A3 Complex electrical circuits

Subexperiment A3.1 Parallel circuits
Subexperiment A3.2 Series circuits

1 Main question

The following questions underlie the subexperiments and guide the activities:

- What happens when several incandescent lamps are installed in the electrical circuit? (Subexperiments 1 and 2)
- How many incandescent lamps can be lit up by a battery? (Subexperiments 1 and 2)
- How must the lamps be connected so that they shine equally brightly? (Subexperiment 1)

2 Background

2.1 Relevance to the curriculum

The experiments on more complex electrical circuits build upon the previous experience the students have already gained through experimenting with simple electrical circuits. They will gain a better understanding of the importance of the individual components in an electrical circuit. They will acquire additional knowledge of simple causal relationships, which they can use to describe the dependence of components in an electrical circuit. Several incandescent lamps connected in succession shine less brightly than one lamp. Several incandescent lamps connected in parallel shine equally brightly, but the battery drains more quickly.

Topics and terms

Complex circuits, electrical circuit, parallel circuit, series circuit, sketched circuit diagram, divided/undivided

2.2 Skills

The students will ...

- distinguish between the structures of series and parallel circuits and the resulting properties of the overall circuit.
- know how the individual components in a series or parallel circuit interact.

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.
- With parallel and series circuits you should focus solely on the phenomenological observation. An explanation of why the lamps light up as they do is possible only if the students have ideas about the link between voltage – current – resistance and carry out energy-related analyses. This would allow discussion at a qualitative level, but such considerations go beyond the curricula.

4.1 A3.1 Parallel circuits

4.1.1 Required materials

Material	Quantity
Battery	6
Battery holder	2
Cable with alligator clips	6
Incandescent lamp (3.5 V)	3
Incandescent lamp socket	3

Material for the additional experiment	Quantity
Cable with alligator clips	1
Slide switch	1

4.1.2 Organizational aspects

Facilities	At a simple table in the classroom
Time required	Approx. 30 minutes Subexperiment 2 should be conducted immediately afterwards.
Experimental variations	The teacher builds the electrical circuit with an incandescent lamp. The teacher demonstrates the modification into a parallel circuit. The students then build their own parallel circuit.
Safety instructions	See the “Safety instructions on the topic of energy” in the guidebook.

4.1.3 Explaining the subexperiment in the teaching context

In a parallel circuit, each component (here each incandescent lamp) is directly connected with the voltage source. The electrical circuit includes junctions. Each component has its own electrical circuit.
All components are supplied by the same voltage. That's why the two incandescent lamps in the experiment shine just as brightly as in the electrical circuit with one lamp. The current branches out to the components according to their resistances.
If the current flow for one of the two incandescent lamps is interrupted after the junction, this does not affect the other incandescent lamp.

Notes:

- The incandescent lamps in this experiment all have the same resistance.
- You will find a summary of the most important basic physics principles on voltage, current, and electrical resistance in the guidebook in the "Electric current and energy – Basic physics principle" handout, chapters 3 – 5.

4.1.4 Ask about the students' prior knowledge and ideas

Parallel circuits are very common in everyday life (for example, power strip, bicycle lighting with a dynamo), but may be more difficult for some students of the specified age to understand than the series circuit. Therefore, initially, the students are to gain only simple experience with these circuits.
The students should already have learned about simple electrical circuits.

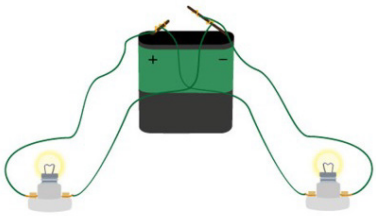
4.1.5 The research cycle

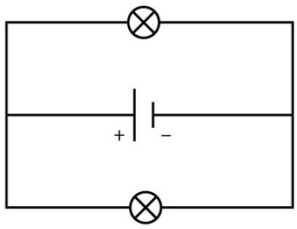
Important aspects and information regarding the individual process steps of the research cycle during the experiment for students:

