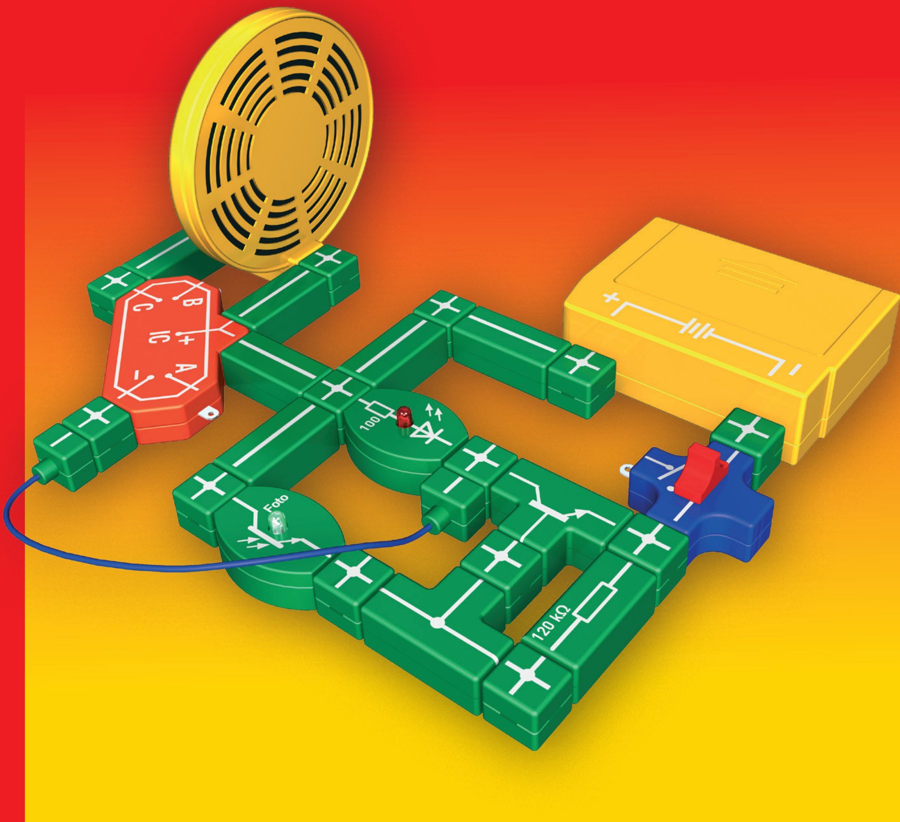
electron-x

ELECTRONICS
learning circuits

Thames & Kosmos



Experiment Manual

Safety Information

Warning! For use only by children who are at least 8 years of age. Instructions for parents or other responsible adults are included and must be followed. Save the packaging, as it contains important information.

Note! Individual parts of this experiment kit are designed with points or sharp corners and edges. Do not injure yourself!

Caution!
- Never connect an LED directly to a battery — it could blow out.
- Do not use electrical wall outlets for the experiments!
- Do not insert wires or components into outlets!
- Main power supply voltage (110 volts) is deadly dangerous.
- For the experiments, you will need two 1.5-volt AA batteries, which are not included in the experiment kit box due to their limited shelf life. You will therefore have to buy two of these batteries.
- When performing the experiments, do not short-circuit the batteries — they could explode!
- Never short-circuit the battery terminals! Remove used batteries from the experiment kit.
- Remove old batteries from the battery compartment. Insert new batteries with the correct polarity. Dispose of used batteries in accordance with environmental guidelines.
- Never use batteries of different types or new and used batteries together.
- Only install batteries with the correct polarity. Never try to recharge non-rechargeable batteries! They could explode!
- Remove rechargeable batteries from the experiment box before recharging them.
- We assume no responsibility for any possible damage of any kind resulting from the experiments. The instructions and materials are for instructional purposes only, and not for professional or practical application.

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Notes on Environmental Protection

None of the electrical or electronic components in this kit may be disposed of in the regular household trash at the end of their lifespan; instead, they must be delivered to a collection location for the recycling of electrical and electronic devices. The symbol on the product, instructions for use, or packaging indicates this.

The materials are reusable in accordance with their designation. By reusing or recycling used devices, you are making an important contribution to the protection of the environment. Please consult your local authorities for the appropriate disposal location.

ELECTRONICS learning circuits

Experiment Manual

Franckh-Kosmos Verlags-GmbH & Co.KG, Stuttgart, Germany
Thames & Kosmos, LLC, Providence, RI USA

Introduction

This experiment kit will explain to your child, in a safe and simple way, what electronic components such as transistors, LEDs, resistors, and capacitors are and how simple electronic circuits work.

It is natural for you to have questions about safety. All of the experiments receive their power supply from the battery box included with the kit, into which you will be inserting two penlight batteries. In other words, the experiments will be performed with a very low and safe electrical current of just 3 volts. In addition, this kit conforms to US and European safety norms that impose requirements on the manufacturer but that also anticipate that parents will stand by their children ready to help with assistance and advice.

Make it clear to your child that he or she should read all applicable instructions and safety notes and keep them ready for reference. Draw his or her attention to the fact that all notes and rules must be followed while performing the experiments.

We wish you a lot of fun and success with the experiments!

Safety Instructions

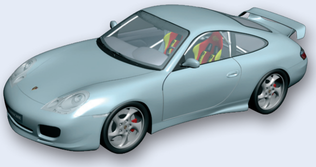
Please Note!

- Warning! Only for use by children 8 years of age and older!
- Notes for parents or other responsible adults are enclosed and must be observed.
- Save the packaging, as it includes important information!
- Do not perform experiments using the household electrical supply outlets! Do not insert wires or other components into outlets! The household voltage (110 volts!) can be deadly!
- For the experiments, you will need two 1.5-volt AA batteries (also known as LR6 or penlight batteries), which cannot be included in the kit due to their limited shelf life. So you will need to provide two fresh batteries.
- Avoid short-circuiting the batteries while experimenting. They could explode!
- Never short-circuit the battery terminals!
- Remove used batteries from the experiment kit (take old batteries out of the battery compartment). Insert new batteries with the correct polarity. Dispose of old batteries in accordance with waste disposal regulations.
- Never combine batteries of different types, or a new battery with a used one.
- Only insert batteries with the correct polarity! Never try recharging non-rechargeable batteries! They could explode!
- Remove rechargeable batteries from the kit box before recharging them!
- We assume no guarantee against any damage that may result from the experiments.
- The manual and materials are for educational purposes only, not for professional or practical use.

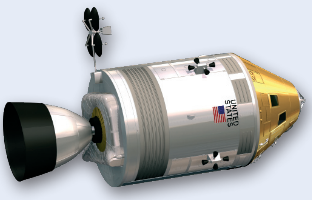
Electronics

Electronic technology shapes our lives.

Radio, television, MP3 players, cell phones, digital cameras, DVD players, video game systems, and computers — all of these devices work thanks to electronics.



Electronic devices control and monitor cars, ships, and airplanes, even entire factories, industrial plants, and refineries. They are at work in microwave ovens, washing machines, and x-ray devices. And space travel would be impossible without the electronic systems in satellites, rockets, and space probes.



Electronics is still fairly young. It has only existed for about 100 years. It more or less began with the invention of the radio tube. Further important milestones were the invention of the transistor and of the computer chip. In recent years, electronics has seen a breathtaking pace of development, with ever smaller and more powerful devices becoming possible. And yet all signs indicate that electronics is still in its infancy, and that its future holds the promise of miracles that we cannot even conceive of today.

But how do all these fascinating electronic devices work?

The experiments that you will be able to perform with this kit will give you a first look at this interesting and newsworthy subject area. The kit contains lots of electronic components such as transistors, LEDs, speakers, phototransistors, resistors, and capacitors.

It is easy to combine them into about 70 different assemblies, or “electronic circuits,” simply by putting them together according to the diagrams.

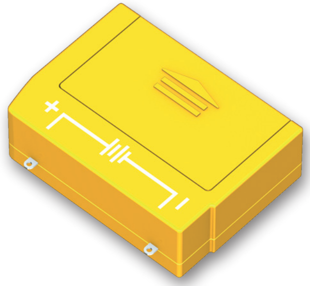
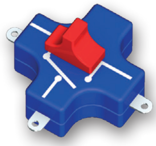
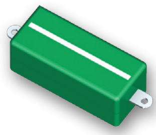
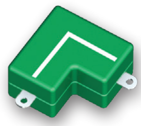
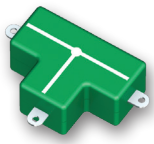
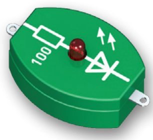
For example, you can build timer switches, flashing lights, alarm systems, amplifiers, rain detectors, dimmer switches, metronomes, and sound generators for police or fire engine sirens.

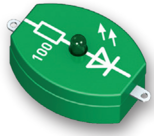
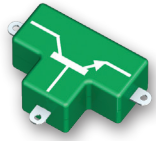
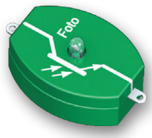
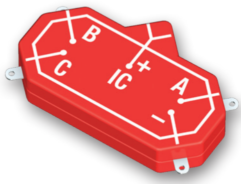
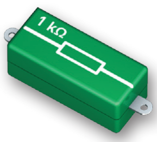
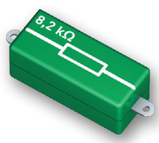
All the electronic circuits that you will be assembling with the blocks in this kit can be powered with the current from two batteries. And if you want to know more precisely how transistors, LEDs, and all the other components work and what’s happening invisibly inside them, read the explanatory **Science Database** boxes.

Have fun with the experiments!

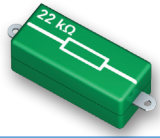
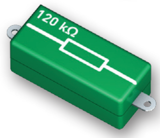
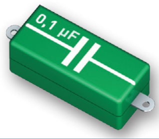
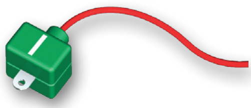
Instruction Manual Contents

The parts in your kit

Component	Qty.	Description	Appearance
Battery box Item No. 704484	1	The power pack that supplies the electricity for the experiments. Before starting the experiments, you will have to install two 1.5-volt AA batteries. You can then collect current from the two terminals (+ and -). Never directly connect these terminals to each other. The batteries and wires can heat up and explode, not to mention that the batteries will be quickly used up.	
Selector switch Item No. 705055	1	Depending on the setting of the switch, one or another pair of the three contact plugs will be electrically connected.	
Connector with 4 terminals (X-shaped) Item No. 705050	20	For connecting components. The metal plugs of the other components are inserted into the side slits so that they are electrically connected to each other as indicated by the white lines. In the instructions, they are called **"X-connectors."**	
Straight connector with 2 terminals (I-shaped) Item No. 705051	10	For the electrical connection of components. The two plugs are electrically connected to each other. In the instructions, they are referred to as **"I-connectors."**	
Angled connector with 2 terminals (L-shaped) Item No. 705052	5	For the electrical connection of components, but in a way that guides the current at a right angle. Looks like an "L," hence referred to as an **"L-connector"** in the instructions.	
Connector with 3 terminals (T-shaped) Item No. 705053	2	For electrical connections. The three plugs are electrically connected to each other as indicated by the white lines. In the instructions, they are referred to as **"T-connectors,"** because their shape is similar to a "T."	
Red light-emitting diode Item No. 708801	1	It emits a red light when current is flowing through it.	

Component	Qty.	Description	Appearance
Green light-emitting diode Item No. 708802	**1**	It lights up green when current flows through it.	
Transistor (npn) Item No. 708800	**2**	The transistor is a fundamental electronic building block. It is hidden inside of electronic devices or computer chips, sometimes by the thousands. It serves as an amplifier or electric switch, and will play an important role in your experiments. It has three terminals — it's important not to mix up the different terminals!	
Phototransistor Item No. 708803	**1**	This component reacts to light: It lets electric current pass through more or less easily, depending on illumination.	
Sound-Generator (IC) Item No. 708804	**1**	This red-orange-colored building block produces various kinds of noises, because it has dozens of transistors inside its housing that work together in a complicated manner.	
Speaker Item No. 708805	**1**	It turns signals from the sound generator and a few other things into sounds you can hear.	
Resistor, 1 kilohm (1 kΩ) Item No. 708806	**1**	Resistors allow you to regulate the flow of current. They come in various electrical values, indicated in "kilohms" (kΩ). Careful, always insert the resistor with the indicated value!	
Resistor, 8.2 kilohms (8.2 kΩ) Item No. 708807	**1**	This is just like the 1-kilohm resistor, except this one offers 8.2 times the resistance to the current.	

The parts in your kit

Component	Qty.	Description	Appearance
Resistor, 22 kilohms (22 kΩ) Item No. 708808	1	This is just like the 1-kilohm resistor, except this one offers 22 times the resistance to the current.	
Resistor, 120 kilohms (120 kΩ) Item No. 708809	1	The same applies as with the 1-kilohm resistor, except this one offers 120 times the resistance to the current.	
Electrolytic capacitor, 100 microfarads (100 µF) Item No. 708810	1	Capacitors have important tasks to perform in circuits. They possess various electrical values, indicated in “micro-farads” (µF). Install capacitors only as shown in the circuit diagrams. Pay attention to the correct value and the + sign, or they might get damaged.	
Capacitor, 0.1 microfarad (0.1 µF) Item No. 708812	1	Here, everything is just like with the 100-microfarad capacitor, except this one has a much lower microfarad value. It makes no difference how you insert this one.	
Red connecting wire with plugs Item No. 706428	1	For connecting electronic parts. At the ends, there are contacts that fit into the green wire connectors. Referred to in brief as **“red wire.”**	
Blue connecting wire with plugs Item No. 706429	1	Like the red connecting wire with plugs, but in a different color. In the instructions, it is referred to in brief as **“blue wire.”**	
Divider Item No. 706078	1	You can use this tool to pry the inserted components or connectors apart without bending the plugs. Slide it between the components and push the components apart.	

Additionally required household items
These are listed in italic (slanted) letters in the “You will need” sections.

- metal paper clips
- tape
- all-purpose glue
- aluminum foil
- scissors
- cardboard
- white paper
- plastic ruler
- very soft pencil
- cloth
- piece of plastic wrap
- table salt
- drinking glass
- teaspoon
- paper towel tube
- deionized water
- tap water
- thin wire
- flashlight
- TV remote
- digital camera

- **First look at the "You will need" list** and get together all the required parts, leaving everything else in the box.
- **Do not use force.** On a smooth table surface, spread out all the parts that you want to assemble with their printed white symbols facing up. Then, keeping them flat on the table, push them together so that their white lines meet up properly. Now you should be able to assemble them without much trouble.
- **Follow the diagrams precisely** during the assembly process. Pay attention to the exact position of the components — especially LEDs, transistors, and capacitors, which have to be installed precisely as indicated. If they are installed backwards, they might not work.
- **Once you have completely assembled everything,** check the entire circuit one more time: Did you use the right components (for example, with the right resistance values)? Are you sure none of the components are turned the wrong way around? Did you forget a connector?
- **Only when everything is certain,** connect the battery box or turn on the switch assembly.
- **If the circuit does not work the way it's supposed to,** switch it off and check one more time whether the components are right and whether all the connectors are making proper contact. Check each connection systematically. Plugs might have slipped out of their slots or might not be making contact correctly. Another possible cause for failure could be that the batteries are used up.
- **Do not leave the circuit switched on for too long,** especially not overnight. It will consume current and eventually use up the batteries.
- **If you want to disassemble the components,** simply pull them straight apart without twisting or bending them. If that doesn't work well due to something being jammed, the divider will help: Push it into the slot and turn it a little, and the building blocks will come apart.

Light-emitting diodes (LEDs) are among the prettiest electronic components, simply because they can emit colored light. So start your experiments by making them shine.

1 Red light with green parts

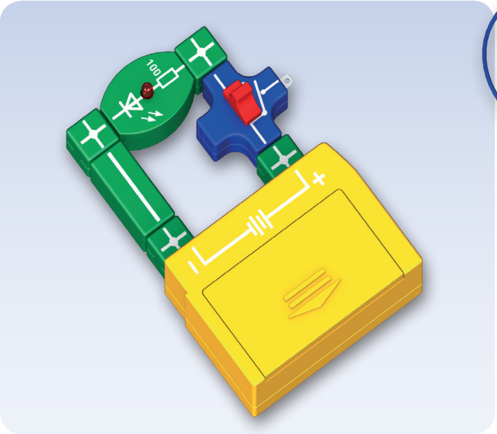
Right in the very first experiment, the red LED will be showing off its light. You can turn it on and off as you like.

You will need:

- Battery box
- 4 X-connectors
- 1 I-connector
- Selector switch
- Red LED

Here's how:

1. Assemble the parts exactly as shown in the illustration. Be sure to guide the pins straight into the X-connector slot.
2. Slide the red-colored switch knob back and forth. Depending on its setting, the light-emitting diode will either light up or turn off.



How it works:

The current flows from the batteries through the metal strips inside the green connectors to the light-emitting diode, and makes it light up. The switch only creates an electrical connection when it is in one of its positions — only then does the current flow through the light-emitting diode. By the way, you've probably noticed that "light-emitting diode" is a pretty long name. That's why people often use the abbreviation "LED."

2 Wire salad

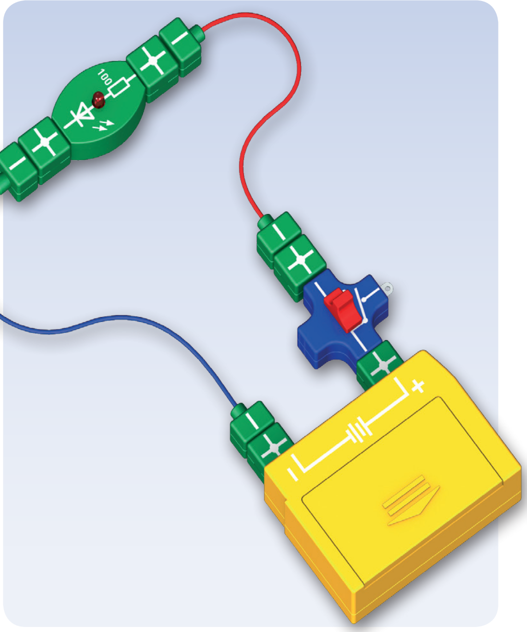
Sometimes, you may want to operate the LED a little farther away from the battery. The wires will help with that.

You will need:

- Battery box
- 5 X-connectors
- Selector switch
- Red wire
- Blue wire
- Red LED

Here's how:

1. Assemble the circuit.
2. Use the switch to turn the LED on and off.



How it works:

The current flows through the wires just as well as through the metal plugs in the green connectors — even if the wires are tangled.

3 Green instead of red

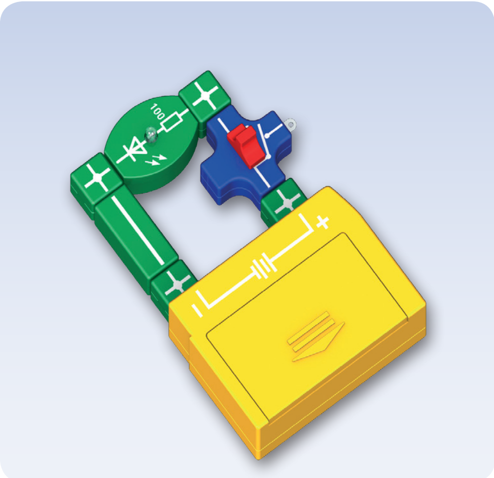
You performed the previous experiments with the red LED. Now it's the green LED's turn to shine.

You will need:

- Battery box
- 4 X-connectors
- 1 I-connector
- Selector switch
- Green LED

Here's how:

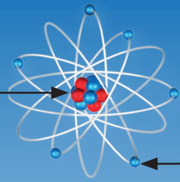
Assemble the same circuit as in Experiment 1, except this time use the green LED. Its green light will shine as soon as you push the switch.



How it works:

The green LED works just like the red one, except the light-emitting material has been changed so that it produces green light.

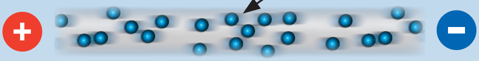
Science Database



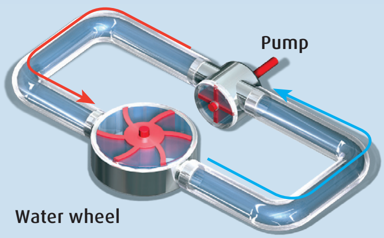
Electrical current and electronics

For a long time, researchers have puzzled over the nature of "electrical current." It is invisible, with only its effects being noticeable. Today, we know that it is a "flow of electrons." Electrons are smaller and more mobile than atoms, and they have lots of unusual properties.

Normally, "electrons" are firmly attached to the atom they belong to. But sometimes, especially in metals, electrons can get free and zoom around among the atoms. You can picture electrons in a wire like water in a pipe.



When water is set in motion by a pump, it starts to flow through the pipe. This flow can be used to drive a small water wheel, for example.



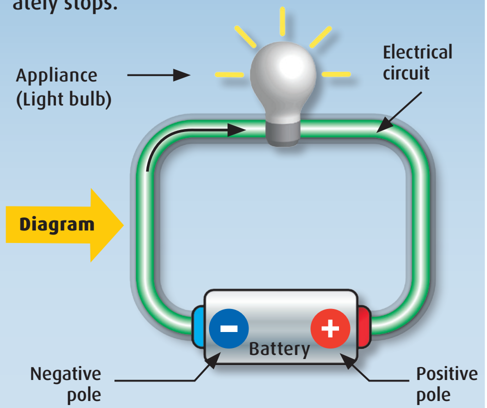
With electricity, too, there are things like pumps (for example, batteries) that set the electron cloud in the wire in motion. This is called "electrical current." You can use electrons to do lots of amazing things. The technology of controlling electrons toward certain goals is called "electronics." With the help of transistors, capacitors, resistors, and LEDs, we can make electrons do what we want them to.

Science Database

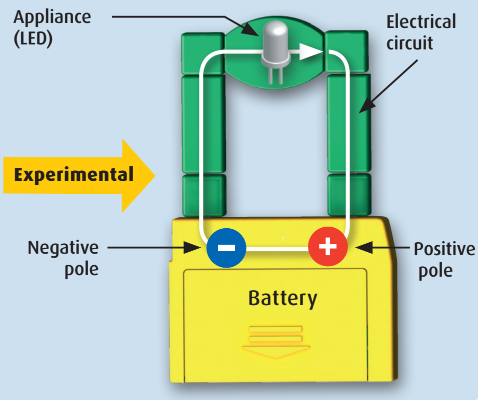
Plus and minus

A water pump has two ends: one for suction and one for expulsion. Electrical current sources also have two ends, or terminals. At one, called the "positive pole," they create a sort of electron vacuum. At the other end, they produce a sort of electron overload. This terminal is called the "negative pole."

