EXPERIMENT MANUAL

Motors & Generators

THAMES & KOSMOS

Franckh-Kosmos Verlags-GmbH & Co. KG, Pfizerstr. 5-7, 70184 Stuttgart, Germany | +49 (0) 711 2191-0 | www.kosmos.de
Thames & Kosmos, 89 Ship St., Providence, RI, 02903, USA | 1-800-587-2872 | www.thamesandkosmos.com
Thames & Kosmos UK LP, 20 Stone Street, Cranbrook, Kent, TN17 3HE, UK | 01580 713000 | www.thamesandkosmos.co.uk

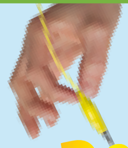
WARNING! Only for use by children aged 8 years and older. Instructions for parents are included and have to be observed.
Keep the packaging and instructions as they contain important information.

⚠ **WARNING!** Not suitable for children under 8 years. This product contains small magnets. Swallowed magnets can stick together across intestines causing serious injuries. Seek immediate medical attention if magnets are swallowed.

WARNING! Not suitable for children under 3 years. Choking hazard — small parts may be swallowed or inhaled. Store the experimental material out of the reach of small children.

Safety for experiments with batteries

- → You will need two 1.5-volt AA batteries for the experiments. Due to their limited shelf life, these are not included in the kit.
- → To insert the batteries, use a small Phillips-head screwdriver to unscrew the screw securing the battery box cover and remove the cover. Place the batteries into the compartment according to the polarity markings (+ and - symbols) in the compartment, close the cover, and screw the screw back in. (See image below.)
- → Never experiment with wall outlets or the household power supply. Never insert wires or other parts into wall outlets! Household voltage can be deadly.
- → Do not use batteries together with the household power supply.
- → Avoid short-circuiting the batteries while experimenting; they could explode!
- → The supply terminals are not to be short-circuited.
- → Never connect the battery terminals to each other.
- → Exhausted batteries are to be removed from the toy.
- → Batteries are to be inserted with the correct polarity.
- → Non-rechargeable batteries are not to be recharged.
- → Rechargeable batteries are only to be charged under adult supervision.
- → Rechargeable batteries are to be removed from the toy before being charged.
- → Different types of batteries or new and used batteries are not to be mixed.
- → Do not mix old and new batteries.
- → Do not mix alkaline, standard (carbon-zinc), or rechargeable (nickel-cadmium) batteries.
- → Dispose of used batteries in accordance with environmental guidelines.



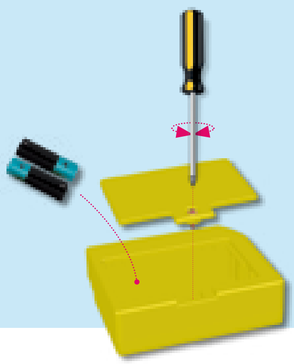
Dear Parents

and Supervising Adults

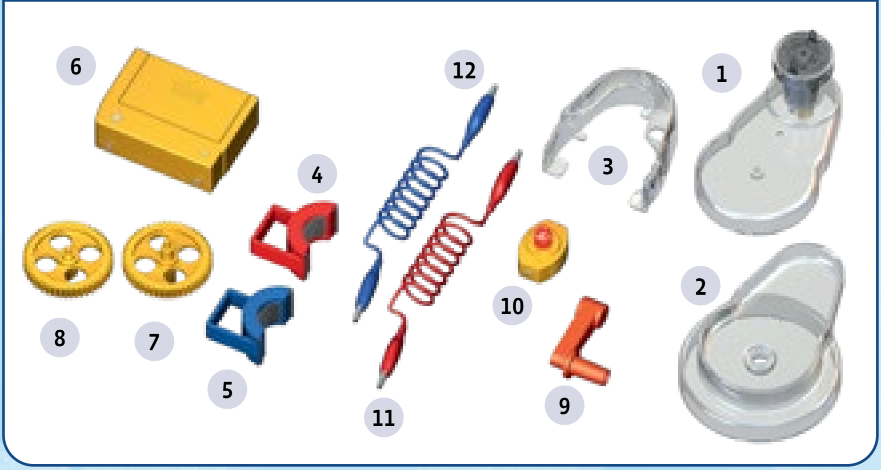
This kit contains a wealth of experiments designed to help your child understand how simple electric motors and generators work. In this way, the kit will provide a first glimpse into the world of electrical engineering. But first of all, you might have questions about the kit's safety.

This experiment kit meets US and European safety standards. These standards impose obligations on the manufacturer, but also stipulate that adults should assist their children with advice and assistance with the experiments. Tell your child to read all the relevant instructions and safety advice, and to keep these materials on hand for reference. Be sure to point out that he or she must follow all the rules and information while performing the experiments.

We wish you a lot of fun with the experiments!



What's in your experiment kit:



Checklist: Find – Inspect – Check off

✔	No.	Description	Qty.	Item No.
☐	1	Engine block (!)	1	704 492
☐	2	Engine cover	1	704 491
☐	3	Stabilizer	1	704 488
☐	4	Red magnet	1	704 489
☐	5	Blue magnet	1	704 490
☐	6	Battery box	1	704 484
☐	7	Gear wheel with crank hookup	1	704 493
☐	8	Gear wheel with drive wheel	1	704 494
☐	9	Hand crank	1	704 581
☐	10	Small lamp	1	706 415
☐	11	Red wire	1	704 486
☐	12	Blue wire	1	704 487

(!) **WARNING!** Do not, under any circumstances, take the engine block apart!

Please check all the parts against the list to make sure nothing is missing. If you are missing any parts, please contact Thames & Kosmos customer service.

Additional things you will need:

Felt-tip pen, two 1.5-volt AA batteries, small Phillips-head screwdriver, jar, teacup, mug, wooden spoon, plastic bag, nails, coins, paper, aluminum foil, scissors, string, tape, saucer, large bowl

Any materials not contained in the kit are marked in *italic script* in the "You will need" boxes.

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CHECK IT OUT

You will find supplemental information on pages 5, 6, 12, 13, 20, 21, 25, 26, 36–38, and 44–48.

Transmissions with Teeth

Gear drives can look pretty confusing at first glance. With all the big and little interlocking gears, it takes a lot of head-scratching thought to predict the direction each one of them will turn. But without gear systems, most engines wouldn't run at all. The first experiment will show you how they work.

