6. Electricity

Electricity plays an important role in the lives of most people on Earth.

Most households around the world make use of electricity, e.g. to light rooms, to cook meals, to listen to the radio, and much more. Workshops and all kinds of services – even on a small scale – depend on electricity to power various machines and appliances. Industries and industrialization are unthinkable without electricity. Most technical occupations require at least some basic knowledge about electricity. In short: Electricity – and knowledge about electricity – is highly relevant to the personal life of students, to their technical and vocational education and professional development, as well as to the economy and economic development of a village, region or country.

Safety

At the beginning of the modules about electricity, introduce the relevant safety instructions to the students when working with the experiments. If you consider it necessary, link the safety instructions to general electrical safety rules:

- Do not put your finger or objects into outlets.
- Do not use electrical equipment or electronics near water or when your hands are wet.
- Don’t plug to many things into the same power strip or extension cord.
- Do not yank cords when you want to unplug electrical equipment.
- Do not ouch outdoor transformer boxes.

In our experiments, we work with safety extra-low voltages, which is 20 volts maximum. Our experiments are designed with 3 volts, so you are on the very safe side. If you use other power sources and work with higher voltages, e.g. power banks and 5 volts, you are still safe. However, note that in these cases for some experiments you may need to adjust the resistor values.

Introducing ‘electricity’ to students

As with any lesson and particularly with the introduction of a new topic, it is worth piquing the students’ interest, assessing their prior knowledge, and linking learning to the individual contexts of the students. To introduce the topic of electricity, you could ask students the question: “Where did you use electricity today?”

Depending on your teaching style, class size and teaching context, and students, your method for providing information and collecting answers will differ; e.g. students answering individually or working in groups, etc.

After your introduction, students should understand the following:
You cannot see electricity, but you can observe its effects, e.g. light, heat and power.
For a light bulb to shine (which is actually a by-product of the generation of heat), an electric motor to run, or a buzzer to ring, you need to connect the electrical load to a power source.

This would be a good starting point for experiment 6.1.

Materials for doing experiments: cables with crocodile clips and/or breadboards

The primary purpose of the experiments is the understanding of electricity, electrical components, and electronic circuits. The experiments to understand electricity and electronics are designed to be conducted as simple as possible.

The experiments can be done with different materials. To make the experiments affordable and sustainable, we have chosen to build our experiments around the use of standard electronic components that are low-cost and easily replaceable.

The introductory experiments **6.1 Simple electrical circuit** and **6.2 (1) Diodes** are designed to be conducted with crocodile clip cables (and components). From experiment **6.3 LEDs** onwards, the experiments are designed using so-called breadboards. Breadboards are good to build more complex experiments, as will be required when progressing in the learning path. Particularly module 7, electronics, requires building increasingly complex circuits. For using breadboards, you need to introduce the students with its function. Doing the experiments with breadboards from 6.3 onwards will help your students to learn and practice with it.

However, the introduction, learning and practice of using breadboards requires additional time. If for whatever reason it will not be possible or feasible for you to use breadboards, you also have the alternative option to do the experiments 6.3, 6.4 and 6.5 (and 7.1 in the electronics module) with crocodile clip cables and the standard components. For each of these experiments, you find alternative experimentation instructions either using breadboards (and standard components), or using cables with crocodile clips (and standard components). Note that the experiment 6.3 with crocodile clip cables differs to experiment 6.3 done with the breadboard (the one with crocodile clip cables uses one LED only).

Using breadboards

If you as a teacher have not used breadboards before, you need to familiarize yourself with the breadboard and its use and practice building circuits. For your additional understanding and as background information, you find some information, hints, and tips about breadboards after the list of components below. Please note that the information provided there has been compiled for you as the teacher and goes way beyond what the students need to know. For students to be able to use the breadboards it suffices to introduce the breadboards to them, clarify their function and support them by using them.

A good time to do introduce breadboards to students would be after they have been doing experiments **6.1 Simple electrical circuit** and **6.2 (1) Diodes** with crocodile clips.
You can then link introduction of the breadboard to experiment **6.1 Simple electrical circuit** and the prior knowledge about electrical circuits. Experimentation instruction for teachers **6.2 (3) Introducing the breadboard** provides you with more information how you can do this.