Current only flows when the poles, or terminals, are connected. Then, the electrons flow from the negative pole to the positive pole, and the force of their flow is capable of lighting up an LED, for example. If the electrical circuit is broken at any point, as you did in Experiment 1 with the use of the switch, the flow of current immediately stops.



This is how the electrons flow through your electrical components:



4 Double light

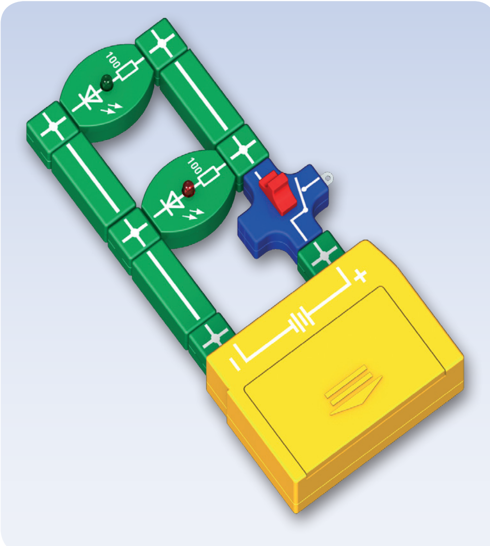
Now it's time for the batteries to show what they can do: Both LEDs are going to light up at the same time.

You will need:

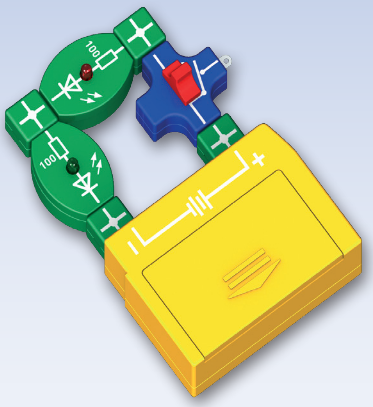
- Battery box
- 6 X-connectors
- 3 I-connectors
- Selector switch
- Green LED
- Red LED

Here's how:

1. Assemble the circuit as shown in the illustration. When you turn it on, both LEDs will light up.



2. Assemble the second circuit. Now, the LEDs won't light up when you turn it on.



How it works:

Follow the path of the current: In the first circuit, it divides into two and flows through both LEDs. The normal way to talk about it is to say that the LEDs are connected in "parallel."

In the second circuit, the current would first flow through one and then through the other: The LEDs are connected "in series." But the batteries don't have enough power for this, so the LEDs remain dark.

Science Database

In what direction does current flow?

Charges are always associated with charge carriers — in other words, with tiny electrically charged particles. In metals, these are "electrons," with each electron carrying a negative charge. In electrically conductive liquids (for example, salt solutions), there are even both kinds of charge, with positive as well as negative charge carriers (which are then called "ions").

Around 200 years ago, when electrical current was discovered, nobody knew any of this yet. So, at that time, the French physicist André Marie Ampère (after whom the unit of current strength was later named) rather arbitrarily established a direction of flow from positive to negative. This is known as the "conventional current flow" and when we use this convention we act as if there were a flow of positive charge carriers. This is sufficient for explaining most electrical phenomena.

Around 100 years ago, though, people discovered the electron, and they discovered that it has a negative charge. In a metal wire, electrons flow from the negative to the positive terminal. This was then called the "electron flow."

Since this naturally led to frequent confusion, people have since agreed on an established direction of current flow, namely the conventional flow. Accordingly, current flows from positive to negative. The electrons themselves, though, move against the direction of current flow — so you have to keep this in mind.

So we draw a distinction between the direction of conventional current flow — from positive to negative — and the direction of movement of the electrons — from negative to positive.

Science Database

Voltage and current strength

Water can really shoot out of a water tap. Or sometimes it just trickles out slowly and weakly. It all depends on the water pressure.

There's something like that at work with electricity too. It's called "electrical voltage." You can think of it as the pressure with which something like a battery pushes electrons out of one of its terminals, and with which it sucks up the electrons at the other terminal. Electrical voltage is measured in "volts" (V).

Each of your batteries in the battery box produces a voltage of 1.5 volts. If they are connected in series, they deliver 3 volts. That's not much: A car battery has 12 volts, and current from a wall socket has 110 volts — a high enough voltage to make it potentially deadly.

You can imagine that high water pressure is able to push more water per second through a pipe than low water pressure can. Something similar happens with electrical current. A "high voltage" sets more electrons in motion per second, producing a higher current strength. A "high current strength" can accomplish more than a low one, although it can also be more destructive. That's why the experiments in this kit use a relatively low voltage of 3 volts. Electronic components are particularly sensitive to high current strengths.

The unit of measure for current strength, by the way, is the "ampere" (A). In your circuits, in any case, there will only be currents of a few "milliamperes" (mA) — with a milliampere equaling one thousandth of an ampere.

5 Morse code

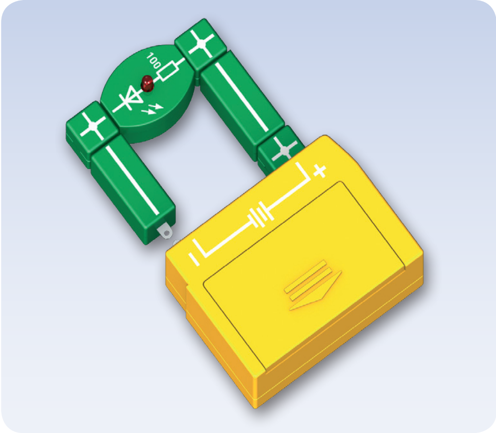
Light can be used to transmit signals and messages. These days, fiber optic cables are used for such purposes, including the transportation of television signals and computer data all around the world. But there's also a simpler way to do it, even though it's slower: Morse code.

You will need:

- **Battery box**
- **3 X-connectors**
- **2 I-connectors**
- **Red LED**

Here's how:

1. Assemble the circuit, omitting the X-connector at the battery's negative terminal.
2. Twist the circuit so that the free metal plugs are positioned over one another, but without letting them touch. You might have to place a piece of paper under the LED. At first, the LED will not light up.
3. Now press on the lower I-connector, making the metal plugs touch each other briefly, and the LED will light up. By pushing rhythmically, you can send Morse code signals of light.



How it works:

When you touch the plugs together, it closes the circuit, and the LED blinks on.

Science Database

Morse code

Morse code, also known as the "Morse alphabet," is used to transmit letters and numbers.

The code can be sent as sound or light signals. Many people are familiar with the "Morse code distress signal":

• • • – – – • • •

The Morse code is used even today in international seafaring and aviation.

The international Morse alphabet

A	• –
B	– • • •
C	– • – •
D	– • •
E	•
F	• • – •
G	– – •
H	• • • •
I	• •
J	• – – –
K	– • –
L	• – • •
M	– –
N	– •
O	– – –
P	• – – •
Q	– – • –
R	• – •
S	• • •
T	–
U	• • –
V	• • • –
W	• – –
X	– • • –
Y	– • – –
Z	– – • •
1	• – – – –
2	• • – – –
3	• • • – –
4	• • • • –
5	• • • • •
6	– • • • •
7	– – • • •
8	– – – • •
9	– – – – •
0	– – – – –

6 Alternating red and green

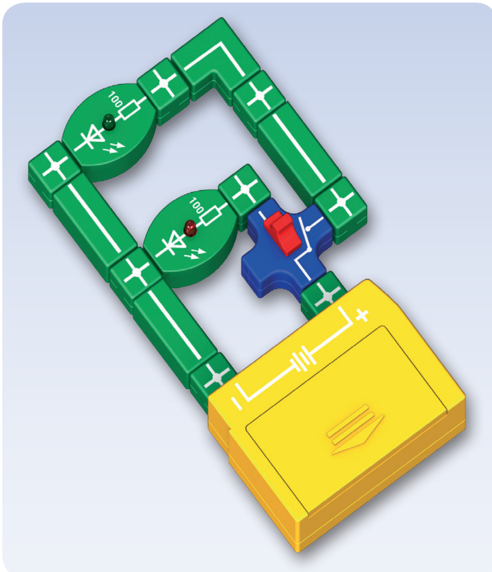
Now the LEDs will be blinking alternately — at the push of a switch.

You will need:

- Battery box
- 8 X-connectors
- 3 I-connectors
- 1 L-connector
- Selector switch
- Red LED
- Green LED

Here's how:

Connect each of the LEDs to one of the selector switch terminals. Now you can make either the red or the green LED light up.



How it works:

The selector switch creates a connection from the positive battery terminal to one or the other of its terminals, depending on its setting. That causes current to get to either the red or the green LED. Then the current flows back through the shared connector to the negative terminal.

7 Current "in line"

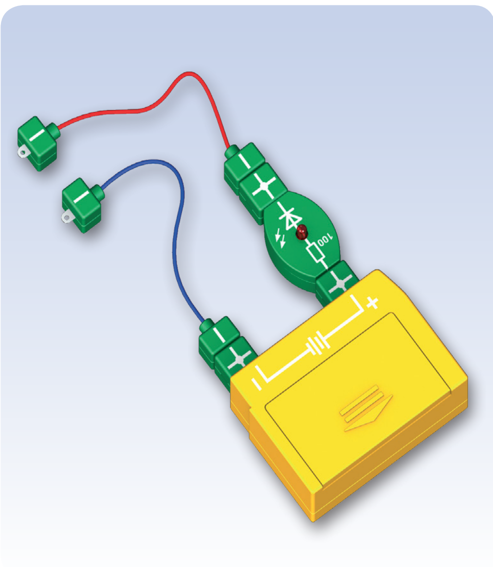
Current flows through the wires, but it apparently doesn't flow through the air, or it would flow without wires as well. What kinds of materials will it move through, and which ones won't let it pass?

You will need:

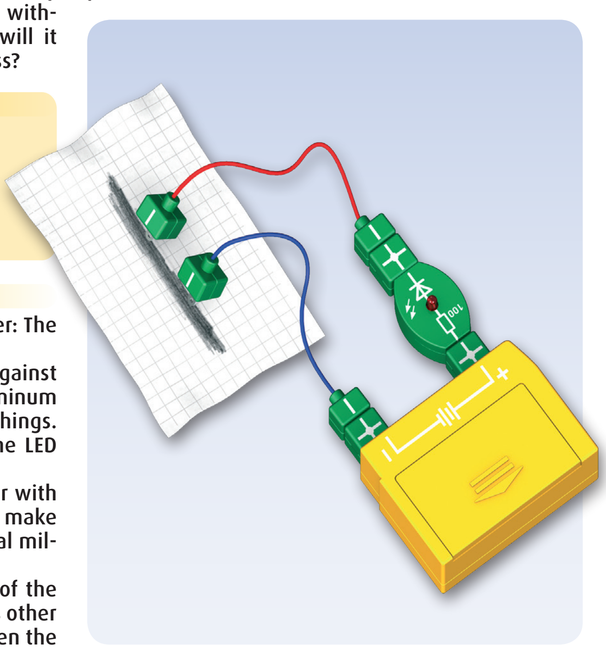
- Battery box
- 3 X-connectors
- Red LED
- Red wire
- Blue wire
- *Various household items*
- *Paper*
- *Very soft pencil (carpenter's pencil)*

Here's how:

1. Touch one of the free plugs against the other: The LED will light up.
2. Now touch both plugs simultaneously against various objects, such as a metal spoon, aluminum foil, porcelain, glass, wood, plastic, and other things. Note where current flows — in which case the LED will light up — and where it doesn't.
3. Draw a thick grey line on the sheet of paper with the pencil. Rub back and forth several times to make it nice and dark, and also make the line several millimeters thick.
4. Press the red wire's plug against one end of the line, and the blue wire's plug against the line's other end, and gradually reduce the distance between the plugs.



5. Watch for the moment when the LED starts to glimmer. You'll be able to see it better if you darken the room a little!
6. Save the paper with the pencil line for later experiments.



How it works:

You can determine that all metals conduct the current. Plastics, porcelain, and wood, on the other hand, do not. The mass of graphite forming the pencil line can also conduct current, albeit rather weakly.

8 Salt makes things conductive

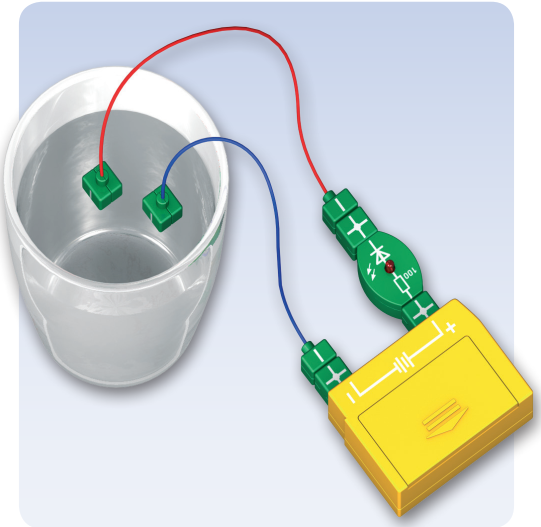
The LED only needs a little current. Will water let enough current pass through it to make the LED light up?

You will need:

- Battery box
- 3 X-connectors
- Red LED
- Red wire
- Blue wire
- *Drinking glass*
- *Deionized water*
- *Table salt*
- *Teaspoon*

Here's how:

1. Hold the two free wire ends in the glass of deionized (distilled) water. Does the LED light up?
2. Move the ends of the wire close to each other in the water, but without letting them touch. Does the LED light up now?
3. Add some salt to the water and stir. The LED will start to shine more and more brightly, independently of how far apart the wire ends are.
4. Rinse the glass thoroughly and fill it with tap water. Does the LED light up?
5. Moisten one finger and press both metal plugs against it. What does the LED do?



How it works:

Pure water is one of the "nonconductors," hardly able to conduct electrical current at all. That is why the LED doesn't light up. But by adding salt, you make it electrically conductive, because as it dissolves salt breaks up into particles (so-called "ions") that take over the job of conducting current in the liquid — even if not as well as the electrons in metals.

Tap water also contains small quantities of ions, so the LED does light up weakly. Even the tiny current flowing through the moisture on your finger can make the LED light up, thanks to the salty sweat on your skin.

Science Database

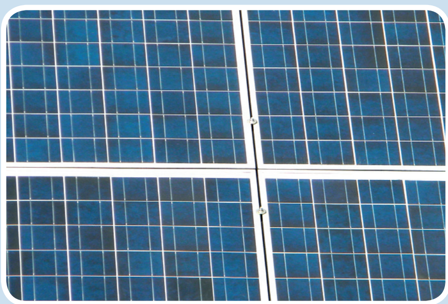
Conductor, nonconductor, semiconductor

Materials that conduct current well are called "conductors." Metals, for example, are among this group. Electrons are able to move easily inside them.

Materials that only conduct current poorly are called "nonconductors." Plastics, air, glass, and other materials belong to this group. With these materials, the electrons hold tightly to their atoms and can't be set into motion so easily. They can be used as insulators, for example, in order to block the current from moving along undesired paths.

In electronics, there is a third category of materials that have a fundamentally important role to play, namely "semiconductors." They are integrated into components such as diodes, transistors, and computer chips that are used for guiding the flow of electrons in a controlled manner. Semiconductors conduct current better than nonconductors, but not as well as conductors. In addition, their conductance depends on a lot of factors — their purity, the temperature, or even the lighting, for example.

People have come to discover many dozens of different semiconductor materials. The most important of them is "silicon," which is produced from silica sand. It has to be put through an extreme process of purification before it can be used, though, and can't have more than one foreign atom per million silicon atoms. Your transistors are made of silicon too.



Solar cells produce current with the help of silicon.

9 Swap meet

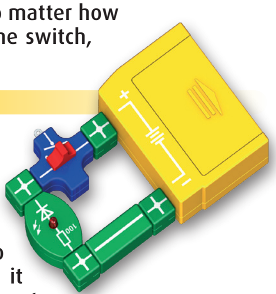
The LED has two terminals, and you can reverse them. What happens if you insert the LED the other way around?

You will need:

- Battery box
- 4 X-connectors
- 1 I-connector
- Selector switch
- Red LED

Here's how:

Install the LED in reverse, as shown in the illustration. Now, no matter how many times you push the switch, the red light stays off.

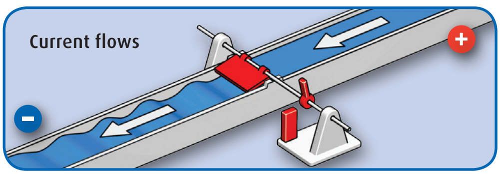


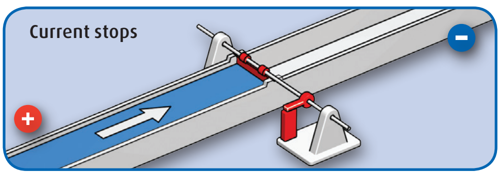
How it works:

You could install a "normal light bulb" one way or the other — it would always light up, since it makes no difference to the current which way it passes through the filament. An LED, however, works completely differently. It is a kind of electronic valve. The current can only flow through it in one direction. When turned around, it blocks the current — and then it won't light up.

You can think of it like this, in terms of a flow of water: In the diagram below, the flap only lets water pass through when it flows from right to left — but it blocks the water flowing in the other direction.

The symbol on the LED housing shows you whether it is positioned the right way around: The large arrow has to point from the positive terminal to the negative terminal in order for the LED to light up.





10 Polarity tester

There is actually an advantage to the fact that you have to be careful to install the LED the right way around: You can use that fact to determine the polarity of a current source.

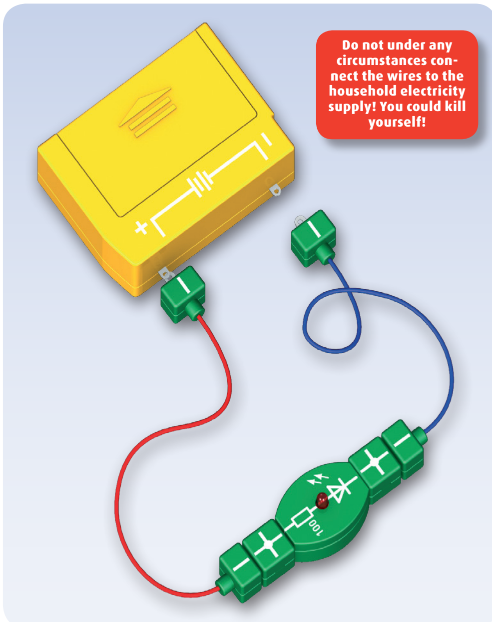
You will need:

- Battery box
- 2 X-connectors
- Red wire
- Blue wire
- Red LED

Here's how:

Touch each of the battery contacts with one of the two free wire plugs. If the LED lights up, the red wire is on the battery's positive terminal and the blue wire is on the negative terminal.

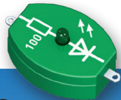
Don't test any other current sources with this, however. They would likely destroy your simple test circuit.



How it works:

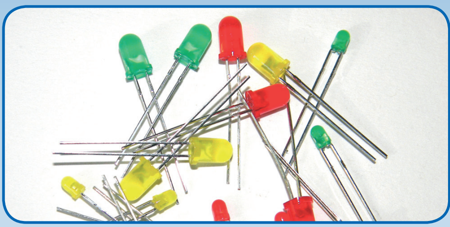
Because the LED only lights up in this position when the red wire is on the positive terminal and the blue is on the negative, it's possible to investigate current sources of unknown polarity.

Science Database



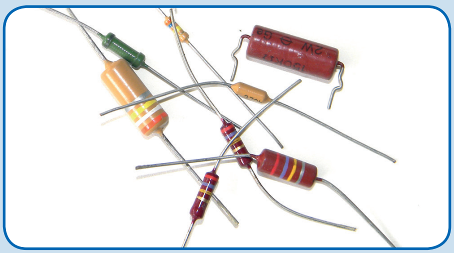
Light-emitting diodes

Light-emitting diodes are made of a "semiconductor material" that emits energy in the form of light when current flows through it. By choosing just the right kind of material, the color of this light can be made into anything from invisible infrared light through the visible range all the way to invisible ultraviolet light. You can also combine different light-emitting diodes into a single housing, and thereby switch between or mix the different colors. Or you can use the invisible ultraviolet light to stimulate other materials into emitting visible light — which is how the increasingly common efficient and long-lasting lighting option known as "white-light LEDs" work.



Resistors

Resistors are components that have a certain constant electric resistance. They usually take the form of small barrels with two terminal wires. The "resistance value" is usually indicated by a color code, or more specifically as a colored ring. There are also continuously adjustable resistors known as "potentiometers." Usually, they work by having a track made of a resistance material and a contact that glides along the track when you turn or push it, thus changing the electrical resistance between the terminals.



11 Improved polarity tester

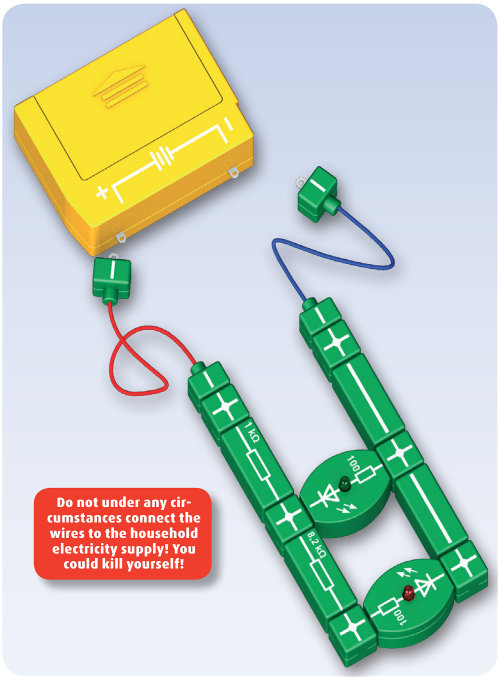
The polarity tester from Experiment 10 lit up — or didn't light up. It would be better if one of the LEDs lit up no matter what. This circuit will do that.

You will need:

- Battery box
- 6 X-connectors
- 2 I-connectors
- Red wire
- Blue wire
- Red LED
- Green LED
- 1 kΩ Resistor
- 8.2 kΩ Resistor

Here's how:

Touch each of the wire plugs to one of the battery contacts. If the red LED lights up, the red wire is touching the battery's positive terminal and the blue wire is on the negative terminal. If the green LED lights up, it's the other way around.



How it works:

In this circuit, the LEDs are inserted in opposite directions. So no matter what direction the current flows, one of them will always light up.