EXPERIMENT 1

Transmission needed

YOU WILL NEED

→ engine block
→ two large gears
→ *felt-tip pen*

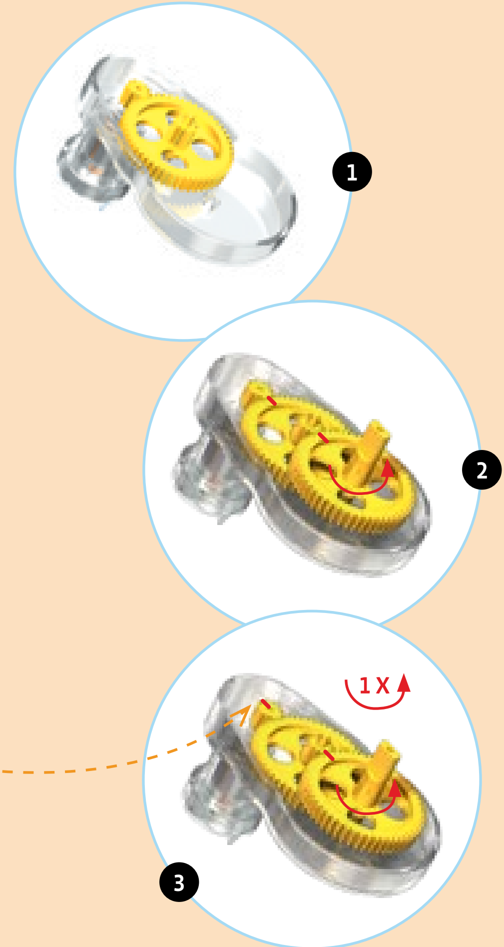
HERE'S HOW

1. Insert the gear with the drive wheel (a small toothed gear in the middle) into the center hole.

2. Now, insert the gear with the crank hookup into the lower hole.

   Use the felt-tip pen to make a mark in the same location on both large gear wheels, as shown in the illustration. Now carefully turn the lower gear wheel.

3. Count the turns on the small gear wheel and mark one of the teeth as the "starting point." Rotate the lower wheel one turn.
   When you do that, how many times does the small gear wheel turn?



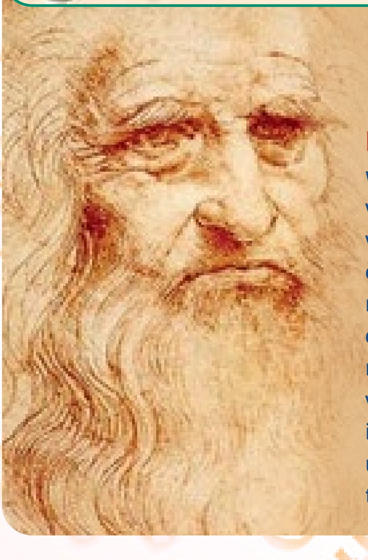
→ WHAT'S HAPPENING?

The greater the difference in the number of teeth, the higher the transmission's rotation ratio. A lot of gear systems use this principle to convert slow rotations into fast ones, or vice-versa.

CHECK IT OUT

Gear wheels and gear drives

If you look at the complicated systems that exist today, it's hard to imagine that gears and gear drives have been around for such a long time. In fact, they have been in use for thousands of years. One impressive example is the mysterious "Antikythera mechanism," built over 2,000 years ago in Greece. It was used to perform automatic calculations of the position of the sun and the moon. Even then, gears were already hard at work.



Leonardo da Vinci (1452 – 1519) was already using lots of gear wheels in his inventions in the 15th century. If you have ever visited an old windmill, you may have marveled over all the wooden gears in its drive mechanism. When more stable gears were constructed out of metal, they were able to transmit much more powerful forces. It isn't just the development of the clock that would have been inconceivable without them. Cars, kitchen utensils, construction equipment, and industrial machinery — all sorts of things use gears.

CHECK IT OUT

TRANSMISSIONS

There is no point to having just one gear all by itself. But as soon as you have two of them, you have a transmission system. This kind of transmission system, obviously enough, is called a **gear drive.**

Of course, there are also transmission systems without gears. **Pulley blocks,** used for lifting loads, are a good example. They are made of pulleys and a rope.

But most transmission systems work with gears. Sometimes, chains interlock with the gears as well. If you have a bicycle with a derailleur system for shifting gears, you probably won't find this kind of thing intimidating at all.

Gears are capable of transmitting forces and movements very precisely. For that to happen, though, they have to be constructed with a lot of care. After all, you want to be able to predict their behavior in advance.

Note

Most transmission systems are made with gears. Their basic function is to change something — rotation speed, rotation direction, or force.

Circuits and Conductors

Electricity is just one of those things. Normally, you don't see it, and you only recognize it by the effect it has. But you have probably come across an electrified fence sometime while taking a walk or hike. There's nothing special about the appearance of its thin wire, but if you touch it you get a powerful shock. The careless hiker likes it no better than a cow in the meadow. So what makes electricity flow?

EXPERIMENT 2

Paths for electricity

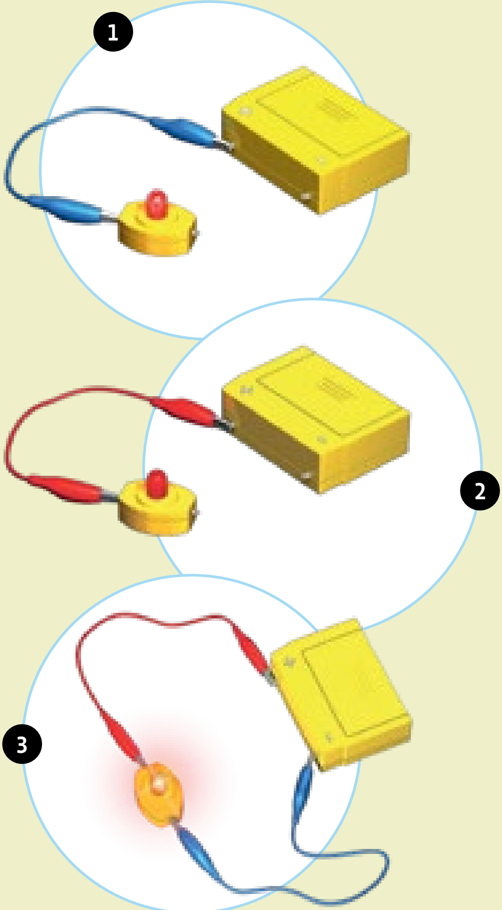
YOU WILL NEED

→ battery box
→ red wire
→ blue wire
→ lamp
→ *two 1.5-volt AA batteries*
→ *small Phillips-head screwdriver*

WARNING! Never directly connect the battery terminals to each other in any of the experiments.

