

Technical background

Substances are divided into three categories in terms of conductivity of electric current: conductors, semiconductors, and insulators. Current can flow in a conductor, not in an insulator. In a semiconductor, the conductivity can be modified across a wide range. All three categories of substances play a role in electrical devices and circuits.
Metals in particular are used as **conductors** and can serve, for example, as the conductive wire in a power cable. **Insulators** are always used when we want to prevent the flow of current. A simple example of this from everyday life is plastics, which are insulators and protect us from electric shocks when used as sheathing for current-bearing cables.

In order to understand how conductivity comes about in a substance, we must know the substance's atomic structure. In principle, a substance needs **free charge carriers** to be electrically conductive. Negatively charged electrons or ions (positively or negatively charged atoms) are possible charge carriers. You will find a summary of the most important basic physics principles related to this in the guidebook in the "Electric current and energy – Basic physics principle" handout, chapter 2.

The electrical conductivity of a salt solution is tested in the additional experiment. Salts consist of positively and negatively charged ions. If the salt is in a solid state of aggregation, the ions have a fixed position; the "mobility" requirement is thus not met. However, if we melt salt or dissolve it in water, the ions can move freely and in a controlled direction when a voltage is applied: A current flows. A solution with ions is called an "electrolyte."

4.1.4 Ask about the students' prior knowledge and ideas

Which substances are suitable for closing a circuit? Most students already have an idea that metals conduct current because they are familiar with the metallic core of a cable. Perhaps a few have heard about someone who has suffered a strong electric shock. Ask them how that happened. The students can certainly answer the question as to why someone should not use a hairdryer while in the bathtub. In this context, it is also important for the students to know that they get an electric shock if lightning strikes water when they are swimming in a lake (danger to life!). The reason is that minerals are dissolved in the lake water that turn the water into an electrical conductor. Just as it flows through the lake water, the electric current flows through the human body since the latter is also electrically conductive.
Students may be aware of fish hatcheries with lightning rods in rural areas. In contrast to staying in water, staying in a closed car made of metal is safe in a storm (keyword "Faraday cage").
It is also important to introduce the term "substance." The term "material" could be confused with textiles. The term "substance" is preferable to "material" because a material can denote several substances next to each other, for example, in a component.

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 the phenomenon that some substances conduct electricity, but others do not.
The research question 	The following alternatives to the research question stated in the student instructions are possible: ▪ What can happen if you stick a knife in a toaster that is still running? ▪ What object would be less dangerous for getting your toast out of the toaster? ▪ Which objects conduct current, and which objects do not conduct current? ▪ How can we check whether a substance is conductive or insulating?
Collecting ideas and guesses 	Some possible guesses: **Related to the research question:** ▪ “Metals conduct current.” ▪ “Plastic does not conduct current.” ▪ “Glass does not conduct current.” ▪ “Water conducts current.” ▪ “A person conducts current/does not conduct current.” **Related to the experiment:** “I build an electrical circuit and clamp the object in between. If the lamp lights up, the substance is conductive.” Segue from the guesses to the experiment.

Experimenting 	**Experiment setup:** After the testing device is set up according to the instructions, you can ask why the lamp does not light up and what they must do so that it does light up: The students will recognize that the testing device is an interrupted circuit. **Conducting the experiment:** ▪ The first test object should be an iron nail; the remaining objects can be tested in any order. ▪ Before the students begin testing, they guess the conductivity of each object/substance and note this by marking an X in the table. ▪ Difficulties may occur when objects are integrated into the circuit. For example, a glass rod is difficult to clamp in the alligator clips. However, when testing the nail, the students will determine that simply touching the object with the alligator clips is sufficient. (Or they can use an interconnecting wire.) ▪ In addition to the specified materials, students with extra time can test everyday objects like an eraser or a pen from their pencil case. For health and safety reasons, objects such as belt buckles and jewelry should not be tested while on the body, but should be taken off first.
Observing and documenting 	The students note their observations in the table: Which objects and substances caused the lamp to light up, and which did not. **Measurement results to be expected:** ▪ The lamp lights up with all metal objects. ▪ The lamp does not light up with textiles, plastic plate, glass rod, wooden stick, or plastic pen. ▪ The students talk about their experience gained during the experiment.