12 Resistance to red

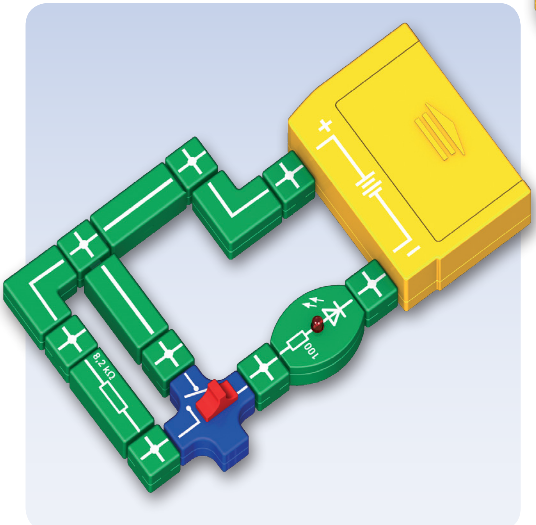
Your kit contains four resistors. Their job is to obstruct the flow of current through your electronic circuits in specific ways — the higher their kilohm value, the less current they let pass through them. Try it with the LED.

You will need:

- Battery box
- 8 X-connectors
- 2 I-connectors
- 2 L-connector
- Selector switch
- Red LED
- all the resistors

Here's how:

1. Assemble the circuit. Depending on the switch setting, the LED will light up with its usual brightness or more dimly.
2. Switch out the resistor shown below for each of the other resistors. What effect does that have on the illumination of the LED, keeping the switch setting constant?



How it works:

Study the direction of current flow. Depending on the switch setting, it can either flow directly to the LED or have to flow through the resistor. In the latter case, the flow of current is reduced, and the LED lights up less. But even with the large 120-kΩ resistor, you can still see it glimmer dimly in the dark.

13 Resistors in a row

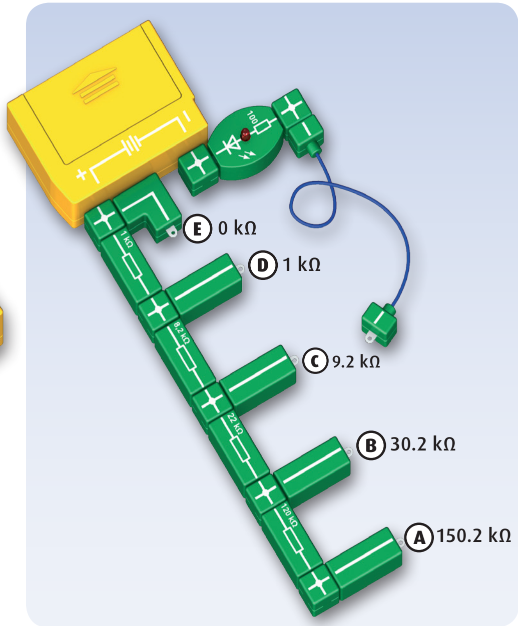
Imagine that the current has to fight its way through a resistor. What would happen if it had to get through two or more of them, one after the other?

You will need:

- Battery box
- 7 X-connectors
- 4 I-connectors
- 1 L-connector
- Red LED
- Blue wire
- all the resistors

Here's how:

1. Assemble the circuit.
2. Touch each of the free plugs in sequence with the free end of the wire. From bottom Ⓐ to top Ⓔ the LED will shine more and more brightly.



How it works:

At **E**, you are connecting the LED directly to the battery's positive terminal, so it lights up at full force. At **D**, the current has to pass through one of the resistors, so the LED lights up more weakly. At **C**, the current has to run through two resistors, since they are connected one after the other — "in series." So the LED is a little darker still. And so it continues, all the way to **A**. When resistors are connected in series, their individual resistance values are added up.

14 Resistors in parallel

If you connect resistors in parallel, the current has various ways to flow. So should the overall resistance be lower? Try it for yourself.

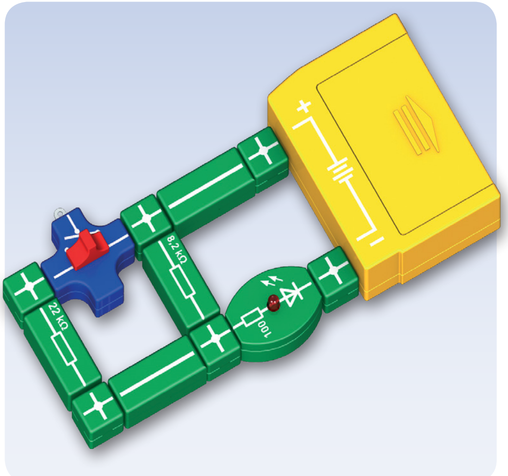
You will need:

- Battery box
- 6 X-connectors
- 2 I-connectors
- Selector switch
- Red LED
- all the resistors

Here's how:

This circuit, depending on the switch setting, will let you connect just one resistor in front of the LED (in the case shown below, the 8.2-kΩ resistor). Or, you can connect a second resistor (in this case, the 22-kΩ one) in parallel to this first one.

Try it with all the resistors and compare the results.



How it works:

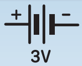
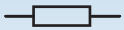
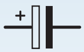
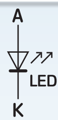
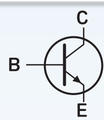
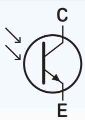
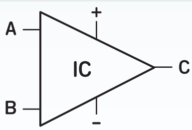
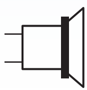
If you connect a second resistor in parallel, the LED actually gets brighter. So the resistance value of resistors connected in parallel is actually less than that of each one alone.

It is not such a simple matter, though, to calculate the precise value. For those who are interested: You have to add up the inverse values and then take the inverse value of that in turn. In our case, then, it would be 1/22 plus 1/8.2, yielding 0.045 + 0.122 = 0.17; the inverse value of that is 5.88 kΩ.

Science Database

Wiring symbols

Electricians use simple symbols for each of the components in the circuit diagrams showing how the pieces are all wired together. These symbols are also printed directly on your components. Lines, for example, indicate simple connections. A rectangle indicates a resistor, the large arrow with a line and arrows to the side marks a light-emitting diode, and the switch uses thick lines to indicate where it will create connections.

	Selector switch
	3-Volt battery
	Resistor
	Capacitor
	Electrolytic capacitor
	Light-emitting diode
	npn-Transistor
	Phototransistor
	Sound generator (IC)
	Speaker

15 All resistors in parallel

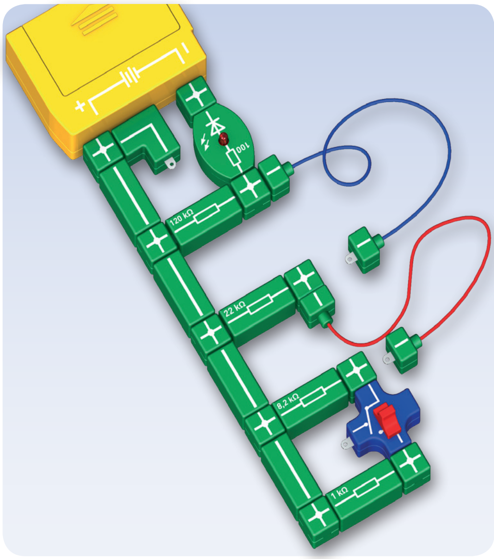
It's interesting to compare the LED's brightness when you connect individual resistors or all resistors in parallel. With this setup, it will be easy to make that comparison.

You will need:

- Battery box
- 10 X-connectors
- 4 I-connectors
- Selector switch
- Red LED
- Red wire
- Blue wire
- all the resistors

Here's how:

1. After assembly, the LED will light up pretty weakly.
2. Insert the blue wire contact into the X-connector of the 22-kΩ resistor. Now the LED will light up considerably more brightly. Follow the current flow: Both resistors are now lying in parallel.
3. Set the selector switch to "Off" (slider toward the top) and insert the red wire contact into the X-connector of the 8.2-kΩ resistor. Now the LED will light even brighter, because there are now three resistors in parallel, and the last one is quite a bit smaller.
4. Turn on the selector switch, which will also turn on the 1-kΩ in parallel. Now the LED is really bright.



How it works:

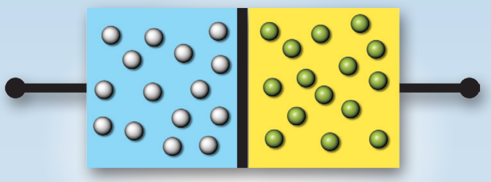
With each step, you open up another path to the LED for the current, and each of these paths is easier (offering less resistance) than the last.

Science Database

How electrical valves work

A diode, which is a sort of "electrical valve," consists of two kinds of specially altered semiconductor materials. One kind, called an "n-type semiconductor," contains a few atoms with somewhat more electrons than pure semiconductor material. The other kind, called "p-type," contains atoms with somewhat fewer molecules. A diode is essentially a tiny crystal with two halves; each half consists of one of these materials and a terminal wire.

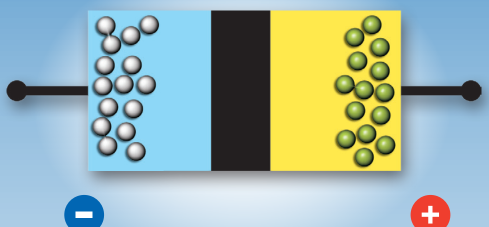
The illustration shows how you can picture these materials. The "n-layer," of course, has extra mobile electrons (green). In the "p-layer," by contrast, there are places with missing electrons. These are known as "holes." You can picture them moving just as electrons do, only in the opposite direction. Picture it the way an open seat will move through a row of seats at the movie theater when each person shifts to the open seat next to him.



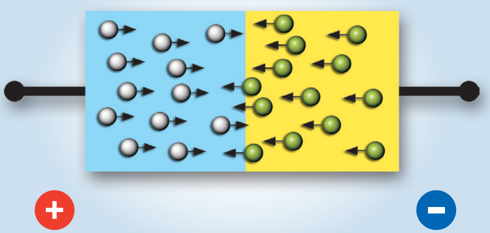
p-layer Junction n-layer

The location where the two halves butt up against each other, of course, is a place where extra electrons and extra holes can combine together. As a consequence, there are no mobile electrons or holes in this layer, known as a "depletion layer." So no current can flow here, and it is therefore sometimes also known as a "barrier layer." Even though it is extremely thin, it is crucial for the component's behavior and properties.

When you connect the n-layer to the positive terminal, as in Experiment 9, the terminal will suck electrons out. The negative terminal does the same to the holes. The depletion layer therefore grows larger, and no current flows. That's why your LED doesn't turn on.



But if the diode is installed the right way around, as in Experiment 1, the battery's negative terminal pushes electrons out of the n-layer into the depletion layer. The depletion layer is then flooded with electrons, and no longer forms a boundary — the diode conducts, and the LED lights up.



Notes

You must be curious to find out what sorts of noises the sound generator can produce. So let's see what it can do.

16 The police are on the way

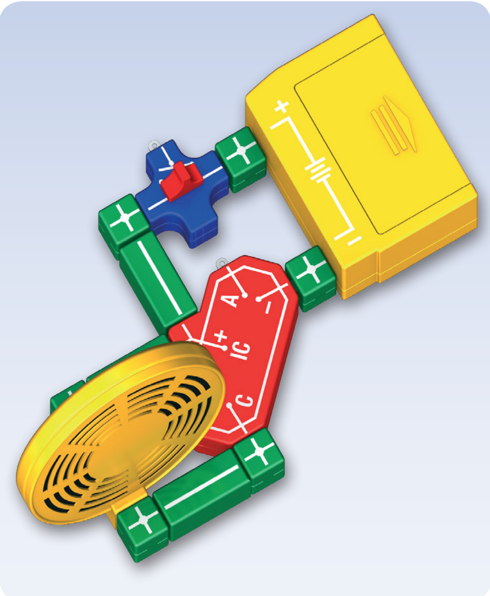
You know the sound that a police siren makes? Now you can make it yourself.

You will need:

- Battery box
- 6 X-connectors
- 3 I-connectors
- Sound generator
- Speaker
- Selector switch

Here's how:

Assemble the circuit. When you switch it on, you'll hear the familiar sound.



How it works:

The transistor circuits in the sound generator produce various noise signals, which cause the speaker to make sounds.

17 Ambulance

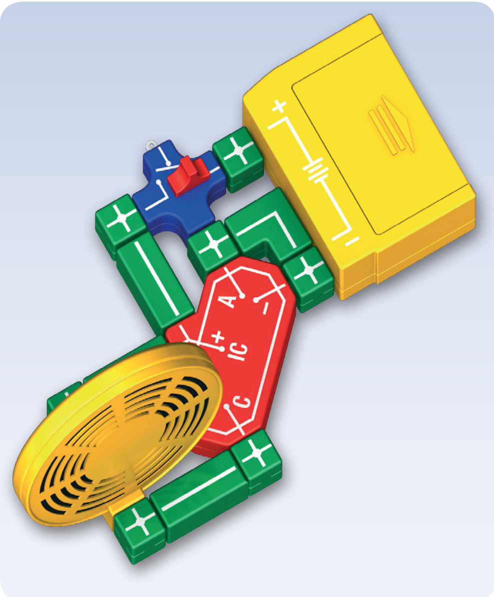
You will also be able to recognize this noise easily enough.

You will need:

- Battery box
- 7 X-connectors
- 3 I-connectors
- 1 L-connector
- Sound generator
- Speaker
- Selector switch

Here's how:

The circuit is just like the one in Experiment 16, except in this case terminal A of the sound generator is connected to the negative terminal of the battery.



How it works:

By connecting point A to the negative terminal, a different transistor circuit is activated in the sound generator, producing a different noise from the speaker.

18 Fire engine

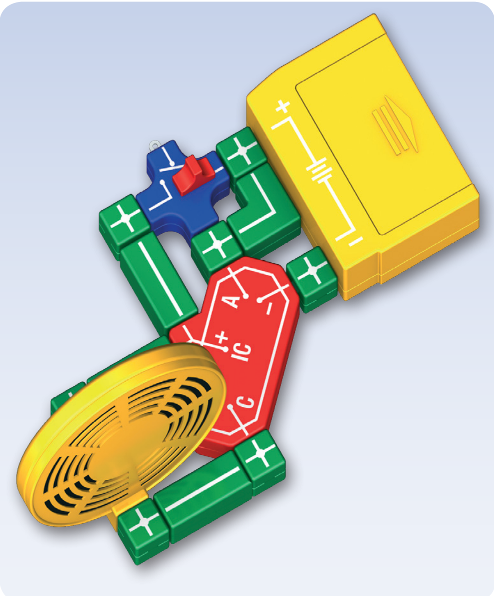
You'll know this sound from the times you've heard a fire engine coming down your street, or when you've heard one on TV or in a movie.

You will need:

- Battery box
- 7 X-connectors
- 3 I-connectors
- 1 L-connector
- Sound generator
- Speaker
- Selector switch

Here's how:

This circuit will already be familiar from the last one: The only difference is that in this one, the A terminal is connected to the positive battery terminal.



How it works:

The connection from A to the positive terminal activates a third transistor circuit, producing a fire engine sound from the speaker.

19 Changing the sound on the fly

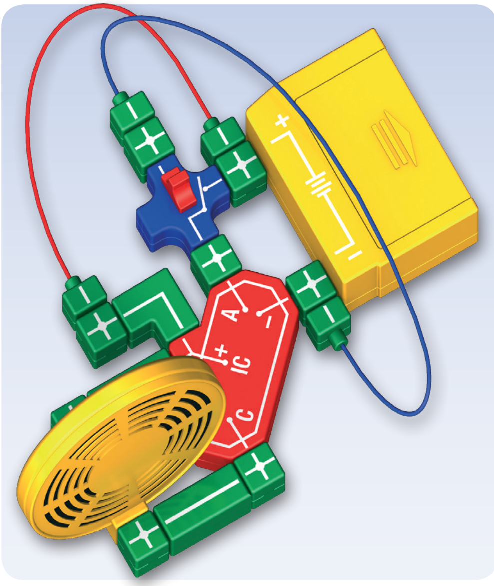
Wouldn't it be fun to switch quickly back and forth between two different sounds? The selector switch will let you do that easily enough.

You will need:

- Battery box
- 8 X-connectors
- 2 I-connectors
- 1 L-connector
- Sound generator
- Speaker
- Selector switch
- Red wire
- Blue wire

Here's how:

1. Assemble the circuit. Either the ambulance siren or the fire engine siren will go off.
2. Disconnect the blue wire. Now you can switch between the police siren and the fire engine siren.
3. How would you have to change the circuit in order to be able to switch between the police siren and the ambulance siren?



How it works:

You can use the selector switch to connection point A to the positive or negative terminal, or you can even leave it disconnected by removing the switch. The sound will change accordingly. If you want to choose between police and ambulance, you will have to remove the connection between the switch and the positive terminal and replace it with the blue wire.

20 Sound or light — your choice

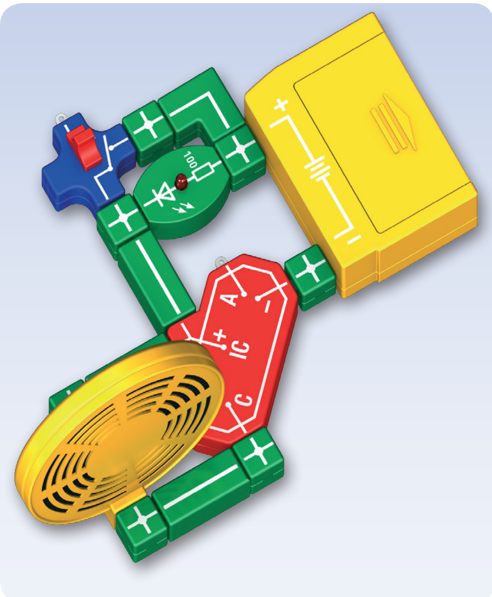
Of course, you can also use the selector switch to turn on the sound generator or the LED.

You will need:

- Battery box
- 7 X-connectors
- 3 I-connectors
- 1 L-connector
- Sound generator
- Speaker
- Selector switch
- Red LED

Here's how:

The LED is connected in series with the positive input of the sound generator. The switch bypasses the LED on command and connects the sound generator directly to the positive terminal.



How it works:

When you connect the LED in series with the sound generator, it lights up. But it also produces so much resistance that there's not enough current left for the sound generator.

If you bypass the LED, it gets full current again and the police siren goes off.

21 Blinking LED

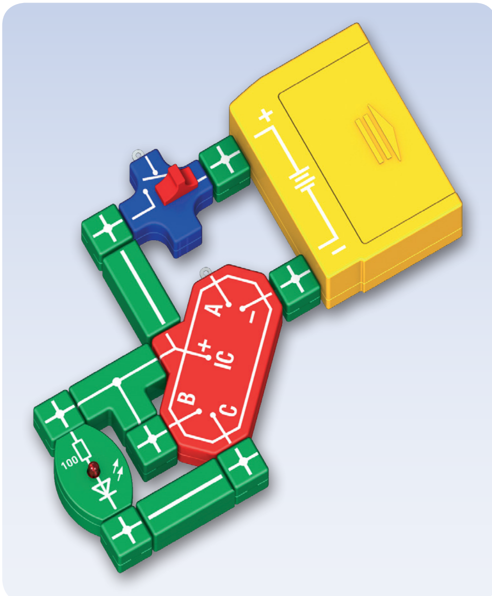
You can use your sound generator not only to make sounds, but also to control the LED.

You will need:

- Battery box
- 7 X-connectors
- 2 I-connectors
- 1 T-Connector
- Sound generator
- Red LED
- Selector switch

Here's how:

The LED is inserted in place of the speaker. In addition, it has to be connected to the B terminal. When it's switched on, it blinks.



How it works:

The transistor circuit inside the sound generator, which controlled the sound until now, provides more or less current to the LED, making it blink. This gives you a visual idea of the varying signals coming from the sound generator to the speaker.

After the experiments with the light-emitting diodes and the sound generator, you will now try assembling your first circuits with individual transistors.
Transistors have a wealth of important tasks to perform in electrical circuits. In this section's experiments, they will be used as switches that can be opened and closed using electrical current.

22 The secrets of the transistor

The transistor is an important electrical component, but also a somewhat mysterious one. You can't see inside it, so you have to learn about its properties through experimentation.

You will need:

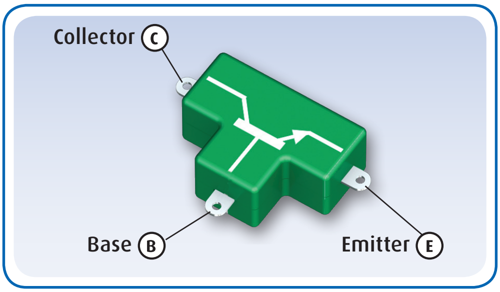
- Battery box
- 4 X-connectors
- 1 Transistor
- Red LED
- Red wire
- Blue wire

Here's how:

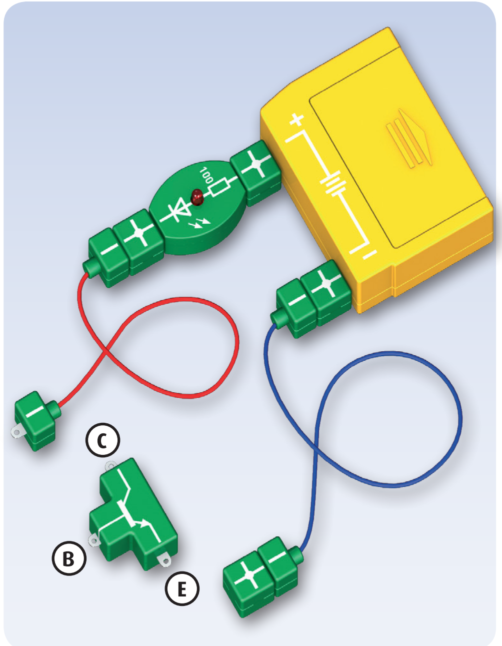
1. First, carefully examine the green housing. A transistor has three terminals:

C Collector E Emitter B Base

You can refer to the symbols on the housing to tell the three terminals apart.



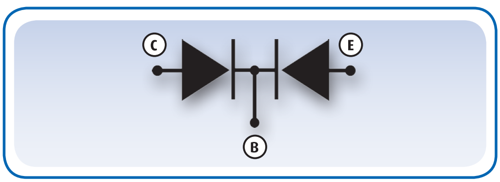
2. Now, assemble the circuit as shown in the illustration to the right.
3. Connect the free red wire plugs directly to the blue wire. The LED will light up — so you know that you installed it correctly.
4. Attach the blue wire's X-connector to the transistor's emitter terminal (E).
5. Briefly touch the red wire's plug to the collector terminal (C). The LED remains dark.
6. Now attach the blue wire's X-connector to the C terminal and touch the E terminal with the red wire's plug. The LED still won't light up.
7. Without moving the blue wire, briefly touch the base terminal (B) with the red wire. The LED lights up!
8. Attach the blue wire's X-connector to the E terminal again. Now briefly touch the B terminal with the red wire. Again, the LED will light up.
9. Attach the blue wire's X-connector to the B terminal and touch the collector (C) and then the emitter (E) with the red wire. In neither case will the LED light up.