Note

Before you begin, make sure you have installed fresh batteries in the battery box. You will need two AA batteries and a small Phillips-head screwdriver to open the battery box.



HERE'S HOW

1. Clamp one end of the blue wire into one of the battery box contacts. Clamp the other end into one of the lamp contacts.
   Does the bulb light up? No? Maybe the wire is damaged.

2. Repeat with experiment with the red wire. The lamp won't light up now, either. The lamp and the battery box each have two contacts.
   Do you think you might need to use both?

3. Connect the lamp with the battery box, as shown in the illustration.
   What do you see now?

→ WHAT'S HAPPENING?

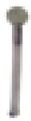
The bulb lights up. If you break any part of the connection, though, it goes out. Electricity flows out of the battery and into the bulb, then out again and back into the other battery terminal. That is why this is called an electrical circuit. (The word "circuit" means "circular route.") If the circuit isn't closed, the flow of current immediately stops, as your experiment demonstrated.

EXPERIMENT 3

Electricity is conducted — or not

YOU WILL NEED

→ battery box *with batteries*
→ red wire
→ blue wire
→ lamp
→ *various household items (such as glass, cup, wooden spoon, plastic bag, nail, coins, paper)*



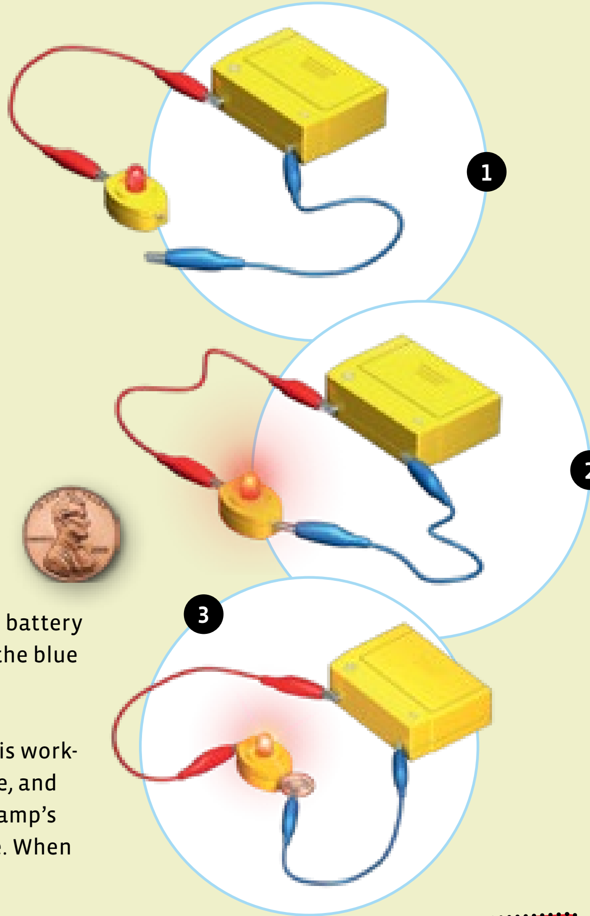
HERE'S HOW

1. Use the red wire to connect one battery contact to the lamp and clamp the blue wire to the other.

2. Test to see whether everything is working okay with the batteries, wire, and lamp by tapping briefly on the lamp's free terminal with the blue wire. When you do that, it should light up.

3. Now try holding various things between the free lamp contact and the free end of the blue wire.
   What happens when you hold a coin between them?

   Try it with a glass, a cup, a wooden spoon, a plastic bag, a nail, or a piece of paper.



→ WHAT'S HAPPENING?

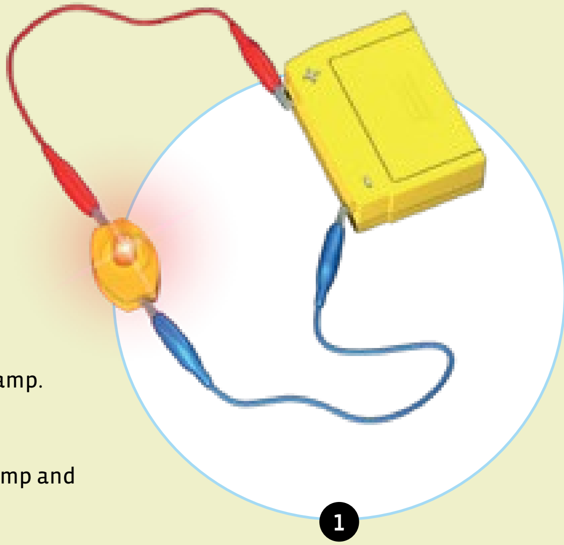
There are some materials — such as metals — that are good at conducting electrical current. Other materials, such as glass, porcelain, paper, and plastic, do not conduct electricity. Now you know why the wires of an electrical appliance always have a plastic covering: It keeps you from touching the metal underneath, which has dangerous household current flowing through it.

EXPERIMENT 4

Does direction matter?

YOU WILL NEED

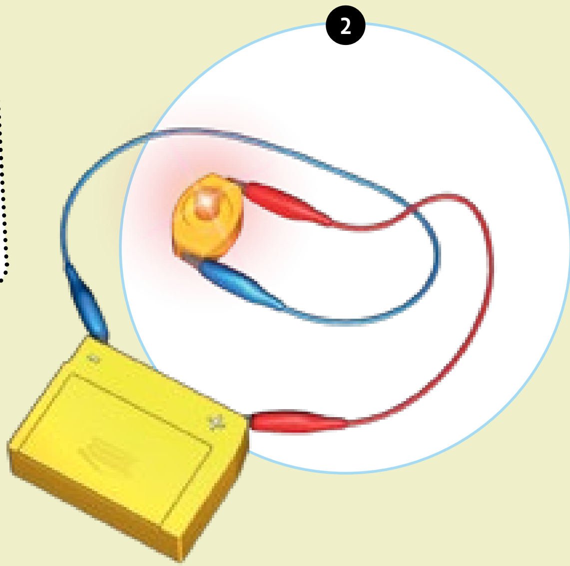
→ battery box
with batteries
→ red wire
→ blue wire
→ lamp



HERE'S HOW

1. Connect the battery box to the lamp.
   What happens?

2. Now release the wire from the lamp and switch the wire clamps.
   What happens now?



→ WHAT'S HAPPENING?