Practical hints and remarks for doing experiments with standard components

As electronic components sometimes break of get lost, we recommend buying the components in bulk to be able to replenish materials. This does NOT mean that you should not teach your students handle the components careless. On the contrary, both a proper, careful, and responsible handling of the components are necessary for safety reasons, for the correct conducting of the experiment, and for pedagogical reasons.
On the side of the teacher, experience has shown that appropriate organization and storage of the material reduces loss and allows to have the components ready when they are needed. This refers to both adequately storing the components in-between experiments as well as for distributing the components before the lesson, collecting them at the end of the lesson, and correctly sorting and storing the components afterwards. For storing the small components, you may want to use container with lids (e.g. old jam glasses) for each component, e.g. one container for green LEDs, another container for red LEDs, another container for transistors, etc. You can pack all the containers in one larger box, together with the other materials you need for the experiments, e.g. crocodile clips, breadboards, etc.

The following listing suggests a stock of components that will enable you conduct the electricity and electronic experiment:

- Battery holders
- Batteries (1.5V)
- Crocodile cables (preferably red and black)
- Buzzers
- Resistors of different values (e.g. 33 Ω, 330 Ω, 1 kΩ, 10 kΩ)
- Diodes
- LEDs (for example red LEDs and another colour, e.g. green, yellow, orange or blue).
  Note that red LEDs have different threshold voltages as green or yellow LEDs, see information sheet in the experimental instructions)
- Additional components for experiments on electronics
- LDR (light dependent resistor)
- npn-transistors
- Capacitors (e.g. 100 μF)

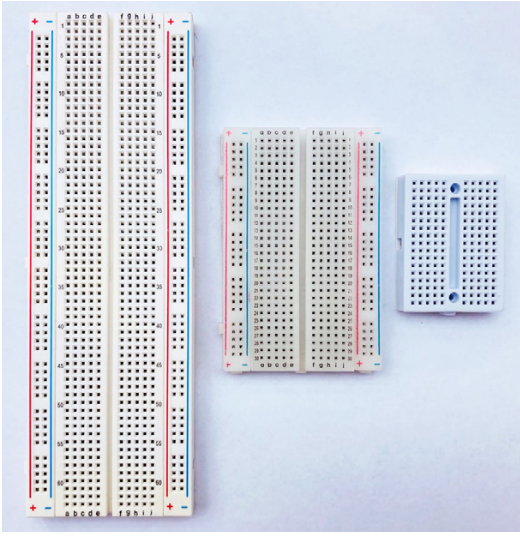
When working with breadboards, you additionally need breadboards and jumper wires (connecting cables).

Breadboards: information, hints, tips, introduction work sheet

What is a breadboard?
A breadboard is a rectangular plastic board with rows of tiny holes in it. These holes let you easily insert electronic components to build an electronic circuit. The connections in the breadboard are not permanent, so it is easy to remove a component from an electrical circuit, or just start over. This makes breadboards great for experimenting with electronic components and building electrical circuits, e.g., our experiments in modules 6 and 7.

Breadboards are made from plastic material, and come in all shapes, sizes, and even different colors. The most common sizes are “full-size,” “half-size,” and “mini” breadboards. A single half-sized breadboard is sufficient for many beginner-level projects.

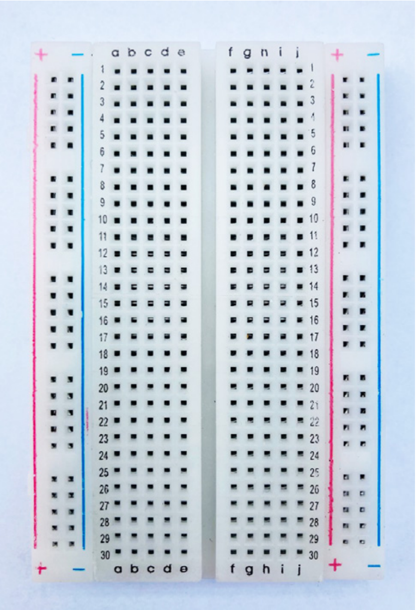
Many electronic components have long metal legs called leads that fit into a breadboard. Sometimes, shorter metal legs are referred to as pins instead. Almost all components with leads will work with a breadboard: you can push these leads into the holes. They will be held in place tightly enough that they will not fall out, but lightly enough that you can easily pull on them to remove them.



You do not need any special tools to use a solderless breadboard. However, many electronic components are very tiny, and you may find them difficult to handle. A pair of miniature needle nose pliers or tweezers may make it easier to pick up small components.