How it works:

You have demonstrated that there is no current flowing between C and E of the transistor. On the other hand, current can indeed flow between E and B when the emitter is connected to the negative terminal. The collector behaves the same. When the polarity is reversed, though, the current is blocked.

You can picture the transistor as two electrical valves, or two diodes, that are connected opposite one another.



23 Quick switch

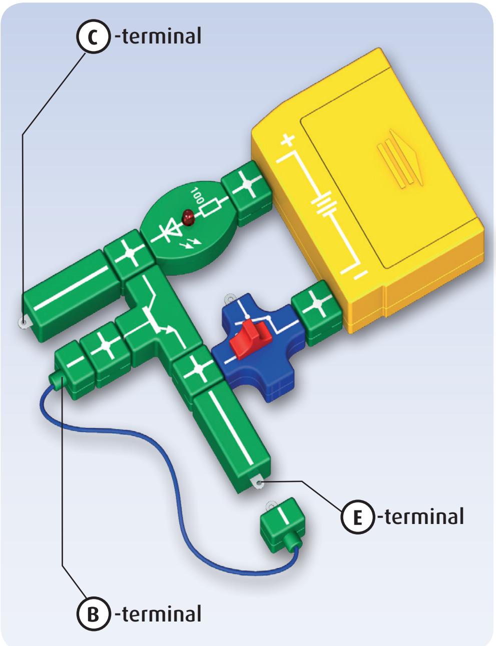
A transistor that won't let any current pass through it might seem like a pretty useless component. But you can use a trick to make it conduct, thus demonstrating its useful abilities.

You will need:

- Battery box
- 5 X-connectors
- 2 I-connectors
- 1 Transistor
- Red LED
- Selector switch
- Blue wire

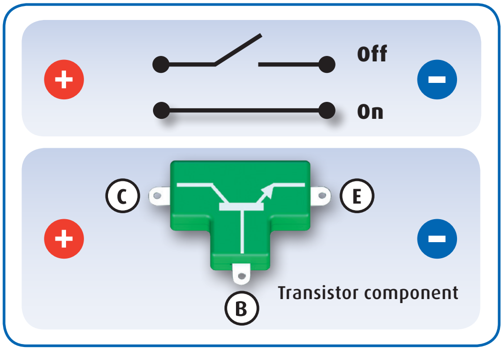
Here's how:

1. Assemble the circuit.
2. After you switch it on, as expected, the LED won't light up, since the connection between the collector and the emitter (the C-E section) blocks the current.
3. Now touch the free wire plug to the C terminal plug. The LED will light up.
4. Touch the free wire plug to the E terminal: The LED remains dark.



How it works:

Think of the collector-emitter section as a switch that you can open and close.



The transistor is switched on and off electronically, instead of mechanically like the selector switch. If you connect the transistor base to the collector — that is, to the positive terminal — then you complete the collector-emitter switch. Current flows, and the LED lights up.

If the base is not connected to anything (open), the C-E section remains blocked, so no current flows (LED won't light up). Even if you connect the base to the emitter — that is, to the negative terminal — C-E remains blocked.

Base to positive:

Base to positive:	C-E section conducts
Base open or to negative:	C-E section blocked

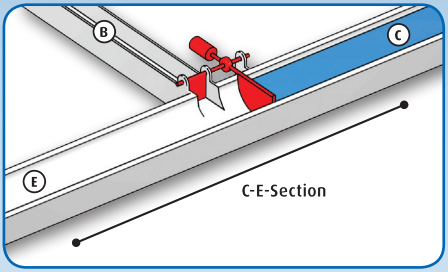
You can use this knowledge in almost every one of the following experiments.

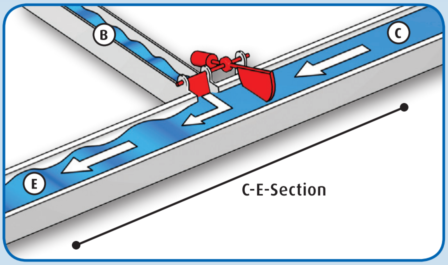
Science Database

The transistor as a switch

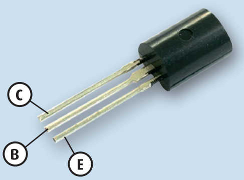
The easiest way to visualize the way a transistor works is by thinking of the flowing-water model again. In the diagram below, the large flap gate prevents the water from flowing through the main waterway — this corresponds to the C-E section. But just a small stream of water flowing through the side channel — the base — opens the large flap gate and lets the main waterway flow.

The transistor can work as a switch that is always either on or off. In this case, that means: Either no water (current) flows at all in the side channel (base), or enough flows for the flap gate (C-E section) to be completely open. You tried both of these in your experiment.





Example of the kind of transistor used in electronic circuits.



24 Only turning the transistor off

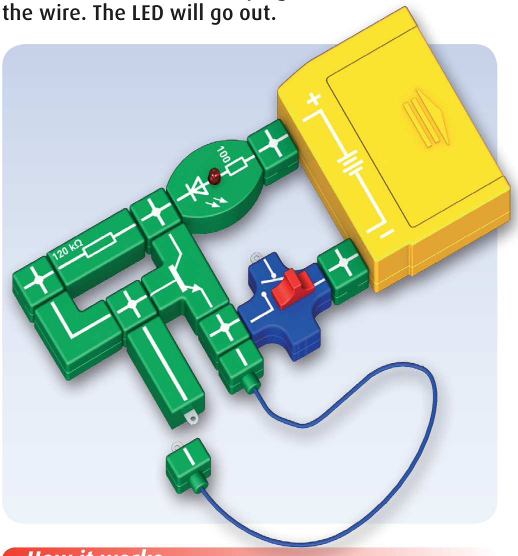
If you initially want to keep the C-E section of a transistor conductive in order to make it non-conductive only when you want, a resistor will do the trick.

You will need:

- Battery box
- 6 X-connectors
- 1 I-connector
- 1 L-connector
- 1 Transistor
- 120 kΩ Resistor
- Red LED
- Selector switch
- Blue wire

Here's how:

1. Augment the circuit from the last experiment.
2. After switching it on, the LED will light up.
3. Touch the I-connector plug with the free end of the wire. The LED will go out.



How it works:

In this case, a resistor of 120 kΩ is connected between collector and base. This ensures that there will be a steady connection between collector and base, so the LED shines. Not until you connect the base to the emitter will the LED go out.

Extra experiment:

In the last experiment, the main current circuit runs from the positive terminal through the LED, the C-E section, and the switch to the negative terminal. So you can also connect the LED between the emitter and the negative terminal, simply by exchanging the switch and the LED. The newly configured circuit will behave just like the one illustrated above.

25 Sound change by transistor

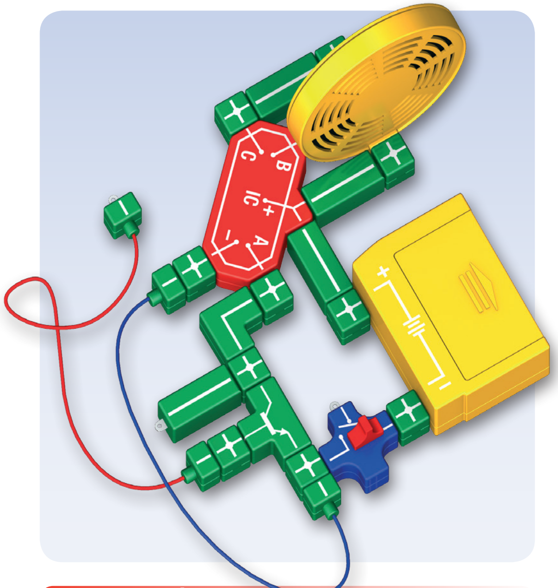
If the transistor is used as a switch, can it be used to change the sound of the sound generator?

You will need:

- Battery box
- 10 X-connectors
- 4 I-connectors
- 1 L-connector
- 1 Transistor
- Selector switch
- Red wire
- Blue wire
- Sound generator
- Speaker

Here's how:

1. This circuit, too, contains sections that you will recognize, such as the sound generator with the speaker and transistor.
2. Touch the free tab of the red wire to the terminal tab of the I-connector at the collector. The sound will change immediately.
3. Moisten your fingers and touch the red wire tab with one hand and the I-connector tab with the other. This should be enough to change the sound.



How it works:

After switching on the circuit, terminal A is not connected to either battery terminal at first, because the transistor's C-E section is blocking the current. So there is no connection to the negative terminal. But as soon as you connect the base and the collector with your moist fingers, that's enough to open the C-E section and make the sound change.

26 Alarm system with light signal

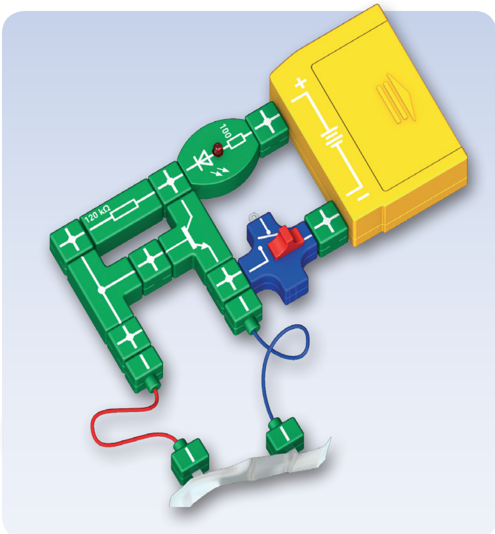
Transistor circuits can also be used as alarm systems – to monitor a door or a window, for example.

You will need:

- Battery box
- 7 X-connectors
- 1 T-Connector
- 1 Transistor
- Red LED
- Selector switch
- Red wire
- Blue wire
- 120 kΩ Resistor
- *Aluminum foil or wire*

Here's how:

1. Assemble the circuit and connect the two free wire plugs with, for example, a strip of aluminum foil or a thin wire. The LED will not yet light up when you switch on the system.
2. But if you cut through the wire or rip the aluminum foil, the LED lights up.



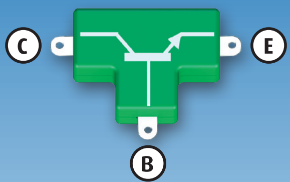
How it works:

The aluminum foil connects the base and emitter, thus blocking the C-E section — in spite of the connection of the base to the collector via the 120-kΩ resistor. The LED won't light up. If the aluminum strip rips, though, the C-B connection takes over, the transistor opens, and the LED lights up.

In an alarm system, you can lay a very thin strip of aluminum foil across a window, so that it rips if an intruder enters.

Science Database

What's going on inside a transistor?

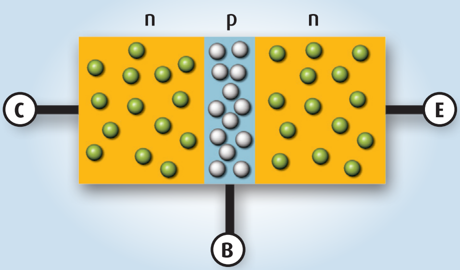


If you were to open up a transistor, you would just see a tiny crystal made of a semiconductor material. The actual processes are invisible.

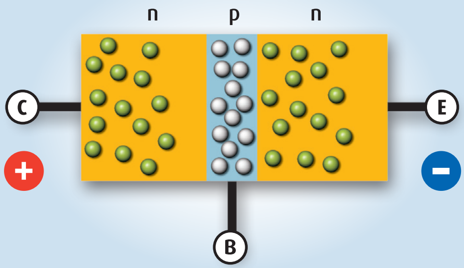
A "transistor crystal" like the ones contained in your transistors consists of three parts: two regions made of "n material," between which there lies an extremely thin layer made of "p material."

Your "n" zone contains mobile electrons (shown in green here), as you already know from your diode, while the "p" zone contains gaps or holes. Thus extremely thin but very effective blocking or depletion layers form between the zones, because that is where the electrons combine with the holes.

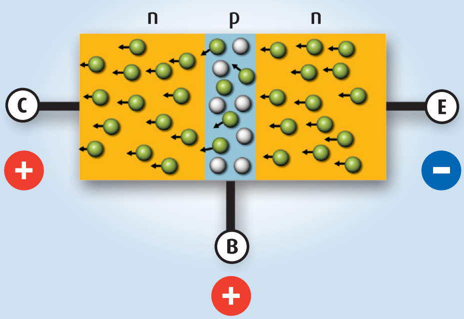
That is the reason why the C-E section of a transistor normally blocks the flow of electricity.



When you insert a collector and an emitter into an electrical circuit — the collector, for example, connected to the battery's positive terminal via an LED, and the emitter connected to the negative terminal — the negative terminal pushes the electrons toward the base, while the positive terminal pulls them away from the base. No current will flow at first on account of the depletion layers.



If, on the other hand, the base is connected to the positive terminal as shown below — even if they're connected via a large resistor — current is able to flow between emitter and base. Even a tiny base current, though, puts so many electrons from the emitter layer in motion that most of them can cross the thin base layer to get into the collector zone. That gets both depletion layers out of the way and opens up the C-E section for a strong flow of current.



These processes, by the way, are what give the terminals their names. The emitter sends out or "emits" electrons. And the collector captures or "collects" them.

27 Alarm with light signal and control

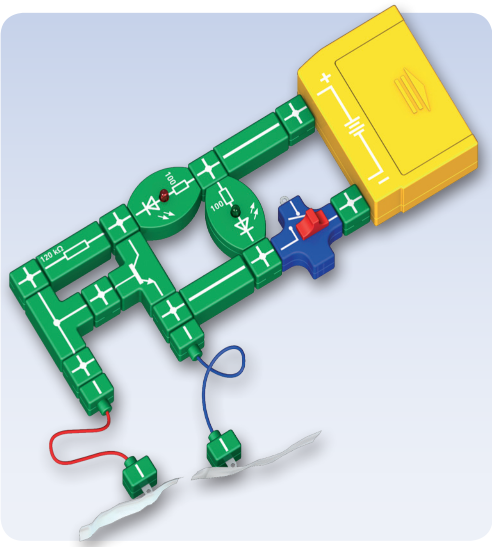
In the previous experiment, the LED wouldn't normally light up — it only would in case of a break-in. But it might happen that it fails to light up due to a power outage, or because the system just wasn't switched on. That's why it's a good idea to put together a control LED to indicate that the system is powered on and working correctly.

You will need:

- Battery box
- 9 X-connectors
- 1 T-Connector
- 2 I-connectors
- 1 Transistor
- Red LED
- Green LED
- Selector switch
- Red wire
- Blue wire
- 120 kΩ Resistor
- *Aluminum foil or wire*

Here's how:

This circuit is the same as in the last experiment, except a green LED is also inserted and the circuit is extended by two I-connectors in order to create more space. When you switch it on, the green LED lights up steadily, while the red one only lights up as an alarm. Of course, you would never power an actual alarm system with small batteries, you would do it with a permanent power source.



How it works:

The actual alarm circuit works as in the last experiment, with the green LED simply connected between the positive and negative terminals.

28 Alarm on contact

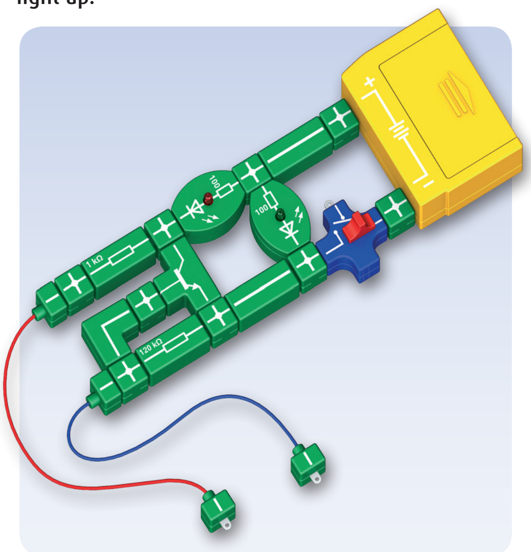
The alarm systems in the previous experiments were activated when the electrical connection was broken. Of course, you could also have a system with an alarm that comes on when a connection is created, for example when two metal contacts touch each other when a door is opened.

You will need:

- Battery box
- 9 X-connectors
- 2 I-connectors
- 1 L-connector
- 1 Transistor
- Red LED
- Green LED
- Selector switch
- Red wire
- Blue wire
- 120 kΩ Resistor
- 1 kΩ Resistor

Here's how:

1. Assemble the circuit. Don't connect the wires yet.
2. When you switch it on, only the green LED will shine.
3. Touch one free wire plug to the other: The LED will light up.



How it works:

The green LED receives current when you switch on the circuit. The red LED, on the other hand, doesn't light up at first because the 120-kΩ resistor connects the base to the emitter, which blocks the C-E section. If the wires touch each other, the base turns positive and the transistor conducts, so the red LED turns on.

29 Alarm system with sound

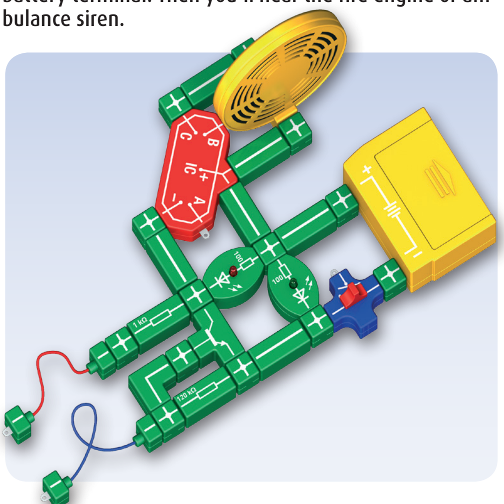
You don't always have an alarm system's light display in sight. So it would be good to have it announce itself with sound.

You will need:

- Battery box
- 13 X-connectors
- 6 I-connectors
- 1 L-connector
- 1 Transistor
- Red LED
- Green LED
- Selector switch
- Red wire
- Blue wire
- Sound generator
- Speaker
- 1 kΩ Resistor
- 120 kΩ Resistor

Here's how:

1. When you switch on the circuit, only the green LED will light up at first.
2. If you touch the two free plugs together, the red LED will also light up, and the police siren will come on at the same time.
3. If you want to make other sounds, you can replace one of the I-connectors between the sound generator and the alarm system with a T-connector and an X-connector, which will connect point A with the positive or negative battery terminal. Then you'll hear the fire engine or ambulance siren.



How it works:

Just as in the previous experiment, the C-E section of the transistor is normally blocked. The LED doesn't light up, and the sound generator is quiet as well. Even though it's connected to the positive terminal, there's no connection to the negative one. If the two plugs touch each other, the transistor opens and current can flow through the LED and sound generator.

Notes

Controlling with light

There's a mysterious component contained in your kit: a phototransistor. As its name indicates, it has something to do with light. And it will make it possible for you to do a lot of exciting experiments.

30 Light makes light

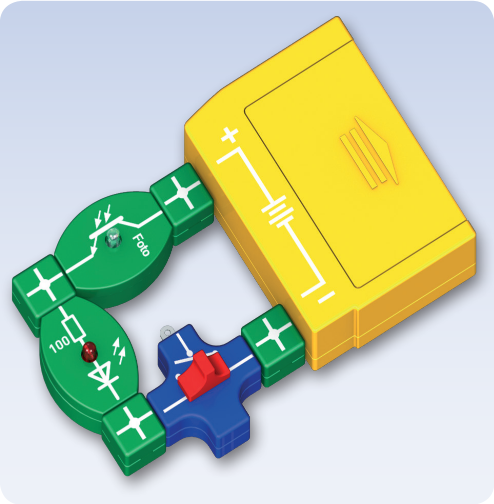
To start, let's see how the phototransistor responds to light.

You will need:

- Battery box
- 4 X-connectors
- Phototransistor
- Red LED
- Selector switch

Here's how:

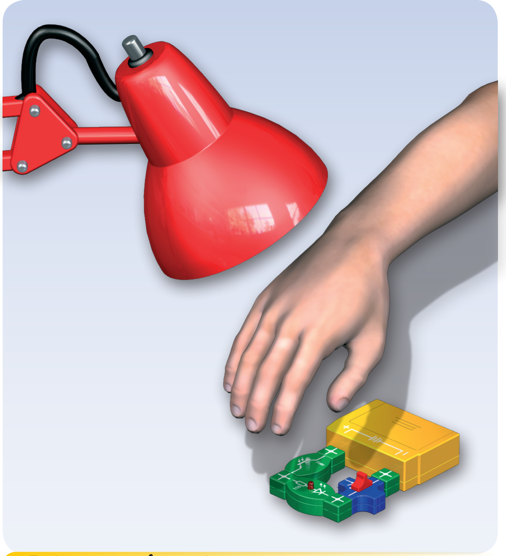
1. Assemble the circuit shown here and switch it on. Assuming you're not sitting in the dark, the LED will light up.



2. Cover the transparent phototransistor dome with your hand, or take the circuit into a dark room — the LED will go out.

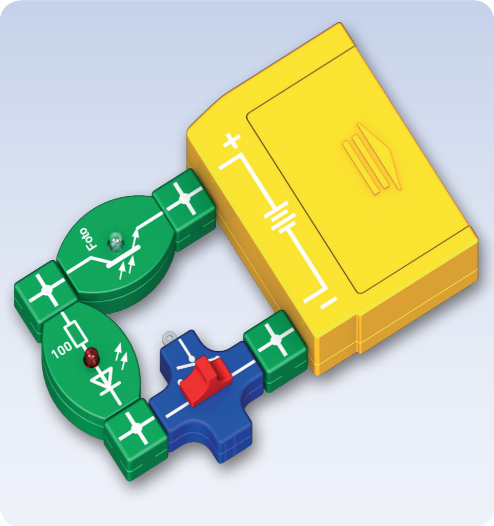
How it works:

The phototransistor acts like an electrical resistor, except its degree of resistance changes dramatically in response to the lighting. Under normal lighting conditions, the flow of current is enough for the LED. If it gets darker, the phototransistor's resistance increases, less current flows, and the LED goes out.



Extra experiment:

Remove the phototransistor and reinsert it in reverse — the wrong way around, in other words. Even if the lighting is bright, the LED won't turn on. So you also have to be careful to insert this component the right way.

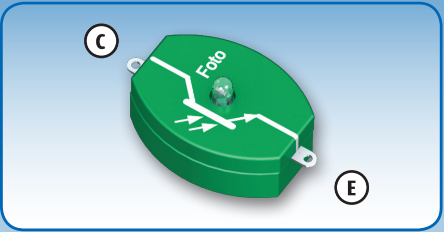


Science Database

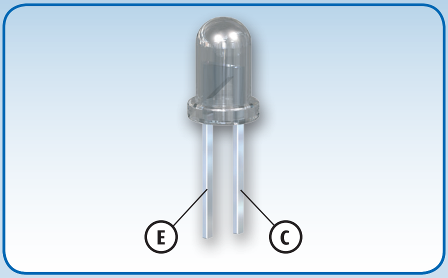
Phototransistor

Our phototransistor sits inside a housing with terminal plugs to make it easy to connect it to the other components.