It makes no difference to the lamp which direction the current flows through it. You will see later on, though, that that isn't true for all electrical appliances.

EXPERIMENT 5

Thrifty lighting

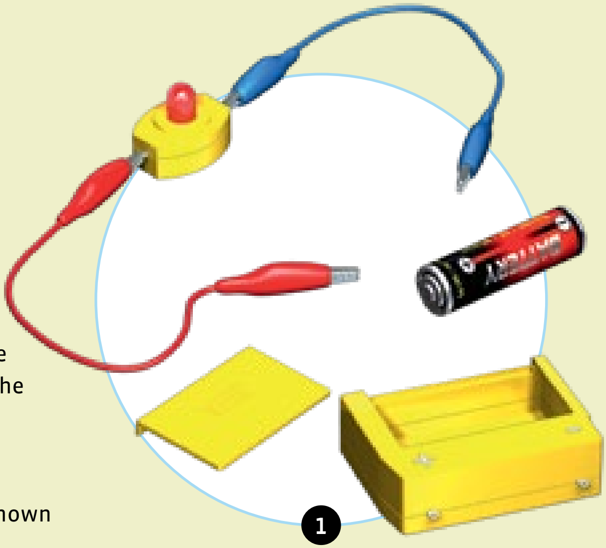
YOU WILL NEED

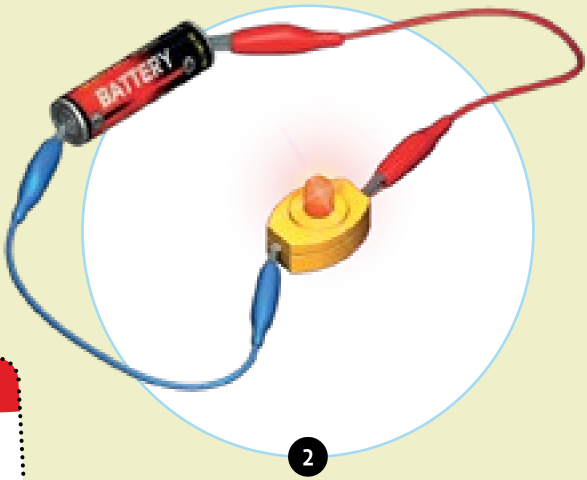
→ red wire
→ blue wire
→ lamp
→ *battery*

HERE'S HOW

1. Take one of the batteries out of the battery box. Clamp both wires to the lamp contacts.

2. Press the other ends of the wires against the battery terminals as shown in the illustration.
What happens? Do you notice any difference from Experiment 2?





→ WHAT'S HAPPENING?

The lamp shows that a single battery accomplishes less than two — the lamp lights up less brightly — just as a single horse will pull a heavy cart more slowly than two horses working together.

Electrical Current

Electrical current sounds like modern technology. But even our ancient ancestors took cover when there was thunder and lightning. Of course, they didn't know that electricity was behind it all. The Greek Thales of Miletus lived around 600 BC. You will probably get to know him sooner or later in math class. Way back then, he is said to have described the electrostatic charge of amber. The word electricity derives from the Greek name for amber — elektron. It wasn't until around 1750 that people began studying electricity and its uses more precisely, however.

Nobody can see electrical current. It consists of the movement of unbelievably tiny particles known as electrons — which are much smaller than an atom.

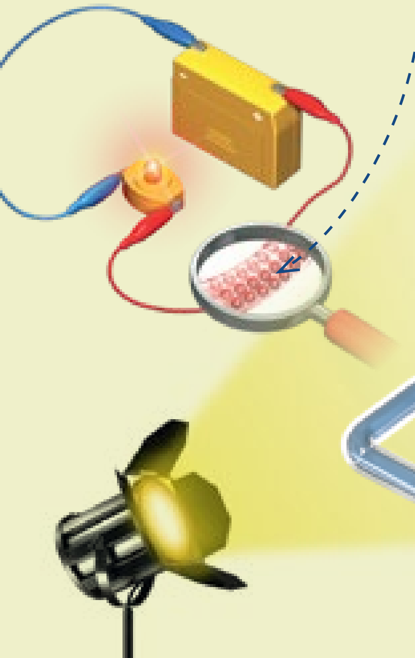
You can use a model to understand the way an **electrical circuit** works. Imagine a pipe filled with water and carrying the water around in a circle. At one spot, there is a pump installed, which sets the water in motion.

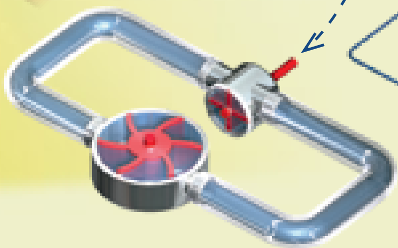
At another location, there is a little water wheel that is turned by the water. In an electrical circuit, the pump corresponds to a battery, the pipes to the wires, and the water wheel to an electric motor, for example.

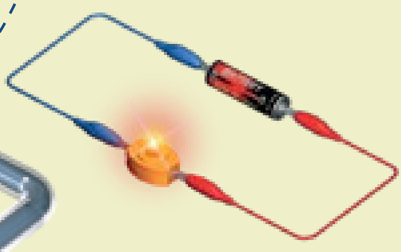
When the pump turns, it sets the water in motion. The water flows through the pipe and, in the process, transfers force from the pump to the water wheel.

If the pump turns slowly, less water moves through the water wheel per second — so the water wheel moves more slowly too.

In the same way, one battery will move less current through the wire than two, so the lamp lights up less brightly in Experiment 5.