Analyzing and reflecting 	**Results to be expected:** ▪ Substances that conduct current: all objects made of metal → conductors ▪ Substances that do not conduct current: textiles, plastic plate, glass rod, wooden stick, or plastic pen. → non-conductors/ insulators **Transfer:** ▪ The teacher shows the objects brought in. The students determine the substance from which the objects are made and postulate a hypothesis regarding conductivity. Afterwards they test the object using the testing device (verification). ▪ Using their knowledge of conducting/insulating properties of substances, the students can explain the structure of a power cable (metal wire with plastic sheathing). **Reference to the story to get the students thinking about the topic:** Now you know why you must not stick a knife in the running toaster: Because the metal conducts current, you could get an electric shock. That would be dangerous to your health.

4.1.6 Further information

In the student instructions

Doing further research 	The experiment shows that an aqueous salt solution can also conduct current. The conductivity is provided by ions. ▪ Depending on which incandescent lamp is used (3.5 V or 6 V), more or less salt must be added. ▪ Depending on the tap water's salt content, the lamp might light up even without added salt, but have the students add salt anyway because this boosts the effect. Due to the conductivity of water, warn the students against bringing electrical devices into contact with water (see section 4.1.4). The measurements can be extended to include other liquids, such as apple juice, or damp soil (also as a homework assignment).

Miscellaneous

- Distilled water has extremely low electrical conductivity that normally cannot be demonstrated in the school experiment.
- An important conductor that does not belong to the group of metals is graphite. Free electrons are responsible for the conductivity in this case. Graphite is frequently used as a material for electronic components. The students can verify the conductivity of graphite, for example, using a pencil sharpened at both ends or the lead of a mechanical pencil.
- Gases can also conduct current under certain conditions, such as under high voltage (see lightning bolt).

4.1.7 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 **A2.1 What are conductors and insulators?** address object-related values.

Object-related dilemma:

An object-related dilemma can be integrated in the discussion of the values "acceptance of responsibility" and "initiative" at the end of the student instructions. The students should express their opinions about it.

Dilemma related to cables: After school you like to play in the basement with your older brother, Florian. Today you want to set up a camp. While you start spreading old sheets on the floor, Florian notices two cables hanging out of the wall in the corner. Florian says, "Let's take a closer look at them!" However, you think that's dangerous. Florian is annoyed. "You're such a scaredy-cat and a spoilsport!"

Think about it: What would you do?

Possible statements by the students for and against looking at the cables:

Reasons for looking at the cables	Reasons against looking at the cables
▪ The students can inspect the cables in a way that does not jeopardize their health. ▪ They can try to minimize the potential harm.	▪ It can be dangerous if the cables are not insulated.

Objective:

The students should reflect upon how they could handle the situation responsibly and on their own initiative. The values of acceptance of responsibility and initiative 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:**  ▪ **Question for discussion:** What dangers exist if loose cables are left hanging around? **Notes**: The students should reflect on values and express their opinions. It may turn out that several values are addressed.

4.2 Subexperiment A2.2 Hot wire

4.2.1 Required materials

Material	Quantity
Battery	3
Battery holder	1
Buzzer	1
Cable with alligator clips	3
Drinking straw	1 – 2
Scissors	1
Screwdriver (Phillips)	1
Shoe box or box of a similar size	1
Silver wire*	1 x 15 cm, 1 x 60 cm

* Instead of a silver wire, you can use a copper wire with a diameter of 1.5 to 2.0 mm.

4.2.2 Organizational aspects

Facilities	At a simple table in the classroom
Time required	Approx. 90 minutes
Experimental variations	Alternatives to the shoe box: wooden board, thick Styrofoam sheet Alternative to buzzer: incandescent lamp in a lamp socket
Safety instructions	See the “Safety instructions on the topic of energy” in the guidebook. Be careful when boring the holes with the screwdriver.
Cleanup	Straighten the pieces of wire again and put them away.

4.2.3 Explaining the subexperiment in the teaching context

The students will design a manual dexterity game. They will observe through this that insulators are necessary for implementing electrical devices.

Technical background

Hot wire is a manual dexterity game. The simple rule of the game is explained in the student instructions. The hot wire consists mainly of a non-insulated cable (bare wire) that is bent into a winding path. Only two small sections at the left and right are insulated using a drinking straw (see figure in the student instructions). Each time the loop mounted on the testing device makes contact with the bare wire, the testing device’s circuit is closed. This elicits a reaction from the signal generator (the buzzer buzzes or the incandescent lamp lights up).
Only the sections of the wire that are insulated with the drinking straw do not generate a signal upon contact. These sections can be used, for example, to place the loop down (“rest”) without triggering a signal when the players switch. This allows the students to vividly experience for themselves how necessary insulators are for safe flow of current.