Using breadboards with students: how breadboards look like and how they function
To use breadboards with students, you must introduce breadboards and their function to the class. Preferably, you link the introduction of the breadboard to prior knowledge about electrical circuits and include a hands-on task. For example, you may to introduce the breadboard with re-doing experiment 6.1 (simple electrical circuit) on the breadboard.

To understand a breadboard, it is helpful to know how they are built. Usually, breadboards are opaque, and you do not see the inside. The inside of the breadboard is made up of sets of five metal clips. This means that each set of five holes forming a half-row (columns A – E or columns F – J) is electrically connected; just as if they are wired together. The rows on the breadboard have numbers and letters. These labels help you locate certain holes on the breadboard so you can follow directions when building a circuit. Row numbers and column letters help you identify individual holes in the breadboard. The electrical connection within one row is the most important point students need to understand. For example, hole A1 is electrically connected to holes B1, C1, D1, and E1. It is not connected to hole A2, because that hole is in a different row, with a separate set of metal clips. It is also not connected to holes F1, G1, H1, I1, or J1, because they are on the other “half” of the breadboard – the clips are not connected across the gap in the middle.



This image shows the main breadboard rows (numbers from 1 to 30, letters from A to J) and the two rails (+, –, the long strips on the sides of the breadboard) and how they are electrically connected in a typical half-sized breadboard, highlighted in yellow lines.

In the image you can see that the breadboard has numbers and letters; in this case numbers from 1 to 30, and letters from A to J. You also see longer lines with '+' and '– '.

The shorter rows and the longer lines (often called 'rails') indicate that there are two kinds of metal strips inside the breadboard. The short rows connect 5 row holes at a time. The long rails connect 25 (or more!) column holes at a time. Breadboards are almost always made so that they have two sets of 5-hole rows and pairs of rails on either side.

These longer rails are typically marked by red and blue (or red and black) lines, with plus (+) and minus (–) signs, respectively. They are typically used to supply electrical power to your circuit when you connect them to a battery pack or other external power supply. Rails on opposite sides of the breadboard are not connected to each other. To make power and ground available on both sides of the breadboard, you would connect the buses with jumper wires. However, in our experiments for modules 6 and 7 it will suffice if you use the buses on one side only.

Breadboards and diagrams

In the experiments from 6.3. onwards, you see diagrams how to insert the electronic components into the breadboard. There are different ways to change the physical layout of a circuit on a breadboard without changing the electrical connections. Although it is not necessary that your experimental set up matches exactly the diagram, it is probably best to follow the breadboard diagrams exactly when you are first starting out using breadboards.

Jumper wires

To make connections on a breadboard ('connecting different rows and rails in the breadboard'), we make us of jumper wires. Jumper wires are flexible and have stiff ends that are easy to push into the breadboard holes. These wires usually come in packs of varying colors. There are several options available when purchasing jumper wires.

Alternatively, instead of purchasing ready-made jumper wires, you can easily make your own connecting wires out of spools of solid-core hookup wire and a pair of wire strippers. Making your own jumper wires, or having students make jumper wires, is also very costeffective. You can also cut them to the length required. Buying a solid-core wire of six different colours is a good way to start. It is important to buy solid core wire (which is made from a single, solid piece of metal) and not stranded wire (which is made from multiple, smaller strands of wire, like a rope). Stranded wire is very hard to push into a breadboard's holes and will fray. You also need to purchase solid-core wire with the right wire diameter.

Color coding

‘Colour coding’ on your breadboard is a matter of convenience in that it can help you stay more organized in your setting-up and understanding of circuits on the breadboard. Using color wires of different colours does not affect how electricity flows through the wire and will not change how your circuit works: all jumper wires are just metal on the inside with colored plastic insulation on the outside. Important: This statement only applies to jumper wires. Some circuit components, like battery packs and certain sensors, come with colored wires already attached to them. Keeping track of these colors does matter very much. Do not get the red and black leads on a battery pack mixed up. In electronics, it is generally standard to use red wire for positive (+) connections and black wire for negative (–) connections. We recommend that you use red wires for connections to positive, and black for connections to negative. This will help you keeping your electrical circuit clear and simple.