CHECK IT OUT

Electric Voltage

The driving force for electrical current is known as electric voltage, indicated in units called **volts**. In our water example, voltage would correspond to the water pressure produced by the pump. **Each of the batteries in the battery box has a voltage of 1.5 volts.** The two batteries are arranged one behind the other in the battery box, yielding 3 volts at the terminals. A car battery can produce **12 volts**, and the current from a wall outlet gets all the way up to **120 volts** — which is why it is so dangerous.

You have to distinguish carefully between voltage and current strength. Available voltage doesn't mean that current is actually flowing — just as water won't flow from a closed water tap just because there is pressure in the water line. On the other hand, high pressure can push more water through the tap per second than low pressure can. A high electric voltage, likewise, can make a current flow with more strength than low voltage.

A battery doesn't produce current, any more than a pump produces water. The pump's energy only sets the water in motion, and the energy stored in the battery does the same thing with electrons to produce a flow of current. Only the flowing current can accomplish work, such as getting an engine going or lighting up a lamp.

Note

Why is it that the bulb lights up but the wire doesn't? Because the wire inside the light bulb is so thin! The electrons have to squeeze themselves through it, and in the process they heat it up so much that it glows white-hot. In the thicker connecting wire, on the other hand, they have much more room, so they won't heat it up very much.

Invisible Forces

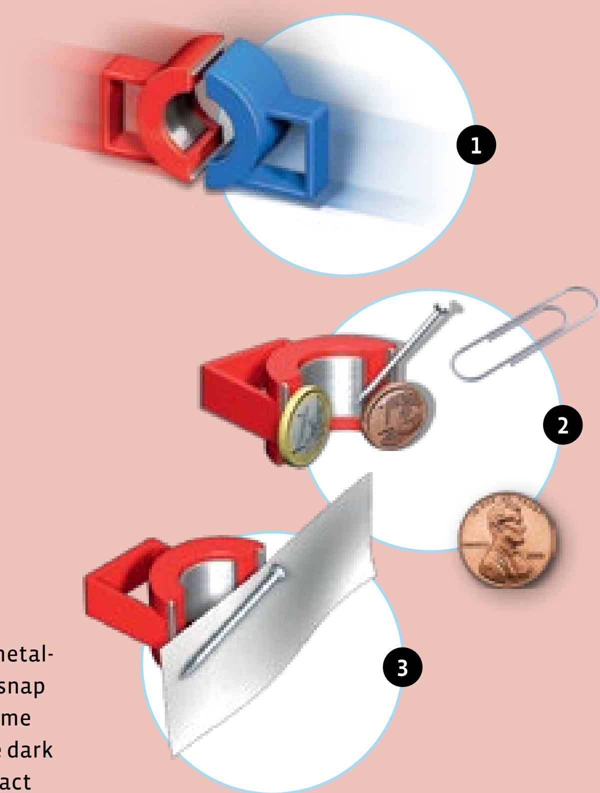
With a crisp click, two magnets attach together. A mysterious force makes them stick. Have you ever felt the way they can push each other apart as well? Have you ever tried pushing one magnet across the tabletop with the other, as if it were being guided by the hand of a ghost? Even once you have learned a lot about magnetism in the following experiments, it will always be a fascinating phenomenon.

EXPERIMENT 6

Secret forces of attraction

YOU WILL NEED

- → red magnet
- → blue magnet
- → *coins*
- → *various household items (such as nails, aluminum bottle caps, paper clips, teacup, plastic cup, wooden spoon, paper, plastic bag, aluminum foil)*



HERE'S HOW

1. Hold the two magnets with their metallic edges against each other. They snap together, and you need to exert some force to pull them apart again. The dark inner surfaces of the magnets attract each other too — but only once you move them close together.
   Do they attract other things as well?

2. Try it with coins, nails, paper clips, and the aluminum bottle caps that you often find on glass bottles. Also try a teacup, a plastic cup, and other objects.

3. Use an iron nail to see if the magnetic force can pass through paper or plastic. Also try wrapping it in aluminum foil.

→ WHAT'S HAPPENING?

Magnets have a special love of iron. It scorns other metals such as aluminum or tin, just as it rejects non-metallic materials.

Magnets will not attract U.S. coins, as they are not made of iron. Nickel is a magnetic metal, but a U.S. nickel does not contain enough of it (it is mostly copper) for a magnet to attract it. Magnets will however attract many coins from other countries.

And now you also know that most materials do not present any obstacle to magnetic force.

EXPERIMENT 7

Magnetizing a nail

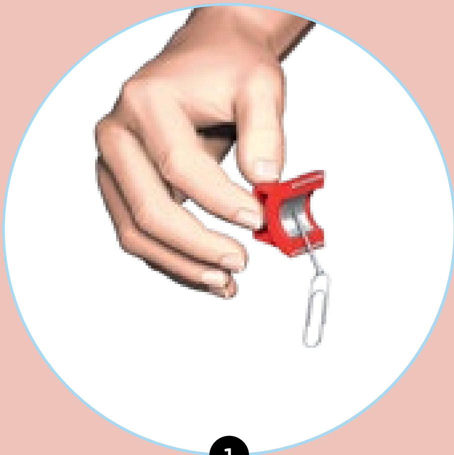
YOU WILL NEED

→ red magnet
→ *nail (a few centimeters long)*
→ *coins and paper clip*

HERE'S HOW

1. Pick up the nail with the magnet, and then see if the other end of the nail can pick up other things, like other little nails or paper clips.

2. Release the nail from the magnet. Does the other object remain attracted to the nail?



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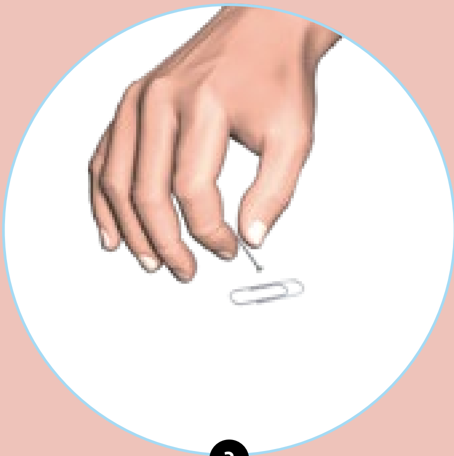


2

→ WHAT'S HAPPENING?