4.2.4 Ask about the students' prior knowledge and ideas

The students' attention was directed especially to conducting substances in the previous experiments. In this subexperiment they will design an application and recognize that it is also necessary to use insulators; otherwise, if insulators were not used, a sound would be generated continuously when the loop is placed down!
Following subexperiment 1, the structure of a power cable consisting of a conductor and an insulator can be discussed. The insulating sheath on power switches and sockets can be discussed. In the low-voltage range, the housing is often used as an electrical conductor. Using examples such as a car, bicycle, hairdryer, and vacuum cleaner, you can ask the students what applies in each case: insulating or conducting property. Two examples: The bodies of most cars are integrated into the electrical circuit and a bicycle frame also functions as a conductor for the lighting. The students should have learned about a simple electrical circuit and switches and know which substances conduct and which do not.

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 should illustrate to the students when an electrical circuit is closed and what consequences this has.
The research question 	The following alternatives to the research question stated in the student instructions are possible: ▪ What you think of conductors and insulators: Which substances are suitable for the "hot wire" and the loop?
Collecting ideas and guesses 	Some possible guesses: **Related to the research question:** ▪ "Metals are suitable for the wires, for example, copper, silver, iron, …" ▪ "The buzzer can take the place of the incandescent lamp." ▪ "The buzzer can take the place of the battery." ▪ "The power source can't be left out." **Related to the experiment:** ▪ The students might believe that they could get an electric shock if they touch the wires or the battery. However, the battery is too weak for this. What can people do, though, to keep from getting an electric shock even with stronger voltage? (Answer: wrap electrical tape around the places that they touch.) ▪ The students might also believe that if the loop is resting on the wire (for example, when the players switch), they have to disconnect the apparatus from the battery so that they won't hear a continuous sound. Segue from the guesses to the experiment.

Experimenting 	**Experiment setup:** ▪ The students can use the testing device from subexperiment 1 directly and will then need considerably less time. They only have to replace the lamp with the buzzer. ▪ Connecting the buzzer to the battery holder: black cable to the negative pole, red cable to the positive pole. ▪ The loop must have a small opening so that it can be easily hooked onto the hot wire. ▪ The wire is rather cumbersome and difficult to bend. Provide assistance if necessary. ▪ At first the students will not come up with the idea of using resting points on their own (drinking straw pieces). Guide them in that direction so that they do not have to unhook the loop to keep the buzzer from buzzing continuously when they get to the finish. **Conducting the experiment:** The students in a group can hold a contest. Who is most dexterous in handling the home-made apparatus? The contest can be expanded to include the other groups (exchange the apparatus among the groups).
Observing and documenting 	By designing their own game, the students will learn that insulators are needed on certain parts, for example, as resting points. They can exchange ideas and optimize their own designs by comparing the games of the various groups.
Analyzing and reflecting 	As they design the game, the students will become aware of how important insulating substances are for electrical applications, based on the example of the drinking straws. **Answer:** The drinking straw is an insulator because it is made of plastic. If the loop touches the hot wire at this place, it does not make a conductive contact. The electrical circuit is interrupted, and the buzzer does not buzz. **Reference to the story to get the students thinking about the topic:** You have now learned why you hear a noise as soon as the loop touches the wire: The electrical circuit is closed as soon as the metal loop touches the wire. And as soon as the electrical circuit is closed, the noise is heard.

4.2.6 Further information

In the student instructions

Doing further research 	The students should vary the level of difficulty of the game. The following parameters are possibilities: ▪ Size of the loop: the smaller the loop, the more difficult the game. ▪ Shape of the hot wire: the more bends and the tighter the bends (for example, a loop), the more difficult the game. ▪ Length of the hot wire: the longer the wire, the more difficult the game. ▪ Number of resting points: small pieces of the drinking straw can be distributed on the hot wire as resting points along the way. ▪ Other possibilities for designing resting points: electrical tape (may need to be removed again afterwards).

Miscellaneous

For further study of conductivity, the teacher can specify that aluminum foil be used instead of wire. Depending on how carefully the students fold or crumple the foil, the conductivity of the design will be higher or lower, and the response (from the buzzer or lamp) will be more or less pronounced. It can be discussed that this results not only in qualitative differences (conductive/insulating), but also quantitative differences (degree of conductivity), as illustrated by the different salt concentrations in water (see subexperiment 1 “Doing further research”).

4.2.7 Reference to technology

Insulators have an important technical significance:

- They protect living organisms from electric shocks. For this reason, for example, all cables that conduct electricity in a home are always insulated (usually with plastic).
- They separate electronic components from each other. Ceramic and porcelain are often used as insulators. Show components, such as an incandescent lamp socket, or point out the insulators of high-voltage power lines.
- They prevent short circuits.