Recognizing the problem/phenomenon 	This experiment is about recognizing how you build an electrical circuit with multiple incandescent lamps so that these incandescent lamps still light up when one of them burns out.
The research question 	The following alternatives to the research question stated in the student instructions are possible: ▪ What happens if two incandescent lamps are powered by one voltage source? ▪ Can a battery light up two incandescent lamps just as brightly as a single incandescent lamp?
Collecting ideas and guesses 	Some possible guesses: **Related to the research question:** ▪ “A battery can light up only one lamp.” ▪ “Clearly that must work. In our lampshade in the living room, all lamps burn equally brightly.” ▪ “The one battery is too weak; you need a stronger one.” **Related to the experiment:** ▪ “Why do I need so many cables?” ▪ “I build an electrical circuit from the cables and lamps and make sure that each lamp is connected to the battery.” ▪ “With several lamps and cables, it is really difficult to build a closed electrical circuit.” Segue from the guesses to the experiment.
Experimenting 	**Experiment setup:** ▪ The purpose of the comparison electrical circuit is to be better able to compare the brightness of the lamps in the experimentation electrical circuit. ▪ If you use materials other than those indicated in the list of materials, make sure that identical incandescent lamps with the same specification are used consistently and that the same battery capacity is used as well. Otherwise, a comparison of the two electrical circuits is not possible.

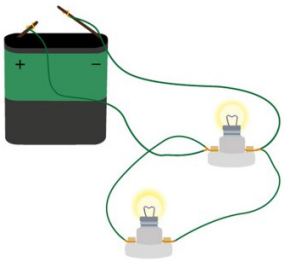
Conducting the experiment:

- Some students will also spontaneously build a series circuit.
- For a parallel circuit, there are several options for installing the wiring. Despite the different appearances, they are functionally equivalent.
- The student will document all built circuits by means of sketched circuit diagrams.

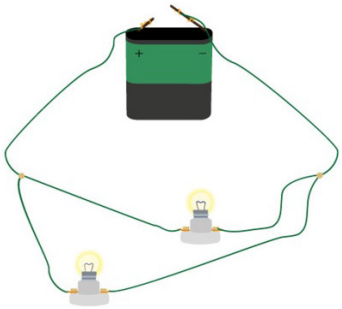


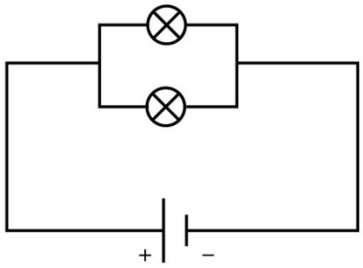


Here, each incandescent lamp is attached directly to the battery terminals. In this case, the underlying concept of “each incandescent lamp has its own electrical circuit” is easier to understand. Most students will probably build this type of circuit.



Here the wires are attached in steps from one incandescent lamp to the next.





Here the wires are attached at a junction.
This variant requires the most cables. The students probably will not figure out this circuit by themselves. That is why the related sketched circuit diagram is explicitly specified again in the observation step and the students are instructed to build this circuit. The students should be capable of recognizing the circuits as being equivalent and graphically converting one to the other.

Observing and documenting 	**Most important observations:** ▪ The two incandescent lamps in the experimentation electrical circuit with the parallel circuit shine <u>just as brightly as</u> the lamp in the electrical comparison circuit. ▪ The students should re-create the specified circuit (sketched circuit diagram provided) if they did not figure it out during the experiment. Another observation may be that in the experimentation electrical circuit, an incandescent lamp continues to shine at an undiminished brightness (compared with the comparison electrical circuit) when a student unscrews the other lamp.
Analyzing and reflecting 	**Results to be expected:** 1. In terms of the wiring, a parallel circuit corresponds to **two** individual electrical circuits. To come to this realization, the students can trace the electrical circuits with their fingers. 2. When an incandescent lamp is unscrewed, only the electrical circuit containing the lamp is interrupted. However, the current can flow back to the battery via the second electrical circuit. The lamp in this second electrical circuit remains lit up. It doesn't make a difference which lamp is unscrewed. This activity reinforces the understanding of what makes up an electrical circuit. **Reference to the story to get the students thinking about the topic:** So that the other lamps still light up if one of them should burn out, a parallel circuit is integrated in the dollhouse.