Your phototransistor from the experiment kit:



A phototransistor without a housing:



Every semiconductor depletion zone is "light-sensitive," so diodes and transistors usually come packaged inside of dark cases. The light energy is sufficient to release electrons there and make electrically conductive regions out of previously non-conductive ones.

A phototransistor lets you take advantage of this in a targeted way. A lens focuses the light on the semiconductor layer, and a connected transistor intensifies the effect about 100 times.

Since the light controls permeability here, you don't need a B terminal — only C and E terminals extend out of the transparent case.

31 Invisible light

Your phototransistor doesn't just respond to visible light. It is also activated by light that is invisible to our eyes. That's a kind of light that comes out of your TV remote, for example.

You will need:

- Battery box
- 4 X-connectors
- Phototransistor
- Red LED
- Selector switch
- *TV remote control*

Here's how:

1. Use the circuit from the previous experiment.
2. Darken the room until the LED barely glimmers.
3. Point the remote at the phototransistor and press one of its buttons. The LED will fire right up.

How it works:

Inside the remote, there is a light-emitting diode that generates invisible infrared light. The remote's electronics encode each push of a button in a certain way, and the light-emitting diode emits these signals in the form of infrared light impulses. That changes the resistance of your phototransistor, as indicated by the LED. There's also a phototransistor in the television set which receives the signals and uses them to control the corresponding responses.

Extra experiment:

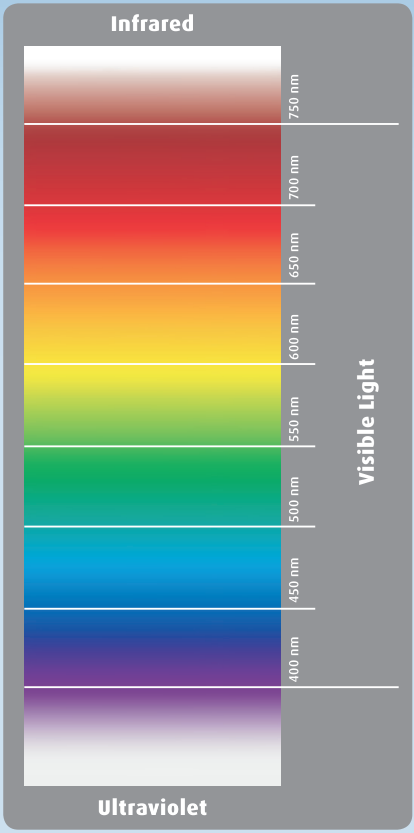
Digital cameras can sense infrared light, too. Simply hold the remote in front of the switched-on camera, look at the viewfinder screen and press one of the remote control buttons. You will see a bright spot show up on its viewfinder screen.

Science Database

Infrared light

Of all the different kinds of light, our eyes are only able to perceive a tiny fraction. There is a further region beyond the red color of a spectrum or rainbow, for example, known as "infrared." Hot objects emit infrared radiation, too — which is why it's also known as "heat radiation." And a rainbow also continues beyond its violet range, to the region of "ultraviolet light." Our eyes don't see it, but our skin reacts to strong ultraviolet radiation by turning red or tanning, and, in the worst case, by turning cancerous.

Light spectrum



32 Police arriving in the darkness

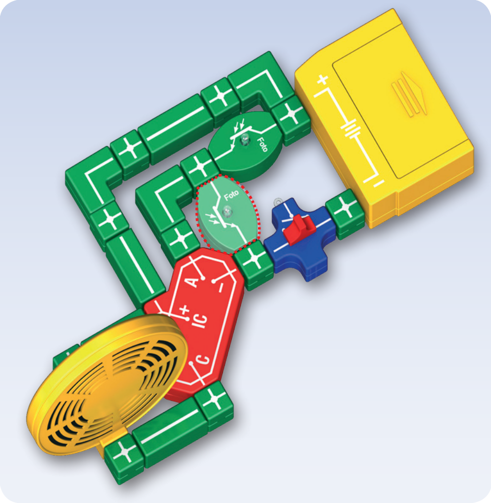
You can also connect the phototransistor to the sound generator, so it creates different sounds depending on the brightness.

You will need:

- Battery box
- 11 X-connectors
- 3 L-connector
- 4 I-connectors
- Phototransistor
- Selector switch
- Sound generator
- Speaker

Here's how:

1. Assemble the circuit and pay attention to the direction that the phototransistor is inserted.
2. Switch on: You will hear the fire engine siren.
3. Darken the room: Now you will hear the police siren.



How it works:

In bright light, the phototransistor connects terminal A to the battery's positive terminal, so you hear the fire engine siren that you know from Experiment 18. In the dark, the phototransistor resistance will be so high that terminal is no longer connected, so you hear the police alarm from the sound generator.

Extra experiment:

If you connect the phototransistor to the negative terminal instead of the positive one, you can switch between the ambulance and police siren. The new phototransistor position is shown outlined in dotted lines in the illustration.

33 Base in the balance

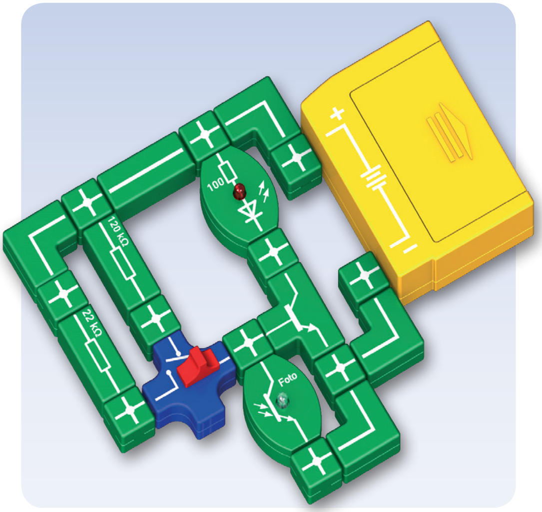
The phototransistor actually behaves just like a resistor with a degree of resistance that you can control — in this case, by lighting. That makes it possible to perform some interesting experiments that may help answer this question: When does a transistor make the C-E section turn conductive?

You will need:

- Battery box
- 11 X-connectors
- 1 I-connector
- 4 L-connector
- 1 Transistor
- Phototransistor
- Red LED
- Selector switch
- all the resistors

Here's how:

1. Assemble the circuit and set the selector switch to "off." The LED won't light up if it's too bright.
2. It would be ideal if you have a room light with a dimmer switch, so you can adjust its brightness continuously. Otherwise, you can shade the phototransistor with your hand. Try it and note how mush shading it needs for the LED to turn on.
3. Now use the selector switch to turn on the 22-kΩ resistor (switch set to the left).
4. Shade the phototransistor again. Now you'll need a lot less shadow than before.
5. Replace the 22-kΩ resistor with the 8-kΩ and 1-kΩ resistors and test the circuit. The LED might first stay steadily lit now, and you may even have to increase the brightness to turn it off. A little shadow will suffice to turn it on.

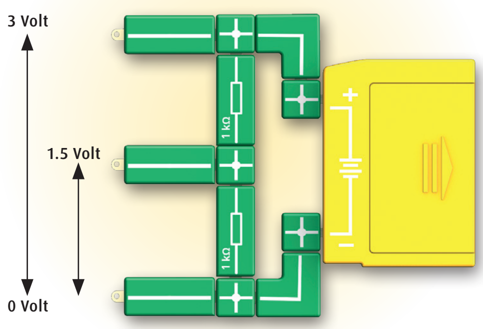


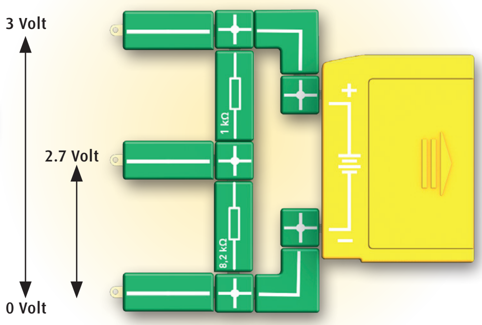
How it works:

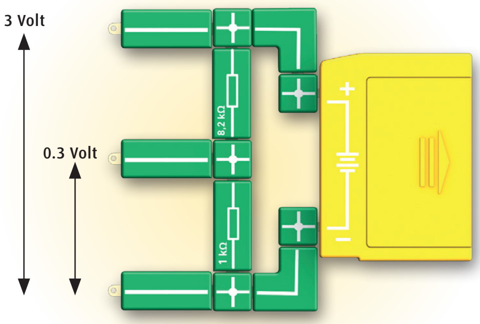
Apparently, both the fixed resistor value and the resistance of the phototransistor determine whether the LED lights up or not. That means that they are changing the voltage at the base.

The two resistors, the 120-kΩ together with the phototransistor, form a so-called "voltage divider." That means that they divide the battery voltage of 3 volts.

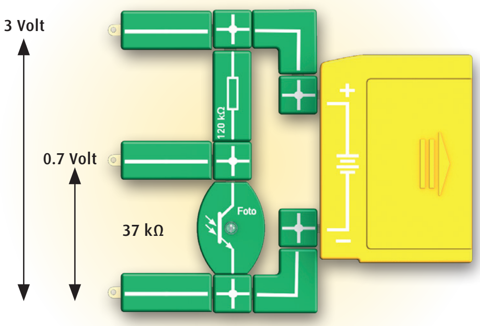
The pictures below and on the next page show a few examples with different resistance values and the voltage you'd measure at the respective points:







As you know from Experiment 23, positive voltage at the base makes the transistor conductive. If the voltage drops relative to the negative terminal, the transistor will cut off at a certain level. This level will be about 0.7 volts, as determined by the semiconductor properties. In the previous circuits, this voltage will be reached with the 120-kΩ resistor when the phototransistor has a resistance of 37 kΩ. If it gets any brighter, it will block the transistor, while if it gets darker, it will open the transistor.



If, on the other hand, you insert the 2-kΩ transistor, the phototransistor only has to have 6 kΩ to block the base.

Even with a slight shadow, though, its resistance will rise, it will open the transistor, and the LED will shine.

Notes

Up to now, you have only used the transistor as a switch. But one of the most important properties of this component is to amplify weak signals — a property used, for example, in radios, microphone amplifiers, earphones, and MP3 payers.

34 Sensitive amplifier

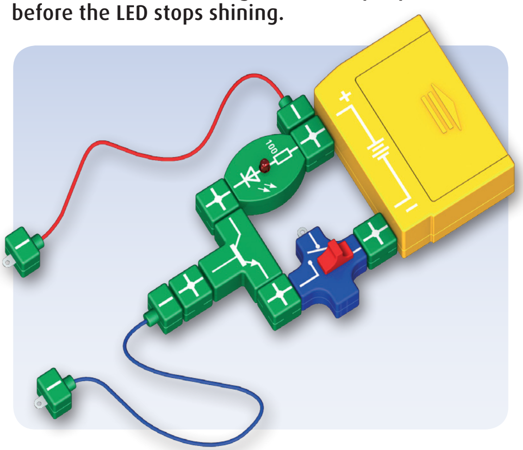
First of all, let's get your transistor to show how well it can amplify. You will be amazed.

You will need:

- Battery box
- 5 X-connectors
- 1 Transistor
- Red LED
- Selector switch
- Red wire
- Blue wire
- *2 Metal paper clips*

Here's how:

1. Assemble the circuit and touch both free plugs at the same time with one hand. The LED will light up.
2. Touch one plug with each hand. The LED lights up now as well, although not so brightly.
3. Attach a metal paper clip to each of the plugs. Now the LED has a stronger response when you touch the plugs.
4. Ask a friend to touch one plug with one hand, while you touch the other one. Now join your free hands together: The LED lights up now, too.
5. You can see how long a chain of people it takes before the LED stops shining.



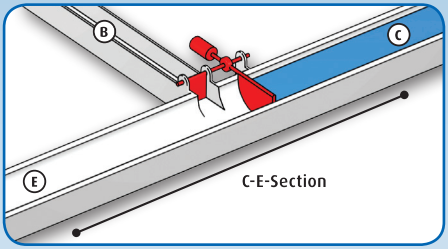
How it works:

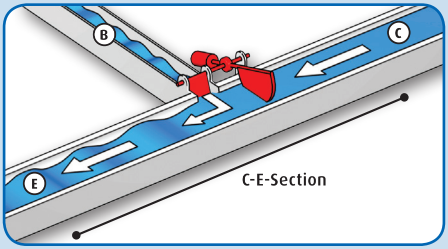
Just a slight positive voltage at the base and an even smaller current flowing into it will be enough to turn the transistor's C-E section conductive and make a strong current flow through the LED.

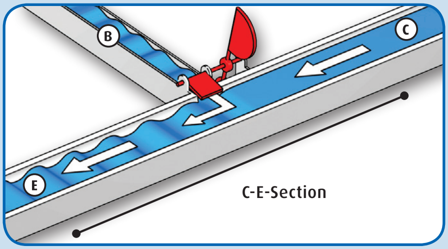
Science Database

Transistor as amplifier

The water model clearly illustrates how the transistor acts as an amplifier. You can see that even a small trickle in the side channel can activate the flap. But that has an effect on a much stronger flow of water in the other channel. This is known as "amplification." In a transistor amplifier — in a radio, for example — a tiny flow of current in the base controls a much stronger current through the C-E section. Thus current can be conducted into the base of another transistor and further amplified. The base current fluctuations generate corresponding, but much stronger, fluctuations in collector current. In this way, very weak currents, such as the current received by a radio or television antenna, can be amplified a million times over until they are capable of controlling a speaker or a picture screen.







35 Multiplied sensitivity

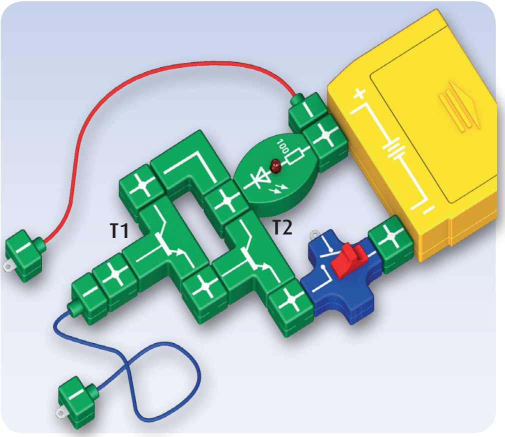
If a horse can't pull a heavy wagon, you can hitch up two horses to it. In the same way, two transistors can accomplish more than one — except that in their case, the amplifying effects don't just add up, they multiply.

You will need:

- Battery box
- 7 X-connectors
- 1 L-connector
- 2 Transistors
- Red LED
- Selector switch
- Red wire
- Blue wire

Here's how:

1. Add another transistor to the circuit from Experiment 34.
2. Switch on the circuit: The LED won't light up, or only very weakly.
3. Lightly touch the two free plugs — the LED clearly lights up, much more strongly than with a single-transistor amplifier.



How it works:

Even a slight positive voltage at the first transistor base opens its C-E section relatively wide. But when that happens, the second transistor's C-E section receives a much higher voltage and opens correspondingly wider, and the LED lights up. This kind of combination multiplies both transistors' amplifications, and is capable of reaching values up to 50,000. Then, the current through the LED is 50,000 times stronger than the current flowing into the base of the first transistor.

36 Touch button

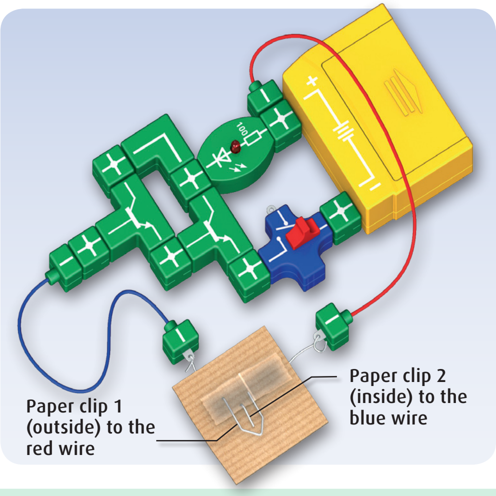
They were quite popular for a few years: buttons on TVs and elevators that responded to a mere touch rather than needing any pressure.

You will need:

- Battery box
- 7 X-connectors
- 1 L-connector
- 2 Transistors
- Red LED
- Selector switch
- Red wire
- Blue wire
- *Cloth*
- *2 Metal paper clips*
- *Cardboard*
- *Scissors*
- *Tape*
- *Plastic ruler*
- *Aluminum foil*

Here's how:

1. Use the circuit from Experiment 35.
2. Using a piece of tape, attach a small piece of aluminum foil to the free red wire plug. Be sure that the metal surfaces make good contact.
3. Touch the aluminum foil with your finger. The LED will flash briefly. This will work especially well in very dry weather, because your body will accumulate an electric charge by rubbing against your clothes.
4. Rub a plastic ruler or protractor a few times against a piece of cloth, and then touch the aluminum foil with it. The LED will flash brightly.
5. Move the rubbed ruler up and down over the aluminum foil from a few centimeters away. Each time you pull it up, the LED will blink on.
6. Piece together a touch button from cardboard, tape, and two paper clips, and connect it to the wire plugs. Now you can turn on the LED with just a touch.

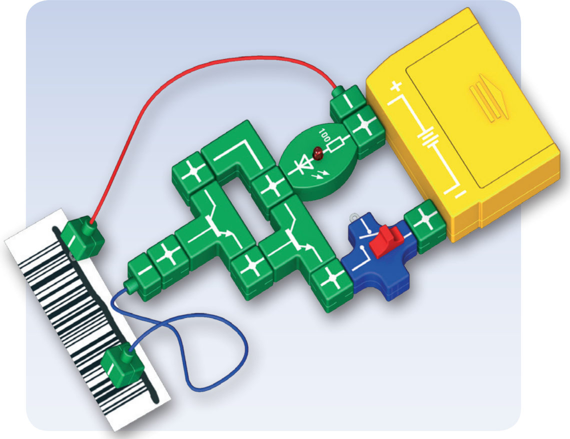


How it works:

The circuit is so sensitive that it responds to even tiny changes in voltage at the first transistor's base — for example, an electrically charged human body or plastic object. Because the aluminum foil "senses" the ruler's electrical charge from a few centimeters away, you will even get a weak current if you just move the ruler away a little.

37 Conductivity tester

In Experiment 7, you used the LED to test the electrical conductance of various materials. You can now use the amplifier circuit as a much more sensitive conductivity indicator.



You will need:

- Battery box
- 7 X-connectors
- 1 L-connector
- 2 Transistors
- Red LED
- Selector switch
- Red wire
- Blue wire
- *Soft pencil*
- *Paper*
- *Pencil line from Experiment 7*

Here's how:

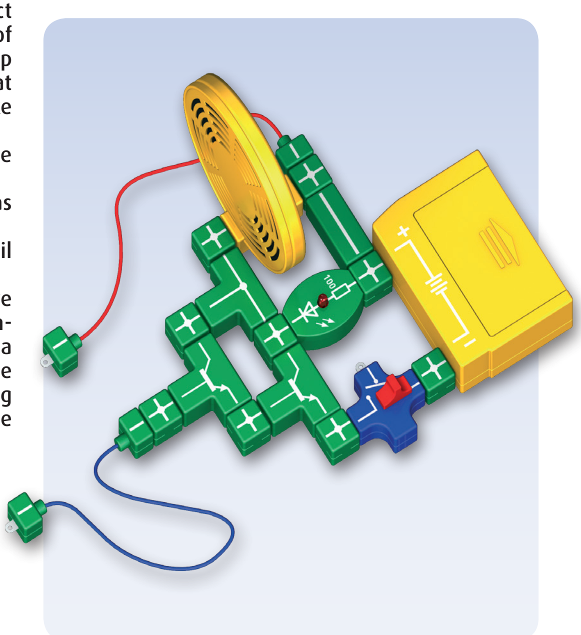
1. First, assemble the amplifier circuit from Experiment 34 with a transistor.
2. Use it to test various materials that don't conduct current very well, such as purified water, a piece of apple or butter, various drinks, damp paper, damp wood, bread, and other things. You will see that even pure water conducts enough current to make the LED light up.
3. Use the amplifier circuit to test the pencil line from Experiment 7.
4. Now add the second transistor to the circuit, as you did in Experiment 35.
5. Use this to test a variety of thick and thin pencil lines. You will notice a much greater sensitivity.
6. Draw a design made of several pencil marks, more or less like a bar code (like the ones printed on commercial products), and connect all the lines with a thick bar along one edge. Now, when you press one of the plugs against this bar and move the other plug over the paper, the LED will blink in rhythm to the bar code pattern.

How it works:

It's the extreme sensitivity of the circuits that makes these effects possible.

Extra experiment:

The LED provides an optical display of the current flow, but you can also get an audible one. Use an I-connector, a T-connector, and two X-connectors to connect the speaker to the two LED terminals. When you rub the plugs against each other, you will hear a crackling or rustling sound. Try hearing what the bar code pencil pattern sounds like.

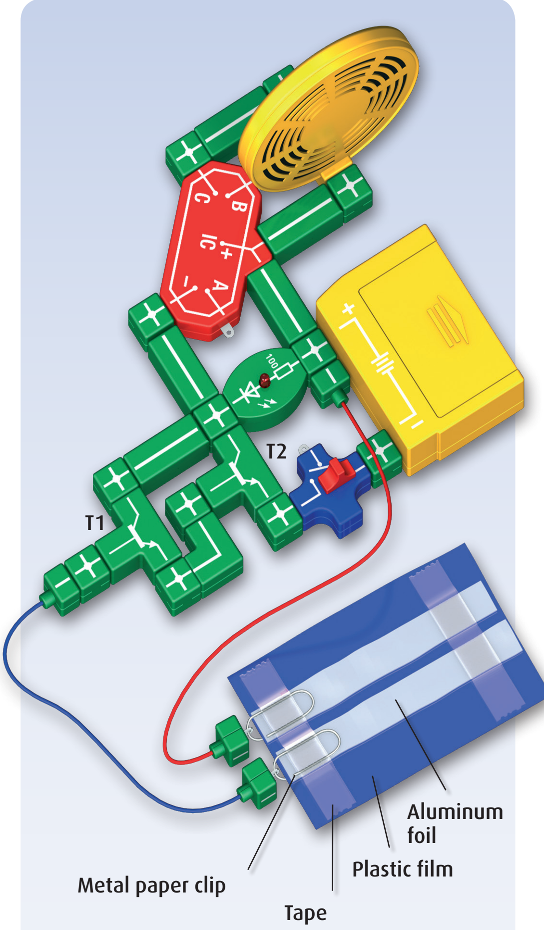


38 Rain sensor with sound

Sometimes an unexpected rain can cause damage, such as when the windows are left open or certain things are left outside. But there are electronic devices that can help with that.