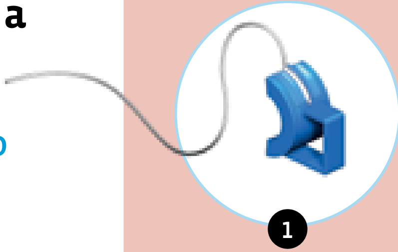
It's astounding: The magnet turns other iron-containing objects magnetic as well — but only as long as they are in direct contact with each other.

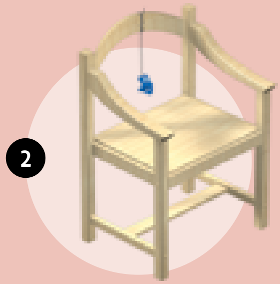
EXPERIMENT 8

Magnet on a string

YOU WILL NEED

→ red magnet
→ blue magnet
→ *scissors*
→ *thread*
→ *tape*





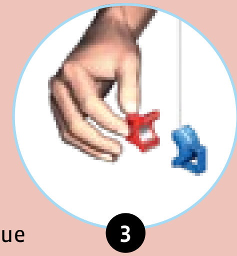
HERE'S HOW

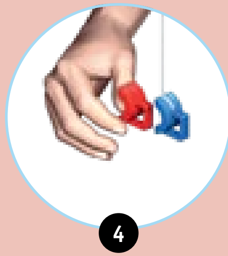
1. Cut a piece of string about 30 cm in length and tape it securely to the blue magnet, as shown in the illustration.

2. Now suspend it from a chair or something similar in such a way that it can dangle freely. Wait for it to stop swinging.

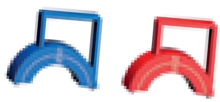
3. Now move the red magnet — inner surface forward — toward the blue one. At first, nothing will happen, but when you get closer the blue magnet will suddenly turn its inner surface toward the red one. If you move it even closer, they will snap together and remain stuck.

4. Repeat the experiment, except this time move the red magnet toward the blue one with its handle toward the front. What do you see now?





→ WHAT'S HAPPENING?



The blue magnet flips around and turns its handle toward the red one too. As this experiment shows, magnets have two different ends, called **poles** — north pole and south pole.

With your magnets, one pole is located on the inside, and the other is on the handle side. On your red magnet, the south pole is inside and the north pole is outside, and on the blue magnet it's the other way around.

Opposing poles — north and south — attract each other. Matching poles repel each other.

EXPERIMENT 9

How far will a magnet's force reach?

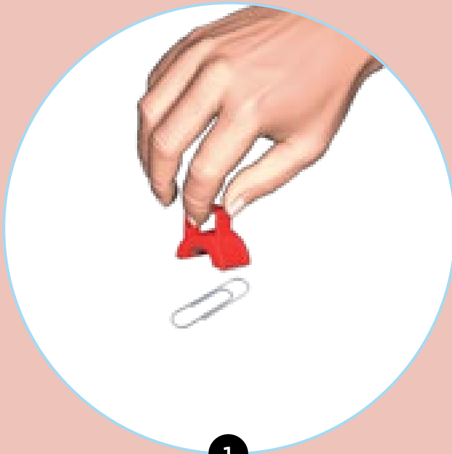
YOU WILL NEED

→ red magnet
→ blue magnet *with string from Experiment 8*
→ *scissors*
→ *tape*
→ *paper clip*

HERE'S HOW

1. See how close you can get to the paper clip before it is lifted up by the magnet.

2. The magnet on the string from the last experiment has an even more sensitive response. Let it hang and slowly move the red magnet toward it. Pay attention to when the blue magnet starts to move. What do you notice?



1

2

→ WHAT'S HAPPENING?

At a certain distance, the blue magnet will move slightly, but as you get closer it will quickly become more lively. The effect of the force doesn't simply get gradually stronger as you approach — it suddenly increases once you get close enough. And as you move away, the magnetic force of attraction suddenly drops again.

EXPERIMENT 10

Dancing magnet

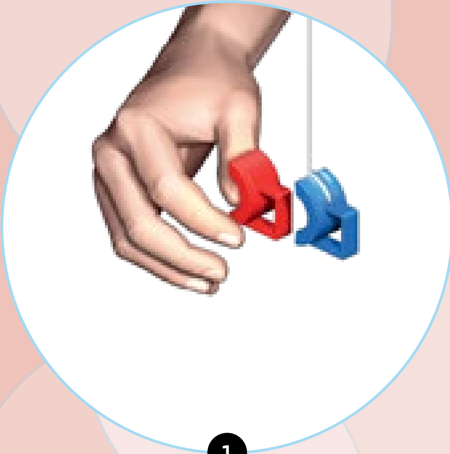
YOU WILL NEED

→ red magnet
→ blue magnet *with string from experiment 9*
→ *tape*

HERE'S HOW

1. First, let the blue magnet hang freely and move the handle side of the red magnet toward the inner side of the blue one. The blue magnet will spin around in order to turn its handle side toward the red one.

2. As soon as that happens, pull the red magnet away and then immediately move it closer again. With a little skill, you will be able to set the blue magnet into a rapid spinning motion.



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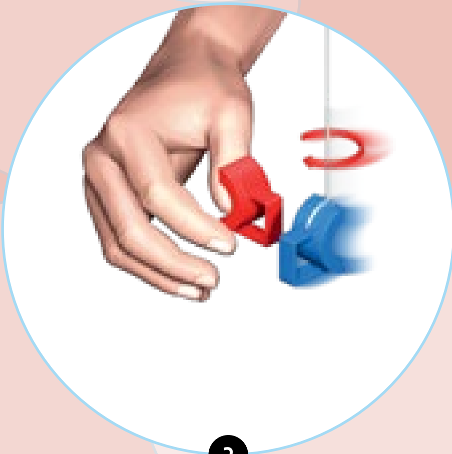


2

→ WHAT'S HAPPENING?

Through skillful alternation of the magnetic force, in this case by changing the distance of one of the magnets, you can make the other magnet spin.