4.1.6 Further information

In the student instructions

Doing further research 	For further study, the students can integrate a switch and observe what it does – depending on where it is added: ▪ If it is added before the junction, it turns all lamps on/off. ▪ If the switch is added after a junction, it turns off only the lamp immediately following the switch. The wiring of lighting in buildings is also a parallel circuit. A switch is installed in each of the parallel electrical circuits so that, for example, you can turn off the light in the bathroom while the light in the hall stays on. Only the fuse is installed as a switch before the junctions. If this switch is turned off, then none of the lights will work.

4.1.7 Reference to technology

In the student instructions

The parallel circuit that the students investigate in various experiments corresponds to standard wiring, for power distribution both via long-distance power lines and in the local grid, as well as in every single house. Although it is ubiquitous in everyday life, most students are completely unaware of it.

Tracking down technology 	The following photos are shown in the student instructions: ▪ As a reference to everyday life: **string of lights with light-emitting diodes** ▪ As another idea: **portable power strip** with a switch for a TV sound system. The students should grapple with the purpose and functioning of the devices shown and establish the reference to the parallel circuit. Creating sketched circuit diagrams allows them to check their knowledge.

All students are familiar with **strings of lights** as Christmas decorations. The teacher should point out that in the past, people often used strings of lights with a series circuit (uses less cable) and explain what the advantage of the modern parallel strings is (operational even if individual lamps burn out). All students are familiar with **power strips** from everyday life. However, the fact that the internal wiring is a parallel circuit is less well known. From their direct current experiments, the students know that in a parallel circuit, the same voltage is available to all electrical devices. With the guidance of the teacher, the students could verify that this is also the case with the power strip at home by analyzing the voltage information on the type plate of various electrical devices. All devices, whether a hair dryer, incandescent lamp, hand-held mixer, or vacuum, are rated at a certain number of volts depending on the country (for example, 230 volts in Europe, 110 volts in the United States). Since several of these devices can be plugged in and operated simultaneously, they must all receive the same voltage and thus be connected in parallel. Discuss the topic of saving energy in the context of power strips, which can be used to completely disconnect devices (television, radios, etc.) from the grid. This is because current flows in many devices as soon as they are connected to the grid (standby mode).

You will find the answers to the questions asked in the student instructions on the answer sheet in the guidebook. In the “Experimento | 8+: Tracking down technology” media package, which is available on the Media Portal, you will find additional technical information compiled in an information sheet and a link list. This media package also includes all of the individual photos as well as the work assignment as a prepared worksheet.

Miscellaneous

Behavior of a parallel circuit in an overload situation: Whether on the main power grid, on the distribution grid, or in a home, if too many electrical devices are connected in parallel, the voltage will drop due to overloading of the voltage source or the lines will become too hot if too much current is flowing. In a home, the fuse is triggered to prevent fire, and in the main or distribution power grid, a blackout may occur.

4.2 A3.2 Series circuits

4.2.1 Required materials

Material	Quantity
Battery	6
Battery holder	2
Cable with alligator clips	3
Incandescent lamp (3.5 V)	3
Incandescent lamp socket	3

Material for the additional experiment	Quantity
Cable with alligator clips	2
Slide switch	2

4.2.2 Organizational aspects

Facilities	At a simple table in the classroom
Time required	Approx. 30 minutes Subexperiment 1 should be conducted first.
Experimental variations	▪ The students work with only one electrical circuit. First, they build the electrical circuit with a lamp. Then they add the second lamp. ▪ The teacher builds the electrical circuit with an incandescent lamp. The teacher demonstrates the modification into a series circuit. The students then build their own series circuit.
Safety instructions	See the “Safety instructions on the topic of energy” in the guidebook.