You will need:

- Battery box
- 12 X-connectors
- 5 I-connectors
- 1 L-connector
- 2 Transistors
- Red LED
- Selector switch
- Red wire
- Blue wire
- Sound generator
- Speaker
- *Tape*
- *2 Metal paper clips*
- *All-purpose glue*
- *A piece of plastic film (back side of an old plastic folder)*
- *Scissors*
- *Table salt*
- *Aluminum foil*
- *Some tap water*



Here's how:

1. Cut a piece of plastic about 5 by 10 cm in size.
2. Cut two strips of aluminum foil, about 1 by 10 cm each, and glue them to the plastic piece. Leave about 3 millimeters between the two strips of foil. Do not let them touch!
3. Assemble the circuit.
4. Attach one paper clip to each free plug, clamping them on tight so they don't wiggle.
5. Tape each paper clip to one of the strips of aluminum foil. Make sure that they make good contact with the foil. This is your rain sensor.
6. Switch on the circuit. The LED and sound generator will be off at first.
7. Drip a little water on the rain sensor, as if it were raining. After a few seconds, you will see the LED light up and hear the alarm.
8. Once the water has evaporated, you can try using the sensor again.
9. If you sprinkle some fine-grained salt on the plastic surface, your rain alarm will work even better. Also, it will sense dew and fog.
10. Keep the circuit assembled for the next experiment.

How it works:

The dry plastic surface hardly conducts any current. But just a few rain drops can create a connection between the strips of aluminum foil, especially if there's salt dissolved in the water. And that's when the LED and sound generator will respond.

39 Alarm! Overflow!

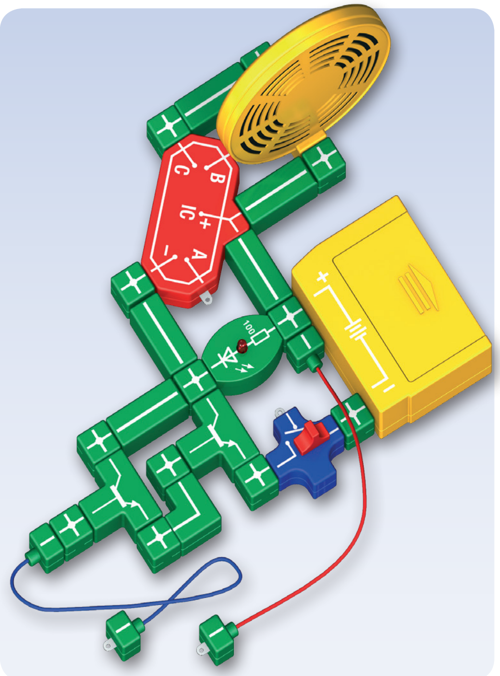
In factories, there are often automatic filling systems for tanks. So they need an electronic means to determine when a tank is full and to switch off the pump. And in the basement of a house, it's useful to have an automatic monitoring system to sound an alarm when rainwater gets in. A water level sensor can handle tasks like those.

You will need:

- Circuit from Experiment 38
- *Tape*
- *Drinking glass*
- *Tap water*

Here's how:

1. Tape the free ends of the wires to the rim of an empty glass. The plugs should hang about 2 cm below the rim, and there should be a few centimeters of space between them.
2. Switch on the circuit and slowly pour water into the glass. As soon as the water reaches the two plugs, the LED will light up and the alarm will sound.



How it works:

The water makes a connection between the plugs when it reaches them and the circuit responds.

40 Low water level alarm

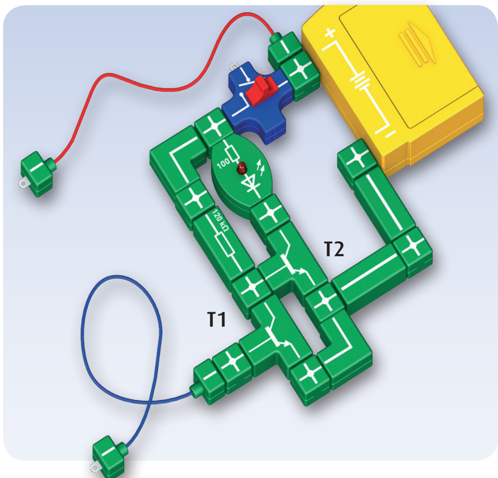
Circuits like this one warn you when a liquid level is too low, such as the gasoline level in a car's gas tank.

You will need:

- Battery box
- 10 X-connectors
- 2 I-connectors
- 2 L-connector
- 2 Transistors
- Red LED
- Selector switch
- Red wire
- Blue wire
- 120 kΩ Resistor
- *Drinking glass*
- *Tape*
- *Teaspoon*
- *Tap water*

Here's how:

1. Assemble the circuit and secure the free wire ends to the inside of the glass. Switch on; the LED shines.
2. Fill the glass with tap water until both plugs are submerged. The LED will go out.
3. Now take water out with the teaspoon. At the moment that the water no longer creates a connection between the plugs, the LED will turn on.



How it works:

As long as the water creates a connection between the plugs, the first transistor's base is connected to the positive battery terminal, so its C-E section is conductive. That means that the second transistor's base is connected to its emitter and the negative terminal, and the current is blocked in spite of the connection with the positive terminal via the 120-kΩ resistor: The LED remains dark. If the water level drops, the first transistor's C-E section cuts off, and the base connection via the 120-kΩ resistor ensures that the second transistor is conductive. Then the LED lights up.

41 Sensitive light display

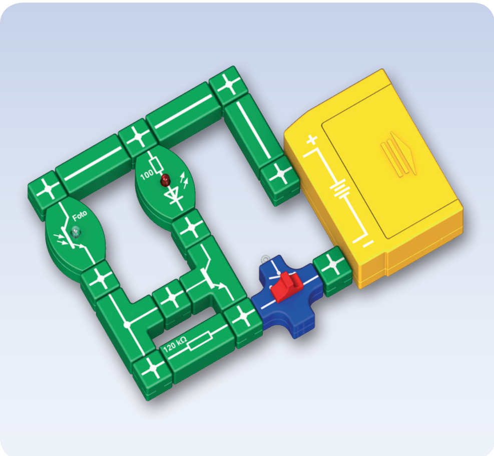
When you combine the phototransistor with the transistor, the LED has a sensitive response to light.

You will need:

- Battery box
- 10 X-connectors
- 1 T-Connector
- 3 I-connectors
- Phototransistor
- Red LED
- 1 Transistor
- Selector switch
- 120 kΩ Resistor

Here's how:

1. Assemble the circuit, and the LED will shine.
2. Darken the room as completely as possible, or at least cover the phototransistor. The LED will only go out once it gets pretty dark.
3. If you remove the 120-kΩ resistor, the circuit will be a lot more sensitive.



How it works:

Even with low lighting, the phototransistor connects the base to the battery's positive terminal, so the C-E section becomes conductive and the LED shines. The 120-kΩ resistor connects the base to the emitter, so the transistor blocks the current if the conditions are at least halfway dark. Circuits of this type may be used as alarm systems: When the light goes on, the alarm goes off.

Tip: The phototransistor is very direction-sensitive. If you position a tube of dark paper over it and secure the tube with tape, you can home in on it quite precisely with a small light source in a darkened room.

42 Night light

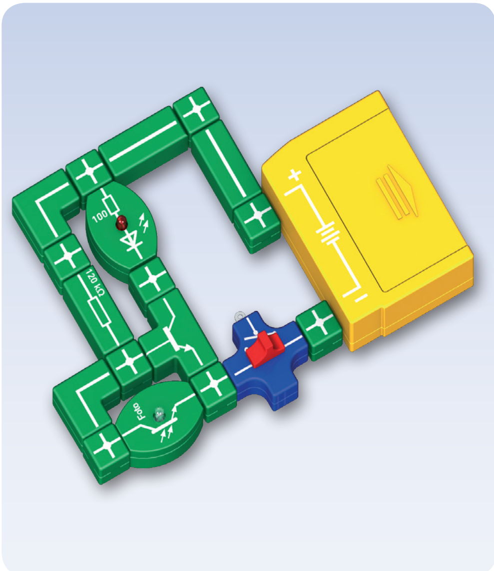
This circuit can be used as a twilight switch: If it's dark enough outside, it will turn on a street light — or in this case, just the LED — and turn it off again in the morning.

You will need:

- Battery box
- 9 X-connectors
- 2 I-connectors
- 2 L-connector
- 1 Transistor
- Phototransistor
- Red LED
- Selector switch
- 120 kΩ Resistor

Here's how:

1. Assemble the circuit.
2. When you switch it on, the LED won't shine.
3. Completely darken the room, or cover the phototransistor. The LED will only come on once it gets very dark.



How it works:

In the dark, thanks to the 120-kΩ resistor, the base is connected to the positive terminal, the C-E section is conductive, and the LED shines. When it's brighter, the resistance value of the phototransistor drops.

The previously positive base is now more and more negative, and it ultimately blocks the C-E section.

43 Light barrier

It is common to use light barriers to guard valuable objects and rooms containing important things. A light barrier consists of an alarm system that sends an invisible beam of light through the room, which is then received by a photo sensor. As long as the beam of light reaches its destination, everything is quiet. But when it doesn't, because someone has walked through it and interrupted it, the alarm goes off. You can set up this kind of light barrier yourself.

You will need:

- **Circuits from Experiment 42**
- ***Flashlight***
- ***Tape***
- ***Cardboard tube (paper towel roll)***

Here's how:

1. Position the circuit on the table in such a way that the phototransistor is pointing to the side. Ideally, lean it edgewise against a wall.
2. Position the cardboard tube over the phototransistor and secure it with tape.
3. Point the beam of a flashlight right into the tube from a few meters away.
4. Darken the room.
5. The LED won't light up as long as the flashlight beam hits the phototransistor.
6. If you break the beam of light with your hand or by walking across it, the LED will light up.

How it works:

The circuit matches the one from the last experiment, except in this case the flashlight is responsible for producing "daylight," which makes the LED stay dark. If you interrupt the beam of light, though, the LED lights up, because the C-E section becomes conductive.

44 Super-sensitive light detector

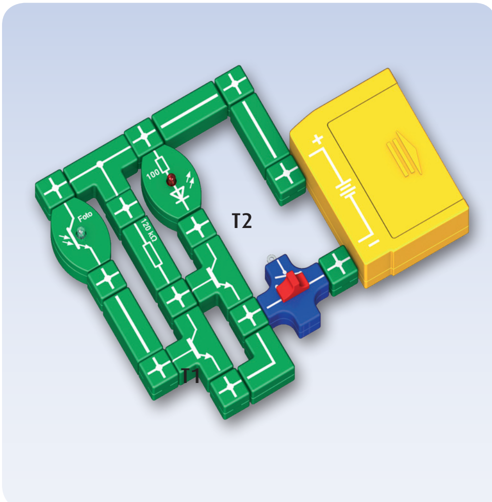
You can increase the system's sensitivity to light even more by using two transistors.

You will need:

- **Battery box**
- **12 X-connectors**
- **3 I-connectors**
- **1 L-connector**
- **1 T-Connector**
- **Phototransistor**
- **Red LED**
- **2 Transistors**
- **Selector switch**
- **Resistor 120 kΩ**
- ***White paper***

Here's how:

1. Assemble the circuit.
2. After you switch it on, the LED doesn't shine.
3. Make the room completely dark. The LED will turn on.
4. Hold some white paper over the LED and the phototransistor: It will shine more weakly, because the phototransistor is responding to the LED's light. You can see that clearly if you hold your finger between the LED and the paper: It gets brighter.



How it works:

In complete darkness, the first transistor blocks the current, and the second transistor's base is connected to the positive terminal via the 120-kΩ resistor, with its C-E section therefore conductive: The LED shines. As soon as the phototransistor gets even a little light, it makes the first transistor's C-E section become conductive, so the second transistor's base turns negative, and it blocks the current to the LED.

45 Light on, sound on

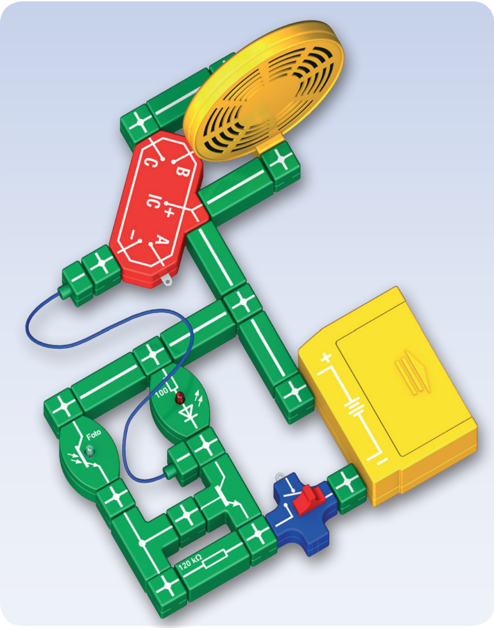
As you know, it can sometimes be useful to be able to hear an alarm signal — even when it's triggered by light.

You will need:

- Battery box
- 14 X-connectors
- 1 T-Connector
- 6 I-connectors
- 1 Transistor
- Phototransistor
- Red LED
- Blue wire
- Selector switch
- 120 kΩ Resistor
- Sound generator
- Speaker

Here's how:

1. Assemble the circuit and switch it on. If it's bright, the siren will sound and the LED will shine.
2. Darken the room or cover the phototransistor. The LED will go out and the siren will turn silent.



How it works:

As in Experiment 42, the phototransistor controls the flow of current through the transistor. Now the sound generator is hooked up in addition to the LED, and when the C-E section becomes conductive it connects to the negative terminal and starts to wail.

46 Lights off, sound on

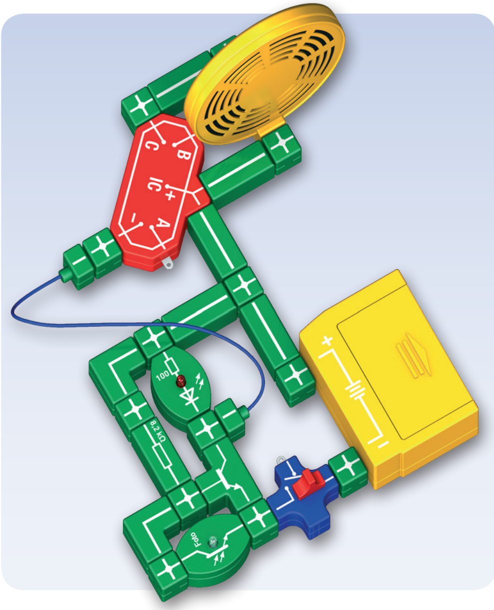
Unlike the previous circuit, this one sets off the alarm when the room lights go out.

You will need:

- Battery box
- 13 X-connectors
- 5 I-connectors
- 2 L-connector
- 1 Transistor
- Phototransistor
- Red LED
- Blue wire
- Selector switch
- 8.2 kΩ Resistor
- Sound generator
- Speaker

Here's how:

1. Assemble the circuit and switch it on.
2. The LED stays dark, and the speaker keeps silent.
3. Darken the room or cover the phototransistor. The LED will light up and the police siren will sound.



How it works:

When it's illuminated, the phototransistor ensures that the transistor cuts off the current. Only when it's dark in the room and its resistance value rises will the 8.2-kΩ resistor pull the base to positive and turn the C-E section conductive.

Extra experiment:

You can convert this circuit into a light barrier. When the beam of light is broken, the sound generator's alarm will go off.

In this section, you will get to know some new, very versatile and useful electronic components: capacitors. They are capable of storing small or large quantities of electricity.

47 Charged with electricity

If the capacitor is going to store electricity, you first have to charge it. But electric current is invisible, so let's make it flow through an LED so we can see it.

You will need:

- Battery box
- 4 X-connectors
- Selector switch
- 100-μF capacitor
- Red LED
- Red wire
- Blue wire

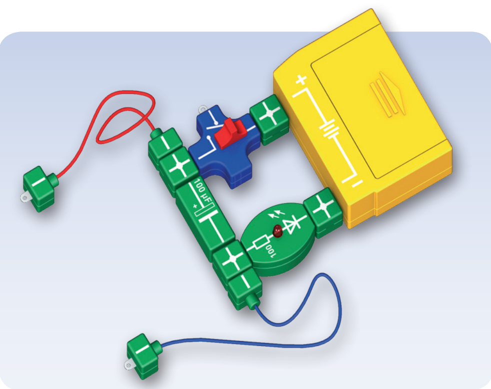
Here's how:

1. Assemble the circuit, but leave the selector switch off (pushed to the right) at first.
2. Briefly hold the free wire plugs against one another so that they touch each other for a moment, and then pull them apart again.
3. Switch on the circuit. The LED will briefly light up.

How it works:

Touching the plugs against each other discharges the capacitor, so it can take up as much electricity as possible. When you switch on the circuit, it takes up a relatively large amount of electricity for a moment, and the current that flows as that happens makes the LED blink on for a moment. Once the capacitor is fully charged, the flow of current stops, and the LED goes out again.

By the way, the 0.1-μF capacitor can also store electricity. But since it stores a thousand times less, the charge current that flows is not enough for the LED.



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Capacitors

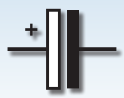
These components consist of two thin pieces of metal foil that are insulated from each other by an extremely thin insulation layer. Hence its circuit symbol shows two metal plates a slight distance apart from each other.

They have the ability to store small quantities of electricity — when you hook up a battery, for example, as in Experiment 47. Different capacitors have very different "storage capacities," indicated in "farad" (F) units. Since the farad is a very large unit, only fractions of it are normally used — for example, "microfarads" (μF), with 1 μF corresponding to a millionth of a farad.

Capacitors assume a lot of different tasks in electronic circuits. They are among the most important components in radios, television sets, timers, and amplifiers, for example.

Specific types of capacitors called **"electrolytic capacitors"** have an insulating layer produced by electrochemical means, so they are sensitive to polarity reversals. So you have to be careful to insert your 100-μF capacitor the right way around — look for the + sign.

Normal capacitor



Electrolytic capacitor

48 One-second electricity supply

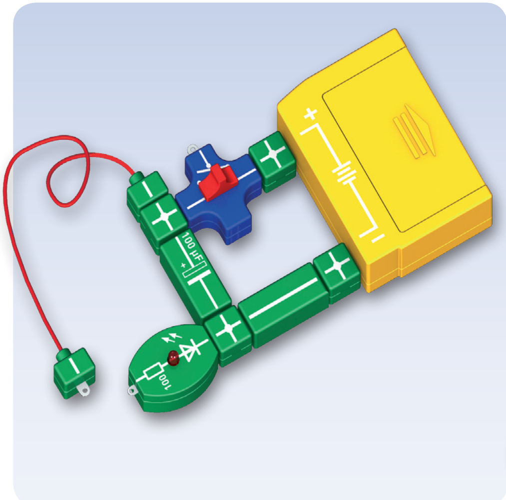
You can't tell by looking at the outside of the capacitor whether it's full, partly charged, or empty. But the LED can tell you.

You will need:

- Battery box
- 4 X-connectors
- 1 I-connector
- Selector switch
- 100-µF capacitor
- Red LED
- Red wire

Here's how:

1. After assembling the circuit, briefly turn on the selector switch and then turn it off again.
2. Briefly hold the free cable plug up to the LED plug. The LED will blink on for a moment.
3. If it stays lit for longer, you forgot to turn the selector switch back off again.



How it works:

While the selector switch is turned on, the capacitor charges itself full of electricity. If you then connect it to the LED, it discharges itself again and the current that flows (the "discharge current") makes the LED light up.

49 Small charges made visible

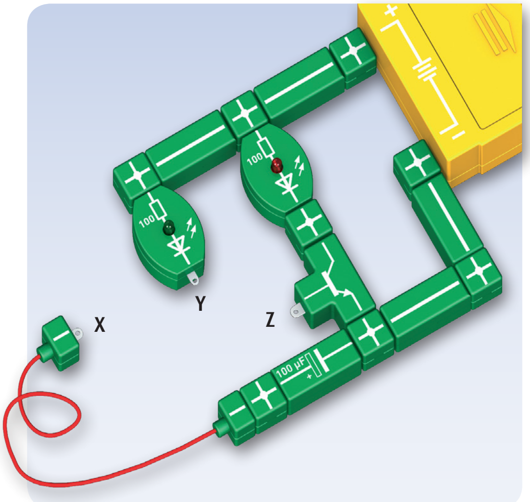
In the prior experiments, the LED only lit up after the capacitor had been completely empty (Experiment 47) or completely full (Experiment 48). But you can use a transistor amplifier to sense much smaller charge currents.

You will need:

- Battery box
- 8 X-connectors
- 4 I-connectors
- 1 Transistor
- 100-µF capacitor
- Red LED
- Green LED
- Red wire

Here's how:

1. Assemble the circuit. None of the LEDs will light up.
2. Connect the X and Y contacts for a moment. The green LED will blink briefly.
3. Now hold the X plug to the Z plug. The red LED will shine brightly, and then gradually darken and go out.



How it works:

First, you charge the capacitor via the green LED. Then you connect it to the transistor's base, which had been open before with the C-E section blocked and the red LED off. Now the full voltage of the charged capacitor is applied to the base and opens the C-E section: The red LED lights up brightly. But then the capacitor slowly discharges through the base-emitter section, so the voltage drops at the capacitor and the base. The C-E section gradually closes and cuts off, slowly causing the red LED to go out.

On stopwatches and timers

In all of the previous experiments, the effect of a change — such as throwing a switch — showed itself right away. Experiment 49 was the first one where the "time" factor came into play: The LED went out gradually, over the course of several seconds. The reason, of course, was the capacitor, which will also make it possible to run a lot of other experiments where time also has a part to play.

50 Stairway light

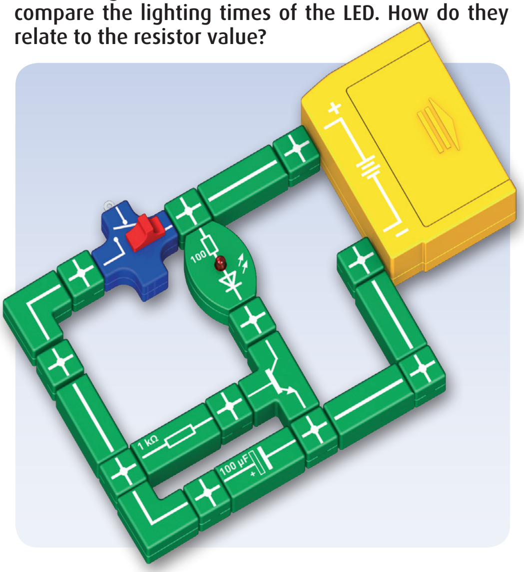
To save electricity, a lot of modern apartment buildings have stairway lighting systems that only stay on for a few minutes after you push a button, and then go out by themselves. You can also build an electronic circuit able to do something like that.