How to build a circuit on a breadboard and common mistakes

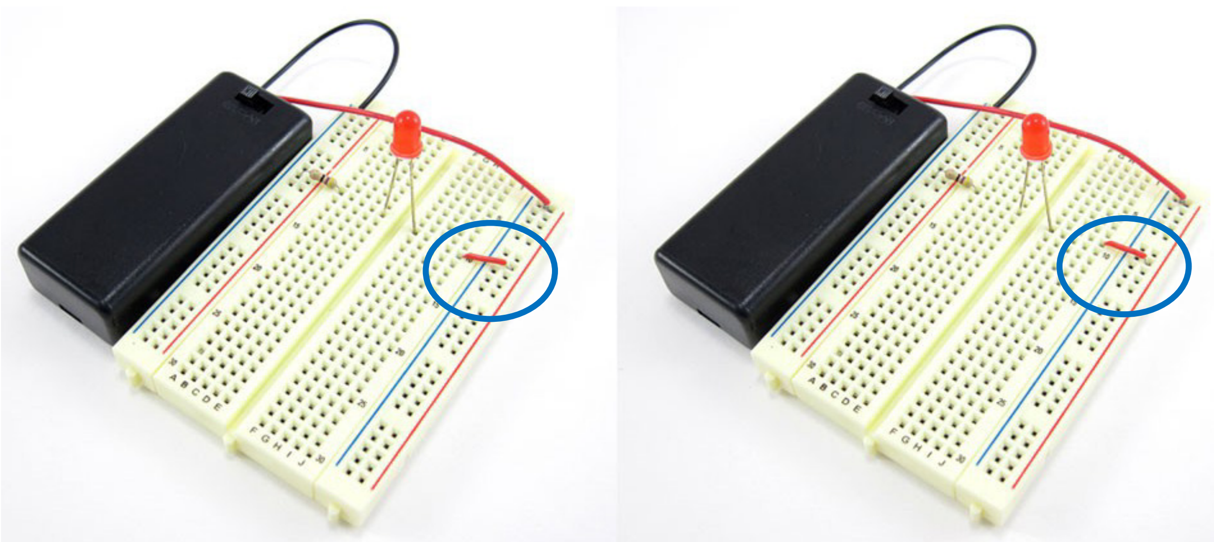
For our experiments it is recommended to follow the breadboard diagram for the circuit exactly, connecting one component at a time.
Always connect the batteries or power supply to your circuit last.
This will give you a chance to double-check all your connections before you turn your circuit on for the first time.

Once your electrical circuit is set up on the breadboard, double-check your circuit and the breadboard diagram to make sure all your components are in the right place. Check what your circuit is supposed to do according to the project directions. Is it supposed to make noise, flash a light, or somehow respond to a sensor (like a light sensor)

Once you’ve checked the circuit, turn the power to your circuit on (for example, connecting the battery pack to your buses). If you see or smell smoke, turn off or disconnect the power supply immediately. Most likely, this means you have a short circuit.

If your circuit or the circuits of the students do not work, you need to troubleshoot respectively instruct your students how to troubleshoot.
The four most common mistakes in using breadboards are:

- **Getting row numbers wrong, inserting a jumper cable into wrong row.**



It only takes one misplaced wire or component lead to stop a circuit from working completely. This is why you should always carefully check and double-check your wiring before you test a circuit. If a circuit is not working, double-check the connections and make sure to count the row numbers.

- **Getting power and ground mixed up**
  Similar to getting row numbers wrong, getting the power and ground buses mixed up is another common mistake.

- **Not pushing leads and wires in all the way**
  Electronic components and jumper wires can all have leads of varying lengths. Sometimes students will only push leads partially into a breadboard hole, instead of pushing them down firmly all the way (until they cannot go any farther). This can result in loose connections that lead to strange circuit behavior, like an LED flickering on and off. Take a look at these two side-by-side images. The image on the left shows leads that have not been pushed into the breadboard all the way. The picture on the right shows leads that are properly pushed into the breadboard as far as they can go. Note that some components, like LEDs, have very long leads that do not fit into the breadboard all the way. Other components, like pre-cut jumper wires, typically have leads cut to the right length, so they fit flush up against the breadboard.

- **Short circuits**
  Short circuits occur when “accidental” connections are made on a breadboard between two components that are not supposed to be connected. This can happen from putting components into the wrong rows or buses, or from letting exposed metal parts touch each other. For example, resistors and LEDs have long metal leads; if you are not careful, these leads could bump into each other and cause a short circuit. If your circuit has components with long, exposed leads, always make sure the leads are not touching each other.

From circuit diagram to breadboard layout

Circuit diagrams, or schematics, are a way to represent a circuit using symbols for each component. Circuit diagrams, as opposed to breadboard diagrams, are used when designing and showing circuits. Unlike breadboard diagrams, circuit diagrams only show electrical connections between components. They do not necessarily correspond to the physical layout of the components on a breadboard.