4.2.3 Explaining the subexperiment in the teaching context

The students will connect two incandescent lamps in series.

Technical background

In a series circuit, the “output” of one component (here, an incandescent lamp) is connected to the “input” of the next component (another incandescent lamp). There are no junctions in the electrical circuit.
Note: A technician also says connected “in series” or “serial” connection.
In a series circuit, equally strong current flows through all components. The voltage is allocated to the components according to their resistances. This is why the two incandescent lamps shine less brightly than if only one incandescent lamp were in the electrical circuit.

Notes:

- The incandescent lamps in this experiment all have the same resistance.
- You will find a summary of the most important basic physics principles on voltage, current, and electrical resistance in the guidebook in the “Electric current and energy – Basic physics principle” handout, chapters 3 – 5.

4.2.4 Ask about the students' prior knowledge and ideas

Only a few students have a notion that two incandescent lamps connected to a battery shine less brightly than one by itself. With antiquated strings of lights for Christmas trees, they may have observed that an entire string of lights went out when someone unscrewed one lamp. Otherwise, series connections are rarely used anymore in the electrical circuits we encounter in everyday life. The students should already have experience with simple electrical circuits.

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 	The students should recognize the difference between a parallel circuit and a series connection. In a series connection, the electrical circuit is interrupted even if only one of the integrated incandescent lamps is defective.
The research question 	The following alternatives to the research question stated in the student instructions are possible: ▪ How can you integrate two incandescent lamps in series in an electrical circuit? ▪ What happens if two incandescent lamps are powered by one voltage source? ▪ Do two incandescent lamps integrated in an electrical circuit with one battery shine as brightly as only one incandescent lamp in the same electrical circuit?
Collecting ideas and guesses 	Some possible guesses: **Related to the research question:** ▪ "The battery supplies all lamps at the same time, so they all shine equally brightly." ▪ "One lamp shines less brightly." **Related to the experiment:** ▪ "You need a lot less wiring than with a parallel circuit." Segue from the guesses to the experiment.
Experimenting 	**Experiment setup:** ▪ The reason the sketched circuit diagram is specified is so that the students do not build a parallel circuit again in this experiment. The challenge is for the students to build an electrical circuit based on a sketched circuit diagram. ▪ For more information, see subexperiment 1. **Conducting the experiment:** No particular information.

Observing and documenting 	**Most important observations:** ▪ The two lamps in the experimentation electrical circuit shine less brightly than the one lamp in the comparison electrical circuit. ▪ In the electrical circuit with the series connection, none of the lamps will shine if someone loosens or completely removes one lamp.
Analyzing and reflecting 	**Results to be expected:** 1. The series circuit is one electrical circuit. If someone unscrews a lamp, this electrical circuit is interrupted and no more current flows. It doesn't matter which lamp is unscrewed. 2. Disadvantage of a string of lights with a series circuit: The entire string goes out when one lamp is unscrewed or burns out. In a parallel circuit, the remaining lamps continue to shine. Modern strings of lights combine series and parallel connections of the lamps (for details see chapter 4.1.7). Point out to the students that this method of "switching off" (unscrewing a lamp so all go out) should not be carried out in everyday life. Always operate the switch or, if there isn't a switch, pull the plug. **Reference to the story to get the students thinking about the topic:** Now you know why a series connection is rather unfavorable for a string of lights: It lights up only if all lamps are working. As soon as one of the lamps is defective, the other lamps in the string of lights also no longer light up.