You will need:

- Battery box
- 11 X-connectors
- 4 I-connectors
- 2 L-connector
- Selector switch
- 1 Transistor
- 100-µF capacitor
- Red LED
- all the resistors

Here's how:

1. Assemble the circuit. Have the selector switch set to "off."
2. Switch it to "on." The LED will shine brightly.
3. Switch to "off" again. The LED will only go out after a few seconds.
4. Exchange the 1-kΩ resistor for other ones, and compare the lighting times of the LED. How do they relate to the resistor value?



How it works:

When you switch on the circuit, it charges the capacitor. The C-E section becomes conductive, and the LED shines. After switching off, the capacitor gradually discharges. Current flows from the capacitor's positive terminal through the resistor and the B-E section. The resistor value determines the discharge current and, thus, the discharge time as well: The greater the resistance, the less current flows, the longer the discharge takes and the longer the LED stays lit. It may be necessary to "empty" the capacitor in order for the experiment to work.

Tip: If it doesn't work, it might be because the capacitor still had a charge stored in it. You can take care of this with the help of a "short circuit": Remove the capacitor from the circuit and briefly touch both capacitor terminals with the wire.

51 Stairway light with sound switch

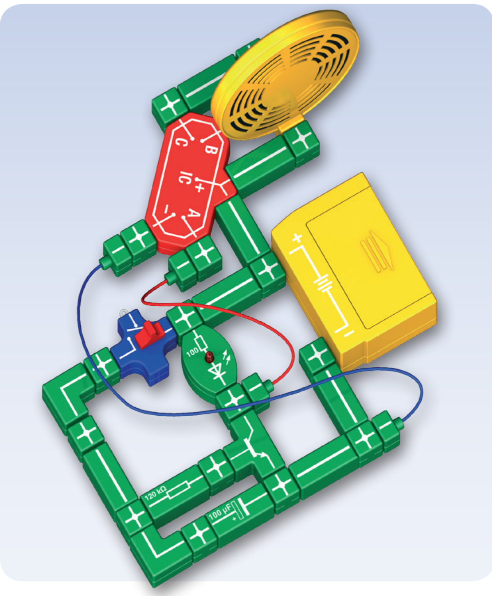
Sometimes you can't keep an eye on a light, and you have to rely on your ears instead. In that case, a sound switch will come in handy.

You will need:

- Battery box
- 16 X-connectors
- 7 I-connectors
- 2 L-connector
- 1 Transistor
- 100-µF capacitor
- Red LED
- all the resistors
- Selector switch
- Sound generator
- Speaker
- Red wire
- Blue wire

Here's how:

1. Assemble the circuit, with the switch set to "off."
2. Operate the circuit as in the last experiment. As long as the LED stays lit, the ambulance siren will wail. After the corresponding period of time, the LED will go out and the police siren will sound.
3. Compare the various resistors. How long does it take for the sound to change?



How it works:

As long as the C-E section is conductive, it will connect the sound generator's terminal A to the battery's negative terminal: The ambulance siren will sound. If it cuts off, the terminal is "left hanging" and it switches to the police siren.

52 Timer

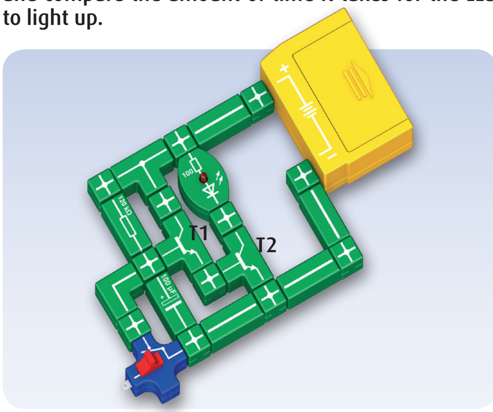
A timer, such as an egg timer or kitchen timer, is supposed to give a signal only after a certain period of time has passed. This kind of circuit is pretty easy to assemble, too.

You will need:

- Battery box
- 12 X-connectors
- 4 I-connectors
- 1 L-connector
- 1 T-connector
- 2 Transistors
- 100-µF capacitor
- Red LED
- all the resistors
- Selector switch

Here's how:

1. As soon as you have assembled the circuit, the LED will start to shine.
2. Push the slider of the selector switch to the left. The LED will go out and then come on again after a certain period of time.
3. Replace the 120-kΩ resistor with one of the others and compare the amount of time it takes for the LED to light up.



How it works:

When you activate the selector switch, it discharges the capacitor. When that happens, there is a voltage of 0 relative to the base, and the C-E section of the first transistor cuts off. That opens the second transistor's base, which likewise cuts off. But the capacitor gradually starts to discharge across the 120-kΩ resistor, and the base voltage rises accordingly. Once it reaches 0.7 volts, the transistor switches through and connects the second transistor's base to the battery's positive terminal, so this transistor also opens and the LED lights up.
The smaller the resistor that you install, the quicker the capacitor will discharge and make the LED light up.

53 Timer with sound change

You can use the sound generator to set up your timer so that you can hear when the right moment has arrived with a change in sound.

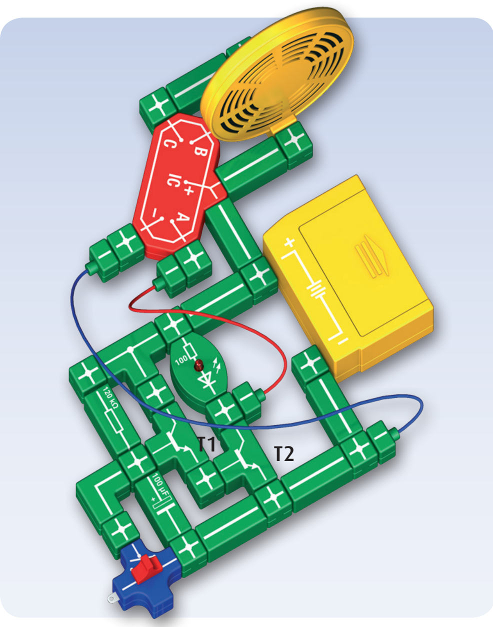
You will need:

- Battery box
- 17 X-connectors
- 7 I-connectors
- 1 L-connector
- 1 T-Connector
- 2 Transistors
- 100-µF capacitor
- Red LED
- all the resistors
- Selector switch
- Sound generator
- Speaker
- Red wire
- Blue wire

Here's how:

1. As you did in Experiment 51, simply connect the sound generator directly to the positive terminal and to the negative terminal via the blue wire. Use the red wire to connect terminal A to the second transistor's collector.

2. After activating the switch (slide to the right), the police siren will go off, and then it will turn into the ambulance siren.



How it works:

As in Experiment 51, the transistor connects the sound generator's terminal A to negative as soon as its C-E section is conductive.

54 Timer with phototransistor control

You can, of course, insert the phototransistor in place of a resistor. Then you will be able to compare levels of brightness with the help of the clock.

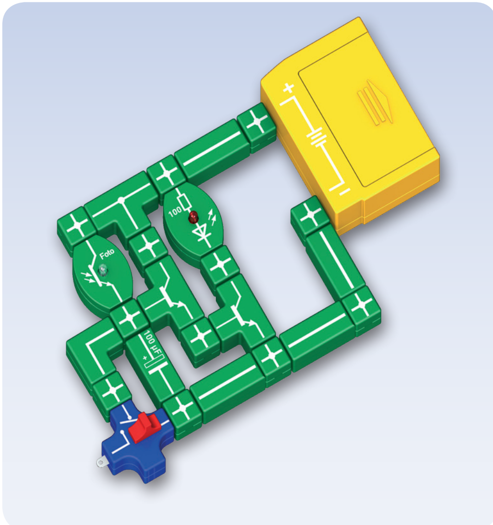
You will need:

- Battery box
- 12 X-connectors
- 4 I-connectors
- 1 L-connector
- 1 T-Connector
- 2 Transistors
- Phototransistor
- 100-µF capacitor
- Red LED
- Selector switch

Here's how:

1. Assemble the circuit. As soon as the battery is connected, the LED should light up.

2. Briefly activate the selector switch (slide to the left). The LED will go out and only come on again after a certain period of time has passed. The darker the room, the longer it will take.



How it works:

This circuit works just like the one in Experiment 52, except the phototransistor is inserted in place of the 120-kΩ resistor. The darker it is, the greater its resistance value, and the longer it takes for the LED to light up.

55 Light-controlled stairway light

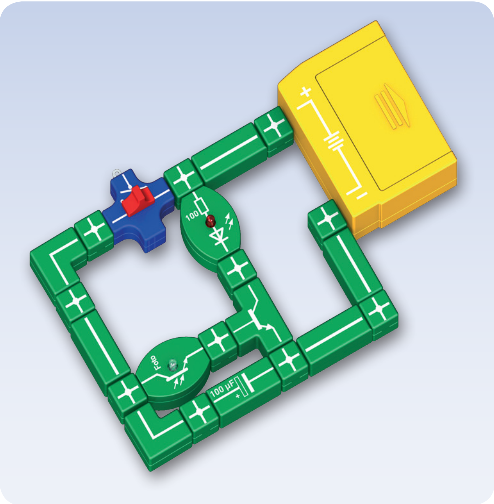
Of course, the circuit from Experiment 50 can also be operated with the phototransistor. In this case, the darker it is, the longer the LED will shine.

You will need:

- Battery box
- 11 X-connectors
- 4 I-connectors
- 2 L-connector
- 1 Transistor
- Phototransistor
- 100-μF capacitor
- Red LED
- Selector switch

Here's how:

1. Once you have assembled the circuit, activate the selector switch. The LED will come on.
2. Turn off the selector switch again.
3. The amount of time it takes for the LED to go out is determined by the lighting: The darker it is, the longer the LED will shine.
4. If you like, you can hook up the sound generator again as you did in Experiment 53. Then the amount of time it takes for the sound to change will vary according to brightness.



How it works:

The circuit works just as described in Experiment 50, except in this case the discharge of the capacitor depends on the resistor value of the phototransistor, which in turn depends on the brightness.

56 First green, then red

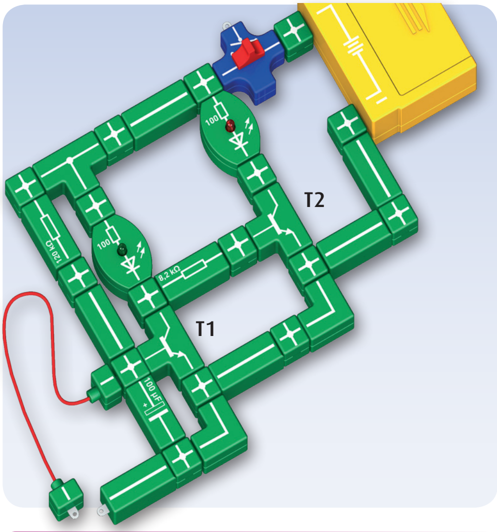
How do two alternating LEDs work in the circuit?

You will need:

- Battery box
- 16 X-connectors
- 6 I-connectors
- 2 L-connector
- 1 T-Connector
- 2 Transistors
- 100-μF capacitor
- Resistor 120 kΩ
- Resistor 8,2 kΩ
- Red LED
- Green LED
- Selector switch
- Red wire

Here's how:

1. Assemble the circuit and switch it on. The red LED will light up and then go out again after a few seconds; in its place, the green LED will come on.
2. Now, briefly hold the free I-connector and red wire plugs against each other. The red LED will light up, while the green one goes out.
3. After a few seconds, red changes to green.



How it works:

The green LED is an indicator of the conductivity of the C-E section of the first transistor, because the capacitor is charged and the base is positive. The T2 base is then connected to the negative terminal via the 8.2-kΩ resistor and T1 — the transistor cuts off, and the red LED goes out. If you discharge the capacitor with the wire, T1 blocks C-E, and the green LED goes out. The current flowing through it is enough to turn the T2 base positive, so it becomes conductive — and the red LED shines.

Flip-flop: a circuit with a memory

"Flip-flops" are circuits with two operating states. They are "tipped" from one state to the other by a trigger, and they then remain in that state until they are reset. Among other things, they have an important role to play in computers, and they are the topic of this section.

57 Alarm system with memory

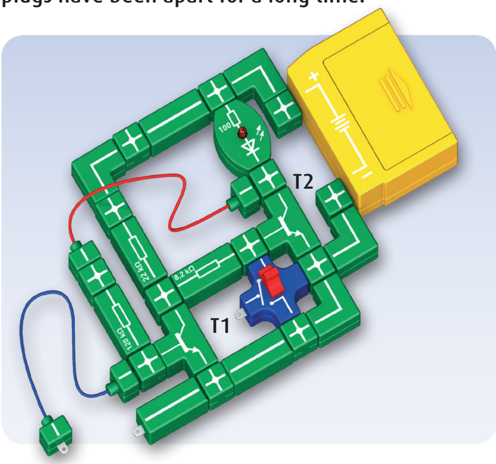
In your alarm systems, the alarm — light or sound — turned off as soon as the activator had passed. This circuit takes note that the alarm was activated and shows you what happened after the fact.

You will need:

- **Battery box**
- **13 X-connectors**
- **3 I-connectors**
- **4 L-connector**
- **2 Transistors**
- **Resistor 120 kΩ**
- **Resistor 22 kΩ**
- **Resistor 8,2 kΩ**
- **Red LED**
- **Selector switch**
- **Red wire**
- **Blue wire**

Here's how:

1. Assemble the circuit, with the selector switch in the "off" setting. Don't let the free plugs touch each other.
2. Briefly switch on the selector switch and then switch it off again. The red LED should be off — but the alarm system has been armed.
3. To set off the alarm, briefly hold the blue wire's plug and the I-connector plug against each other. The LED will light up and stay on, even after the plugs have been apart for a long time.



How it works:

The selector switch briefly connects the base to the emitter, so the second transistor cuts off. For a while, that remains the case because T1 is conductive thanks to the connection through the blue wire and therefore keeps the T2 base connected to negative. If the two plugs touch, though, T1 is blocked. Then, the influence of the positive terminal wins out over the 22-kΩ resistor and the 8.2-kΩ resistor at the T2 base, and its C-E section starts to conduct. The LED lights up, and the T1 base is connected to negative via the red wire, so now it stays cut off, regardless of the plugs.

58 Flip-flop with red and green

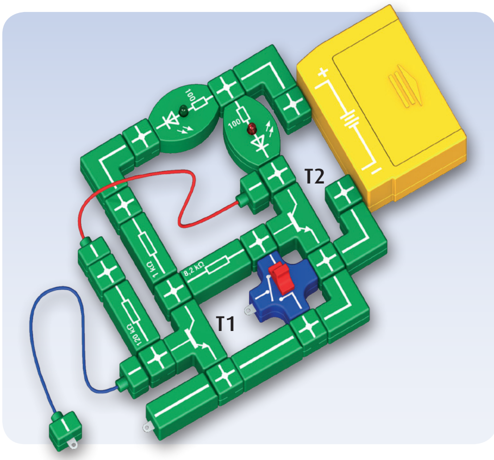
Sometimes it's good to know that the system is working right, even if it hasn't yet been triggered. The green LED can help with that.

You will need:

- **Battery box**
- **13 X-connectors**
- **2 I-connectors**
- **4 L-connector**
- **2 Transistors**
- **Resistor 120 kΩ**
- **Resistor 1 kΩ**
- **Resistor 8,2 kΩ**
- **Red LED**
- **Green LED**
- **Selector switch**
- **Red wire**
- **Blue wire**

Here's how:

Change circuit 57: Switch out one of the I-connectors for a green LED. It will need a little more current, so also exchange the 22-kΩ resistor for a 1-kΩ resistor.



How it works:

After the system has been armed (switch pushed down), the green LED lights up, while the red one is dark. If the alarm is triggered, the green LED goes out, because now the first transistor cuts off.

59 Optical alarm system with memory

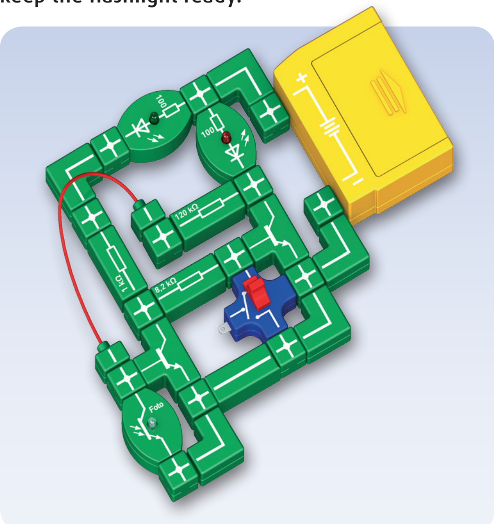
The alarm systems in the previous experiments could be triggered by a door contact, for example. How about an optical trigger? You could use a beam of light to alert you to an intruder. Or you could insert the trigger inside a drawer when you have to leave, and then after you return you can look to see whether a curious individual looked inside.

You will need:

- Battery box
- 14 X-connectors
- 1 I-connector
- 5 L-connector
- 2 Transistors
- Phototransistor
- Resistor 120 kΩ
- Resistor 1 kΩ
- Resistor 8,2 kΩ
- Red LED
- Green LED
- Selector switch
- Red wire
- *Flashlight*

Here's how:

1. The circuit matches the one from Experiment 58, except a phototransistor is installed instead of a wire.
2. Test the sensitivity of the circuit. Just a little light is enough to trigger it. So test it in a dark room and keep the flashlight ready.



How it works:

When a beam of light briefly reduces the resistance value of the phototransistor, it triggers the circuit just like touching the plugs did in the previous systems.

60 Alarm with invisible light

Real alarm systems work with invisible infrared light, to avoid alerting the intruder. Your alarm system can respond to infrared light too.

You will need:

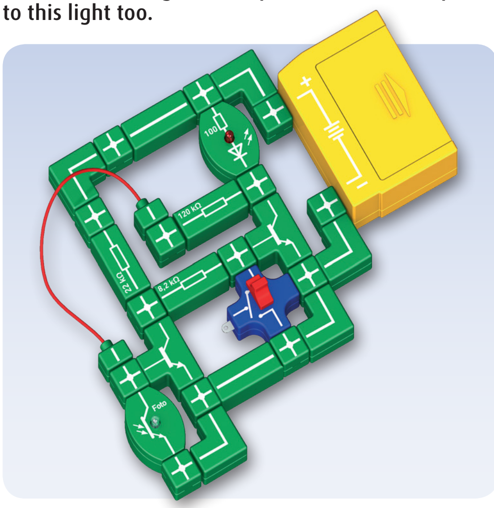
- Battery box
- 14 X-connectors
- 2 I-connectors
- 5 L-connector
- 2 Transistors
- Phototransistor
- Resistor 120 kΩ
- Resistor 22 kΩ
- Resistor 8,2 kΩ
- Red LED
- Selector switch
- Red wire
- *Flashlight*
- *Remote control for a TV, DVD player, or the like*

Here's how:

1. Modify circuit 59 slightly, as shown.
2. Darken the room and arm the system with the selector switch (set the switch to the lower position). The red LED is dark.
3. Briefly shine the flashlight at the phototransistor, to make sure that the system is working and responding to light.
4. Arm the system again and point the remote at the phototransistor — just as if you were pointing it at the TV.
5. Press any button. The red LED will light up.
6. See how far away you can stand. It will probably be a few meters.

How it works:

In the remote, there is a light-emitting diode that emits infrared light. Your phototransistor responds to this light too.



In your sound generator, you have a sound source and a blink producer, both of which you have already tried. But it's also fun to build flashers or buzzers with special circuits — especially since it gives you the opportunity to learn how they work. Also: In this chapter, there are dozens of different variations for you to explore on your own.

61 Green flasher

You'll finally be giving the green LED a chance to blink, with the help of two transistors.

You will need:

- Battery box
- 17 X-connectors
- 6 I-connectors
- 2 L-connector
- 2 Transistors
- all the resistors
- 100-µF capacitor
- 0.1-µF capacitor
- Red LED
- Green LED
- Selector switch
- Blue wire
- Red wire

Here's how:

1. After switching on the circuit (switch set to the left), the red LED will shine steadily, while the green one blinks several times a second.
2. Switch out the 22-kΩ resistor for the 8.2-kΩ resistor. Now the green LED will blink a lot faster — it flickers.
3. Now, if you switch out the 8.2-kΩ resistor for the 1-kΩ resistor, it will blink so fast that you'll see it as a steady light.
4. Swap the capacitors and repeat the previous experiments. Now the red LED will blink quickly.
5. Try all resistor combinations and observe what happens.
6. Also try swapping the red and green LEDs while keeping everything else the same. Since they don't have precisely equal electronic properties, that will cause a change as well.

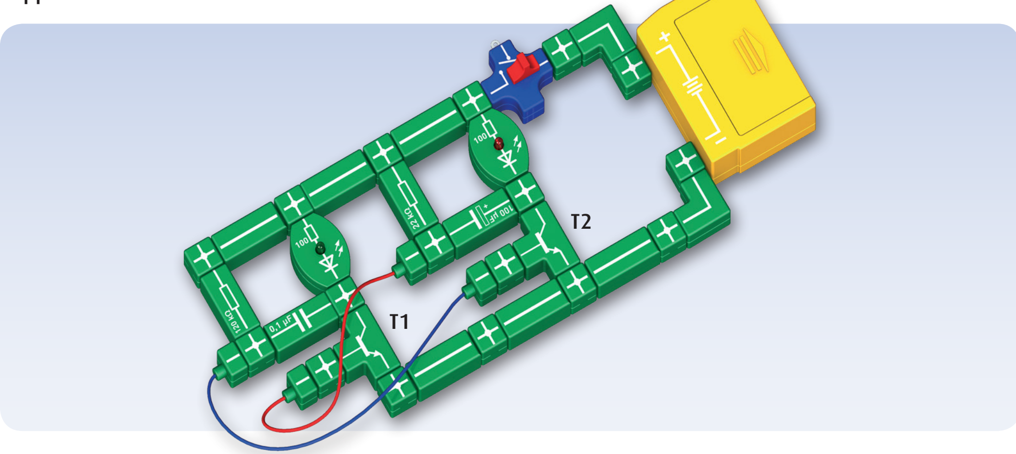
How it works:

The circuit basically consists of two time-delay circuits connected together, like the one from Experiment 52. It switches constantly back and forth between two circuit states. The speed at which that happens is determined by the two capacitor and resistor combinations.

Let's assume that the first transistor is already conductive. Then, the green LED will light up, and the 0.1-µF capacitor charges up across the 120-kΩ resistor. Up to that point, the second transistor base is set to minus via the blue wire, so it cuts off, and the red LED is out.

If the 0.1-µF capacitor is full, the voltage at the base of the second transistor turns positive, and it opens. The red LED turns on, and the 100-µF capacitor charges up across the 22-kΩ resistor. When that happens, the previously normal positive voltage at its left terminal collapses, because the capacitor is now using up a lot of electricity, which can't be resupplied so quickly across the 22-kΩ resistor. Since this point is connected to the first transistor's base via the red wire, we suddenly get low voltage here, and it cuts off.