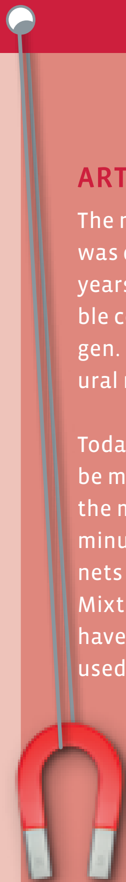
Magnets

It was thousands of years ago that people discovered the attractive power of a certain mineral made of iron. Because this mineral was particularly common around the ancient city of Magnesia in Asia Minor, it was called **magnetite**. From this word in turn came the name **magnet** for an object with magnetic properties.

Magnets and magnetism really inspired the fantasy of the ancient Greeks, and in China, too, there was interest in magnets since ancient times. But it wasn't until about 1600 that people began experimenting with these phenomena in a scientific way.

Note

A magnet alters the space around it, giving it a special character. The name for this altered space is "magnetic field."



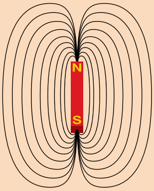
ARTIFICIAL MAGNETS

The mineral magnetite, which was discovered several thousand years ago, consists of a very stable compound of iron and oxygen. Magnetite is formed in a natural manner by volcanic activity.

Today, artificial magnets can also be made by using compounds of the metals iron, nickel, and aluminum. But there are also magnets that contain no iron at all. Mixtures of much rarer metals have been produced that can be used to make magnets many times more powerful than the magnetic materials found in nature.

PERMANENT MAGNETS ...

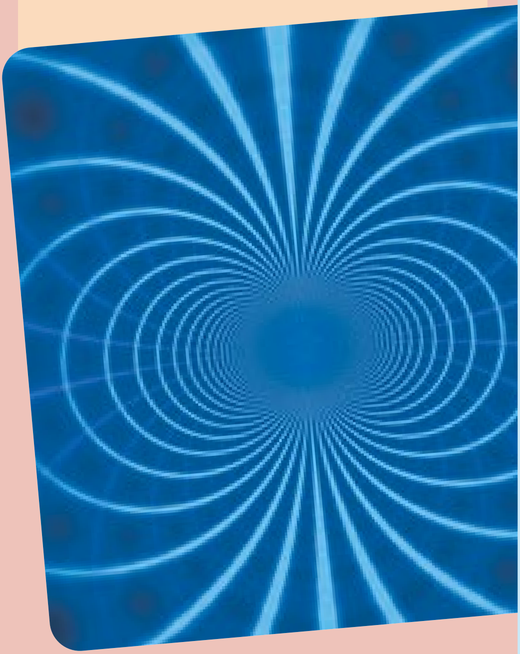
... have a magnetic force all on their own and retain this force constantly. Permanent magnets are used, for example, to make magnetic needles for compasses, in electronic gauges, in earphones and speakers, as well as in countless other modern electronic devices.



LINES OF FORCE

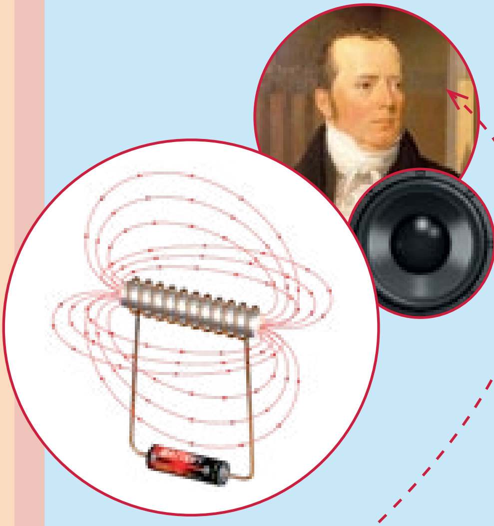
You can picture a **magnetic field** as a bundle of lines projecting out from the north pole, forming an arch toward the south pole, and continuing back to the north pole through the interior of the magnet. They are called “lines of force,” since iron particles are affected by magnetic force wherever they run.

The gap between neighboring lines of force can serve as an indication of the strength of a magnetic field. The closer the lines, the stronger the field. As magnets get farther away, their magnetic field quickly grows weaker, but it can penetrate materials such as paper, aluminum, and plastic.