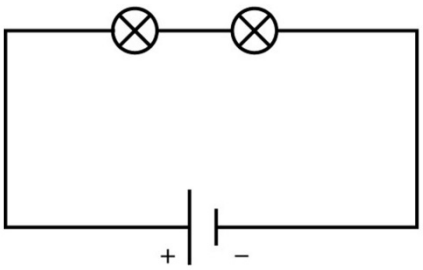
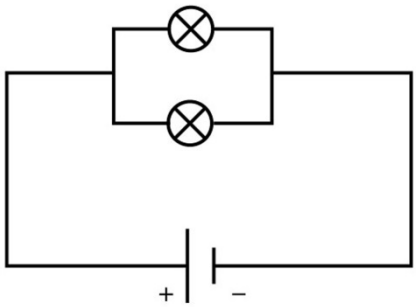
4.2.6 Further information

In the student instructions

Doing further research 	Two switches are added to the series circuit. The students can integrate them anywhere in the electrical circuit (before or between the lamps); the effect is always the same. The electrical circuit is completely interrupted as soon as a switch is opened; neither of the two lamps will light up anymore. Current flows only when both switches are closed. In technology, the principle of the series connection of switches is applied, for example, to increase the safety of electronic devices. Deeper reflection on the advantages and disadvantages of series circuits makes sense after the students have already conducted the subexperiment with parallel circuits (see subexperiment 1).

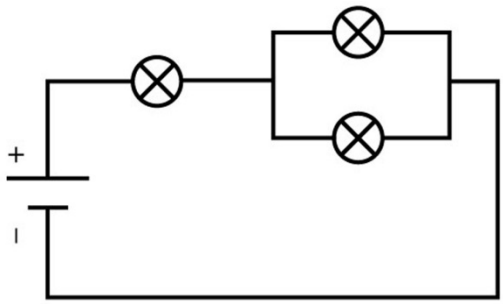
Miscellaneous

- The students add more identical incandescent lamps to the series circuit. They could also use a higher-capacity battery so that all incandescent lamps light up more brightly. To increase the battery capacity, they can connect batteries in series (see experiment A4.1).
- We recommend that teachers conclude the topic of series and parallel circuits by having the entire class reflect upon the observed differences (see table).

	Series circuit	**Parallel circuit**
Sketched circuit diagram (with incandescent lamps)		 (one of three possible variants)
Electrical circuit	Undivided; the components are installed in a common electrical circuit.	Divided; each component has its own electrical circuit.
Voltage	Only a portion of the voltage is applied to each component.	The same voltage is applied to every component.
Electricity	The same current flows through each component.	The current is divided among the parallel electrical circuits.
Compared with a simple circuit with only one incandescent lamp …	... all lamps shine less brightly.	… all lamps shine equally brightly.
Switches in the electrical circuit	Turn all components on/off.	Depending on where the switch is installed, it turns all components on/off or only the component in the partial electrical circuit.
Advantages	The battery lasts just as long as with one component.	If a component is broken or missing, the others are still supplied with current.
Disadvantages	If a component is broken or missing, then no other component is supplied with current.	The battery drains more quickly than with one component.
Applications in technology	▪ Lamps: string of lights (outdated) ▪ Switches: safety switches (for example, on a washing machine or microwave oven), fuses in a fuse box	Lamps: strings of lights, bicycle lighting, dollhouse lighting

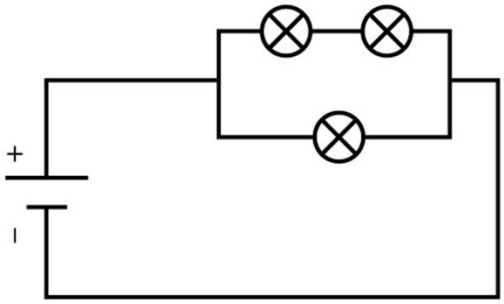
- For further study, the students can design a combined series and parallel circuit. They should predict how brightly the incandescent lamps will shine. This exercise will more firmly establish the differences between series and parallel circuits. Due to the complexity of the topic, the students will likely need assistance.

  The following circuit options are possible:



Observation:

- All incandescent lamps shine less brightly than the lamp in the comparison electrical circuit.
- The lamps connected in parallel do not shine as brightly as the lamp connected in series.
- The lamps connected in parallel shine equally brightly.



Observation:

- Only the lower incandescent lamp shines as brightly as the lamp in the comparison electrical circuit.
- The two upper lamps do not shine as brightly as the lower lamp.