Only when the 100-µF capacitor is full does the first transistor open again, and the game starts all over again from the beginning.



62 Crackling and purring

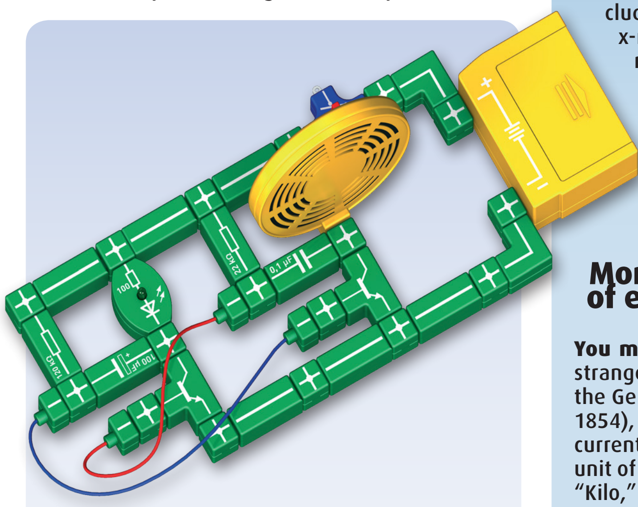
Of course, you can also take the current fluctuations that make LEDs blink and turn them into sound.

You will need:

- Battery box
- 17 X-connectors
- 6 I-connectors
- 2 L-connector
- 2 Transistors
- all the resistors
- 100-µF Capacitor
- 0.1-µF Capacitor
- Speaker
- Green LED
- Selector switch
- Blue wire
- Red wire

Here's how:

1. Assemble the circuit with the speaker.
2. Test various combinations of resistors and capacitors. Depending on the combination, you can hear the sounds as anything from individual pulses through rhythmic rasping to a high-pitched hum.
3. Also see whether the sounds change when you connect the speaker and green LED in parallel.



How it works:

With some of the combinations, the voltage fluctuations are so fast that the speaker converts them into audible tones. The smaller the capacitor-resistor combination, the higher the tone.

Science Database

Frequency

This is a very important concept when we're dealing with oscillations or pulses. It actually denotes something quite simple, namely the "number of oscillations, or pulses, per second." It is measured in "hertz" (after the physicist Heinrich Hertz, who discovered radio waves). One hertz is one oscillation or one pulse per second. If, for example, you hear a crackling sound at 10 pulses per second, its frequency is 10 hertz. The standard pitch of A is 440 oscillations per second, and young people can hear sounds all the way up to about 16,000 hertz.

An indication of frequency doesn't say anything about what's doing the oscillating — it could be waves of water, waves of sound (which are oscillations in air), electrical currents, or electromagnetic waves — which include infrared, visible and ultraviolet light, x-rays, and gamma rays, in addition to radio waves.

Monuments to the pioneers of electricity

You may already have wondered about the strange word "ohm." The word goes back to the German physicist Georg Simon Ohm (1789-1854), who studied the relationship between current strength, voltage, and resistance. The unit of resistance was named ohm in his honor. "Kilo," then, is just the prefix for "a thousand times," just as a kilometer is a thousand meters.

"Volt," too, arose in a similar way. In this case, it honors the person who discovered the battery, the Italian physicist Alessandro Volta (1745-1827).

The "ampere," finally, which is the unit of current strength, comes from the French physicist André-Marie Ampère (1775-1836).

63 Adjustable sound pitch

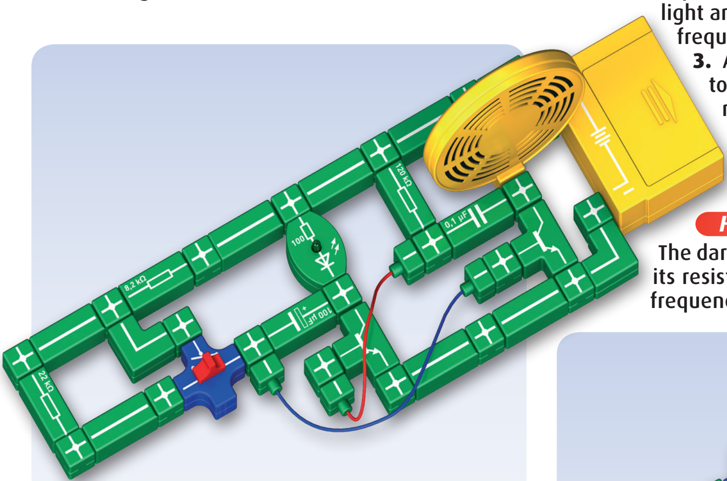
It can be a little bit tedious to reinsert resistors. You can use the selector switch to choose between two tone pitches.

You will need:

- Battery box
- 20 X-connectors
- 7 I-connectors
- 3 L-connector
- 2 Transistors
- 120 kΩ Resistor
- 22 kΩ Resistor
- 8.2 kΩ Resistor
- 100-µF capacitor
- 0.1-µF capacitor
- Speaker
- Green LED
- Selector switch
- Blue wire
- Red wire

Here's how:

1. After assembly, you will hear a tone in the speaker.
2. Push the selector switch to the other setting: The sound changes.



How it works:

When you slide the selector switch, it connects the 22-kΩ resistor in series with the 8.2-kΩ resistor, which changes the left capacitor-resistor combination and, thus, the sound as well.

64 Light-controlled flasher

In addition to the fixed-value resistors, you also have the phototransistor. With its help, you can use changes in external lighting conditions to adjust the flash tempo.

You will need:

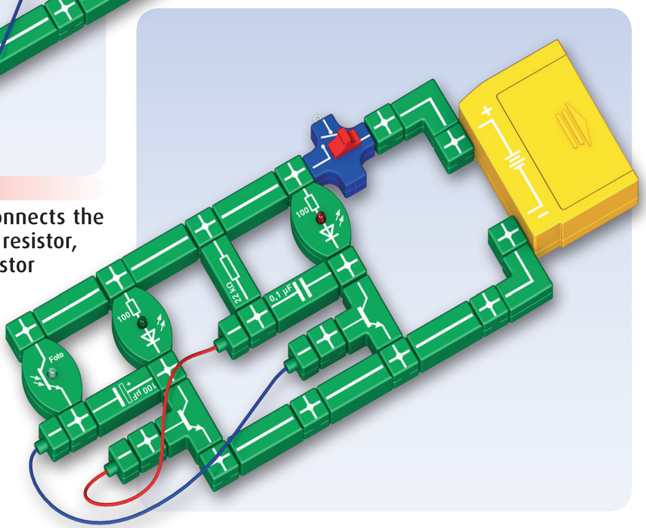
- Battery box
- 17 X-connectors
- 6 I-connectors
- 2 L-connector
- 2 Transistors
- Phototransistor
- all the resistors
- 100-µF capacitor
- 0.1-µF capacitor
- Red LED
- Green LED
- Selector switch
- Blue wire
- Red wire

Here's how:

1. Insert the phototransistor into the blinker circuit from Experiment 61 in place of the resistor mounted on the left.
2. Shade the phototransistor or expose it to bright light and observe how the blink frequency changes.
3. Also try inserting different resistors on the right, and compare the results.
4. Swap the capacitors and check what happens.

How it works:

The darker the phototransistor, the higher its resistance value. That causes the blink frequency to drop as it gets less light.



65 Light-controlled noisemaker

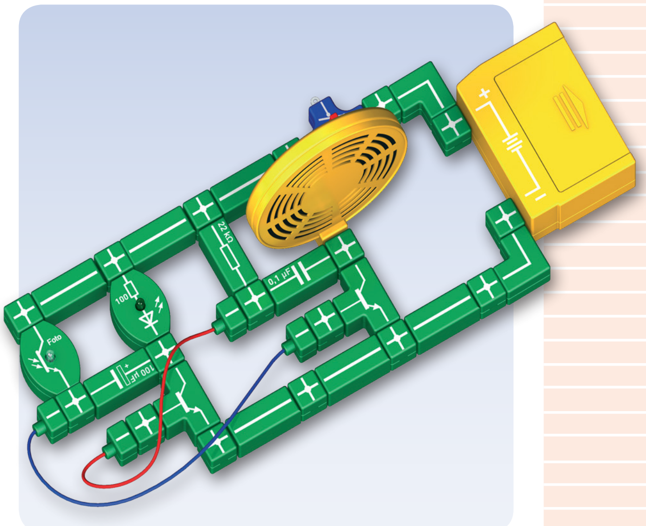
Of course, you can also use the phototransistor to change the sounds your device makes.

You will need:

- Battery box
- 17 X-connectors
- 6 I-connectors
- 2 L-connector
- 2 Transistors
- Phototransistor
- all the resistors
- 100-µF capacitor
- 0.1-µF capacitor
- Speaker
- Green LED
- Selector switch
- Blue wire
- Red wire

Here's how:

1. This circuit matches the one from Experiment 64, except the red LED is replaced with the speaker.
2. Test what happens with different levels of brightness on the phototransistor. You will be able to produce some amazing sounds this way.
3. Also try what happens when you use different resistors and swap the capacitors.



How it works:

The very different resistance values of the phototransistor at different levels of lighting lead to radical changes in sound.

Notes

This chapter's circuits play a particularly important role in computers. You can find them by the thousands in computer chips, because they provide the computer with a simple form of logical thinking — which you would hardly guess by looking at their simple circuitry.

66 A circuit for addition

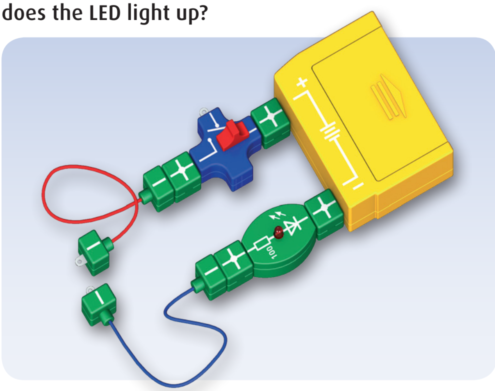
Sometimes, instead of having a single circuit trigger an action, you only want something to happen when several conditions are met at the same time. This kind of requirement is addressed electronically with an "AND gate."

You will need:

- Battery box
- 4 X-connectors
- Red LED
- Selector switch
- Blue wire
- Red wire

Here's how:

Press the two free wire plugs together. Try it first with the selector switch on, then with it off. When does the LED light up?



How it works:

This is pretty much like a series circuit for the two switches: The electrical circuit is only closed when both switches (selector switch and plug contact) are closed. If even just one of them is open, the LED won't light up. The following so-called "truth table" shows it clearly:

Selector switch	Plug contact	LED
Off	Off	Off
Off	On	Off
On	Off	Off
On	On	On

67 Double sound protection

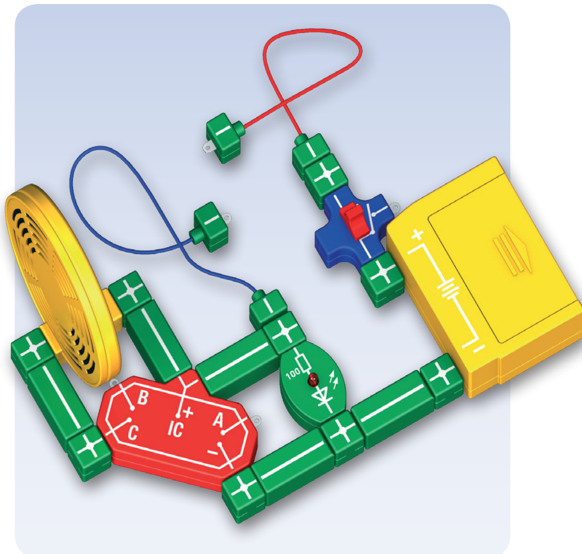
You can also combine your AND gate with the sound generator, of course. In this case as well, both switches have to be closed before you can hear anything.

You will need:

- Battery box
- 9 X-connectors
- 5 I-connectors
- Red LED
- Sound generator
- Speaker
- Selector switch
- Blue wire
- Red wire

Here's how:

Proceed as in the previous experiment. The police siren will sound and the LED will light up only when the selector switch is set to "On" and the plugs are touching each other.



How it works:

The LED and sound generator only have current running through them when the circuit is closed.

68 OR gate

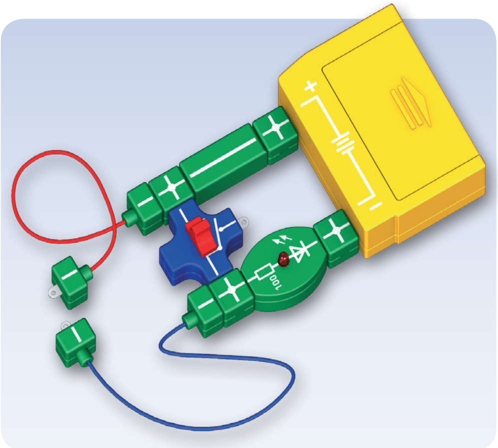
Once in a while, you want something to happen when at least one of two conditions is met. In that case, an "OR gate" can be helpful.

You will need:

- Battery box
- 4 X-connectors
- 1 I-connector
- Red LED
- Selector switch
- Blue wire
- Red wire

Here's how:

Assemble the circuit and test it to see when the LED lights up — what position the selector switch needs to be in, or whether the plugs have to be touching or not.



How it works:

Both circuits are connected in parallel. So to provide the LED with current, all you need to do is have contact between the plugs or set the selector switch to the "on" position.

Selector switch	Plug contact	LED
Off	Off	Off
Off	On	On
On	Off	On
On	On	On

Extra experiment:

Of course, you can also use the OR gate in combination with the sound generator. To do this, simply adjust the circuit according to the design of the previous experiment.

69 A circuit in denial

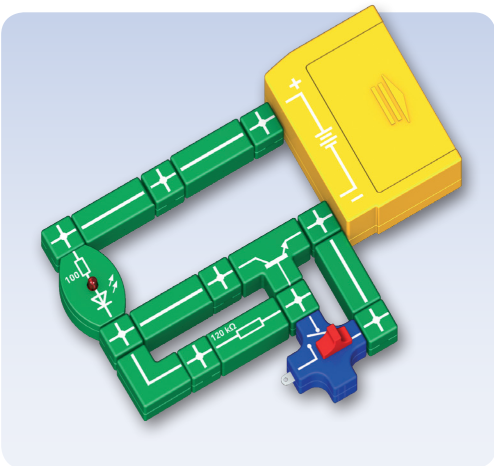
A lot of people are always doing the exact opposite of what they should. The same applies to this circuit, too. It is called a "NOT Gate."

You will need:

- Battery box
- 9 X-connectors
- 4 I-connectors
- 1 L-connector
- Red LED
- 1 Transistor
- 120 kΩ Resistor
- Selector switch

Here's how:

1. Assemble the circuit.
2. The LED will be on or off depending on the setting of the selector switch. When the switch is set to "On" (slide it to the right), it's off, while if it's set to "Off," the LED will shine.



How it works:

The LED is connected to the circuit via the transistor's C-E section. The transistor is usually conductive thanks to the 120-kΩ resistor, which raises the base to positive voltage. But when the selector switch connects it to the negative terminal, the transistor cuts off, and the LED goes out.

Selector switch		LED
Off		On
On		Off

70 AND-NOT gate

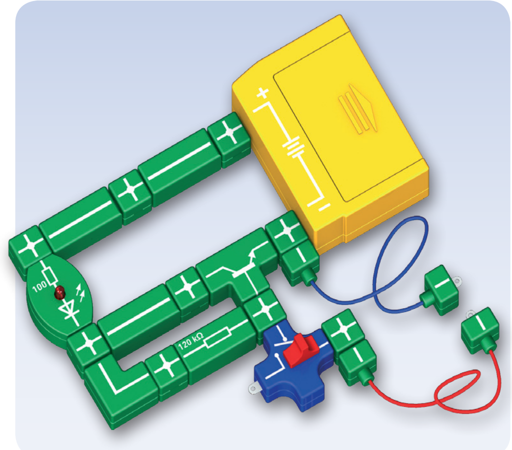
The gates can also be combined in some ways, when certain conditions need to be met. This gate, for example, shuts off when both switches are set to "On."

You will need:

- Battery box
- 9 X-connectors
- 3 I-connectors
- 1 L-connector
- 1 Transistor
- Red LED
- 120 kΩ Resistor
- Selector switch
- Blue wire
- Red wire

Here's how:

1. For this circuit, all you have to do is adjust the design from Experiment 69 a little.
2. The LED will almost always be lit up. It only goes out when the selector switch is set to "On" while the plugs are also touching each other.



How it works:

The circuit matches that of the NOT gate, except it has two switches in series. It works just like the AND gate, only with reversed results: Where the LED will be off in one, it's on in the other, and vice-versa — as you can see in the table:

Selector switch	Plug contact	LED
Off	Off	On
Off	On	On
On	Off	On
On	On	Off

71 OR-NOT gate

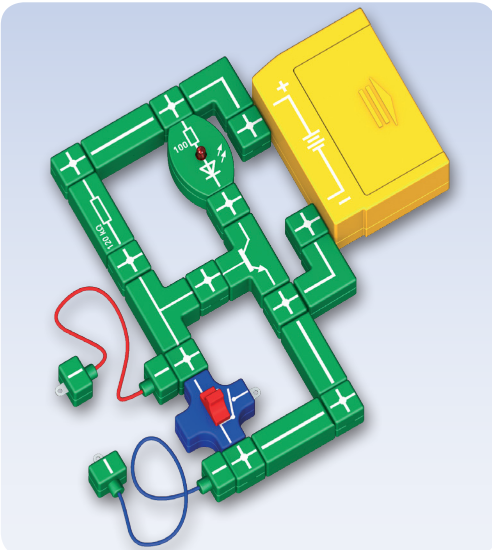
This is the opposite counterpart of the OR gate, a combination of OR and NOT gates.

You will need:

- Battery box
- 11 X-connectors
- 3 I-connectors
- 2 L-connector
- 1 T-Connector
- 1 Transistor
- Red LED
- 120 kΩ Resistor
- Selector switch
- Blue wire
- Red wire

Here's how:

This circuit will already seem familiar to you. The LED shines unless the selector switch is set to "On" or the plugs are touching.



How it works:

The circuit is that of the NOT gate again, enhanced through the parallel connection of the two selector switches.

Selector switch	Plug contact	LED
Off	Off	On
Off	On	Off
On	Off	Off
On	On	Off

72 Smart alarm system

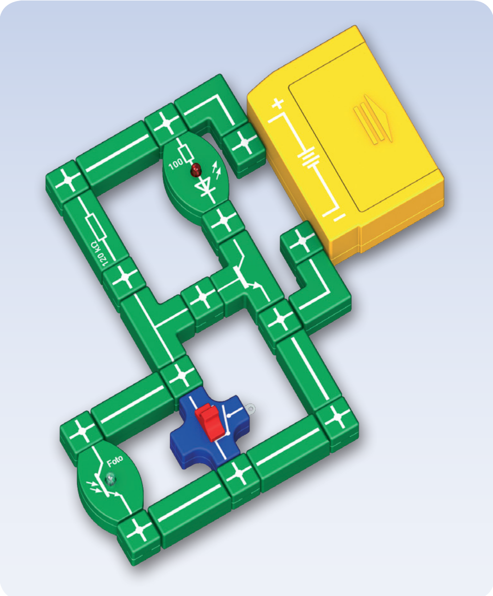
Imagine an alarm system with a brightness sensor and a window contact element. It is designed to go off only when, first, it is dark and, second, the window is opened — which breaks the window contact. In that case, you'll need to use an OR-NOT gate.

You will need:

- Battery box
- 13 X-connectors
- 4 I-connectors
- 2 L-connector
- 1 T-Connector
- 1 Transistor
- Red LED
- Phototransistor
- 120 kΩ Resistor
- Selector switch

Here's how:

1. Assemble the circuit. The LED won't light up when the phototransistor is getting sufficient light and the selector switch is set to "On" (pushed upwards).
2. Shade the phototransistor: The LED remains dark.
3. Set the switch to "Off" under bright lighting conditions: The LED still stays dark.
4. The LED will only light up and set off the alarm when it's night (shade the phototransistor) and someone opens the window (the selector switch is "Off".)



How it works:

The table shows the four possible states and the response of the LED:

Selector switch	Phototransistor	LED
On (Window shut)	Bright	Off
On (Window shut)	Dark	Off
Off (Window open)	Bright	Off
Off (Window open)	Dark	On

73 Double security

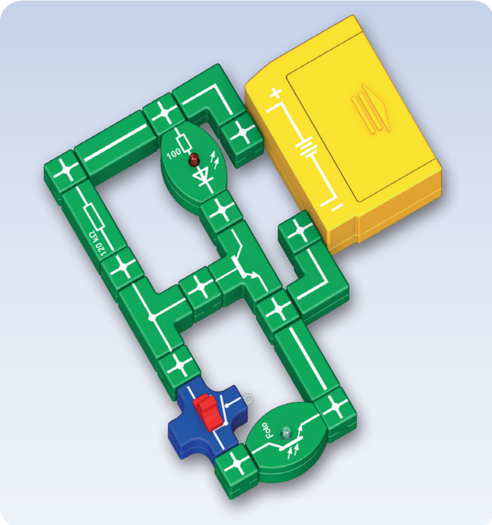
Most alarm systems have multiple safety devices combined together, and it's enough for just one of them to be activated for the alarm to go off. For example, it could be a safety device on the door that only lets the current flow when the door is closed, and a light barrier that only reacts when the beam of light is interrupted.

You will need:

- Battery box
- 11 X-connectors
- 2 I-connectors
- 2 L-connector
- 1 T-Connector
- 1 Transistor
- Red LED
- Phototransistor
- 120 kΩ Resistor
- Selector switch

Here's how:

1. Assemble the circuit as usual. The selector switch should be set to "On" (pushed up) and the phototransistor should be illuminated. Then, the LED won't light up.
2. Check how the LED behaves when you open the door (selector switch turned off).
3. What happens when the door is closed and you activate the light barrier (darken the phototransistor)?
4. And what happens when you activate the light barrier while the door is open?



How it works:

The circuit is basically an AND-NOT gate. Only when the phototransistor receives light and the selector switch is also closed will the LED not light up.

Selector switch	Phototransistor	LED
On (door shut)	Receives light	Off
On (door shut)	Receives no light	On
Off (door open)	Receives light	On
Off (door open)	Receives no light	On

Extra experiment:

Of course, the alarm system is even more effective if it also makes noise. You can connect the sound generator with the speaker directly to the positive terminal via an I-connector. Connect the collector to the negative terminal using the blue wire. Then when the alarm is triggered the police siren will go off, and any intruders will hopefully be scared away.

Notes

Notes