CHECK IT OUT

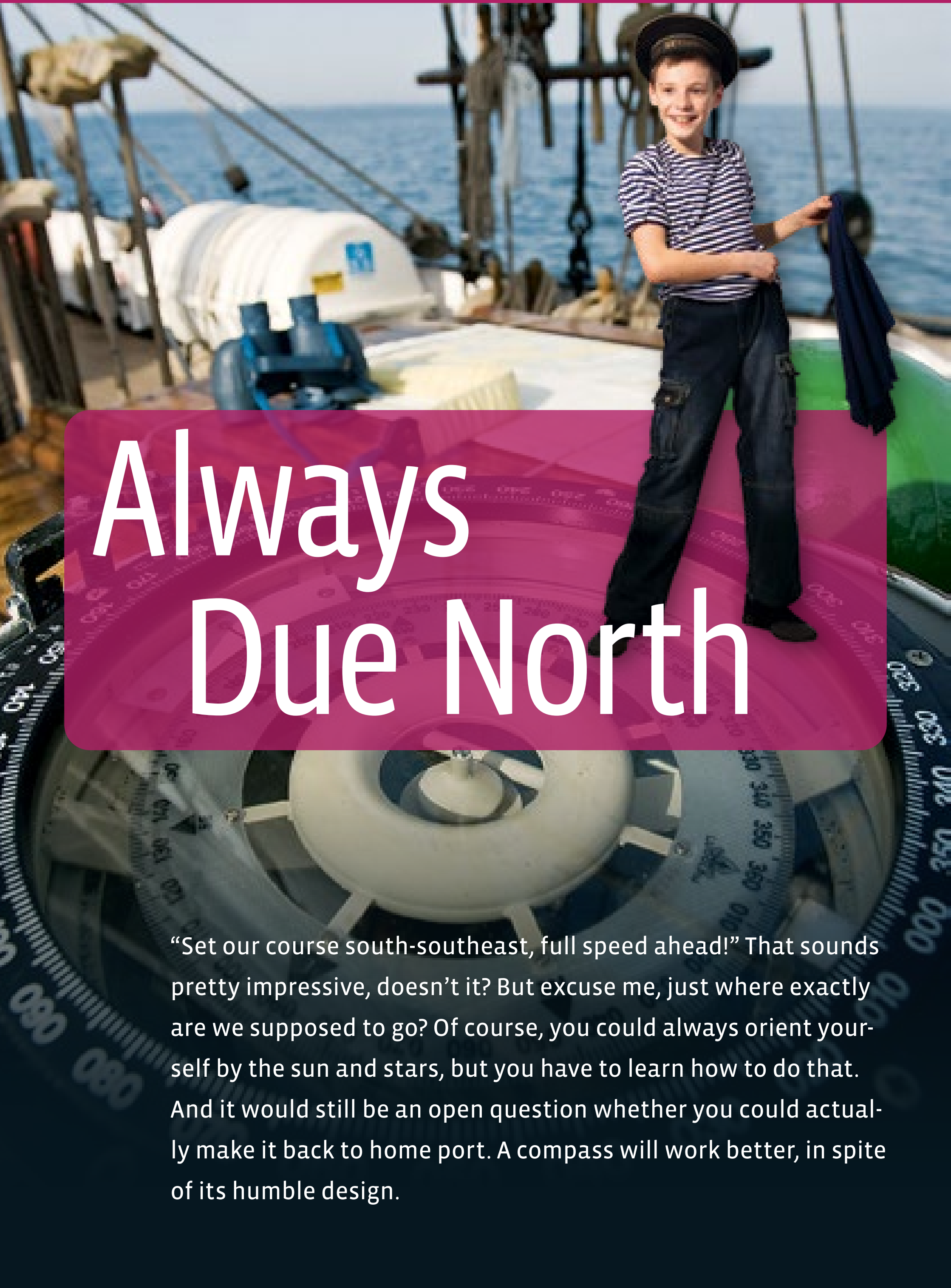
ELECTROMAGNET



Almost 200 years ago, the physicist **Hans Christian Ørsted** made an important discovery: A wire can turn into a magnet if electric current is flowing through it. And the magnetic force is particularly strong if the wire is wrapped up into a coil with a core of iron shoved inside it.

This kind of electromagnet can produce a much stronger magnetic field than a permanent magnet — although only as long as current flows through the wire.

Electromagnets are used in electric motors and generators, for example. Electronic door openers also use electromagnets to pull back the door’s locking bolts.



Always Due North

“Set our course south-southeast, full speed ahead!” That sounds pretty impressive, doesn’t it? But excuse me, just where exactly are we supposed to go? Of course, you could always orient yourself by the sun and stars, but you have to learn how to do that. And it would still be an open question whether you could actually make it back to home port. A compass will work better, in spite of its humble design.

EXPERIMENT 11

North needle

YOU WILL NEED

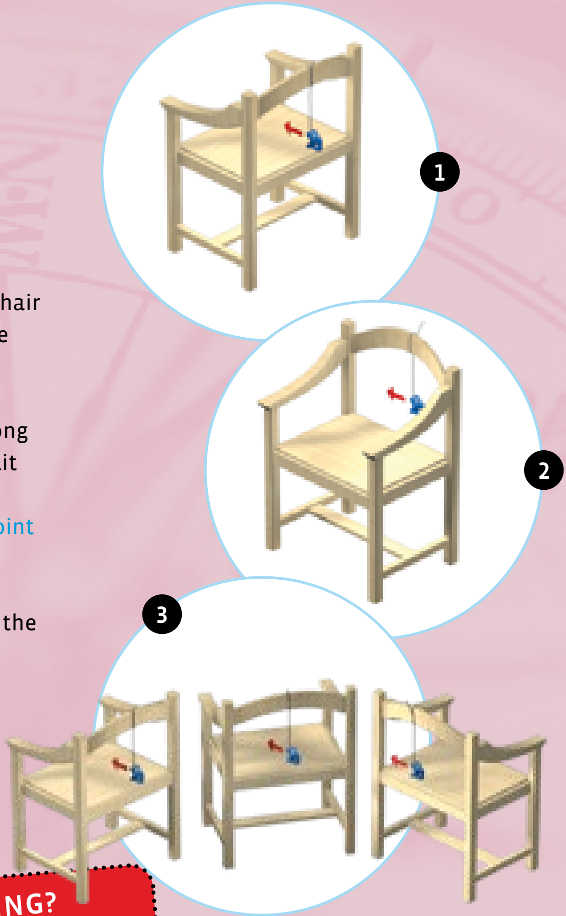
→ blue magnet *with string*
→ *tape*
→ *chair*

HERE'S HOW

1. Suspend the blue magnet from the chair and wait for it to stop swinging. Note the direction the handle is pointing.

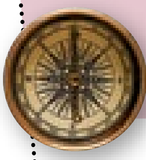
2. Rotate the chair, and the magnet along with it, about a quarter turn, and wait again.
   In what direction does the handle point now?

3. Keep rotating the chair and observe the orientation of the magnet.



→ WHAT'S HAPPENING?

A compass helps you find your way, because its needle always points in a north-south direction. But it wasn't until centuries after its invention that people learned why it does that. Earth itself acts like a magnet, with magnetic poles lying more or less at its geographic north and south poles. The compass needle is a magnet too. It orients itself according to the magnetic poles of Earth — just as your blue magnet does.



Stubborn magnet

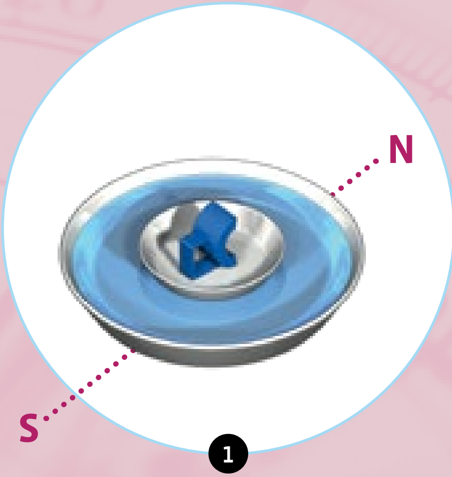
YOU WILL NEED

→ blue magnet
→ *saucer*
→ *large bowl*

HERE'S HOW

1. Fill the bowl with water. Set the magnet upright in the middle of the saucer, and let the saucer float freely in the bowl.
   What do you observe?

2. Rotate the saucer a little, first in a clockwise direction, and then counter-clockwise.
   What do you observe now?



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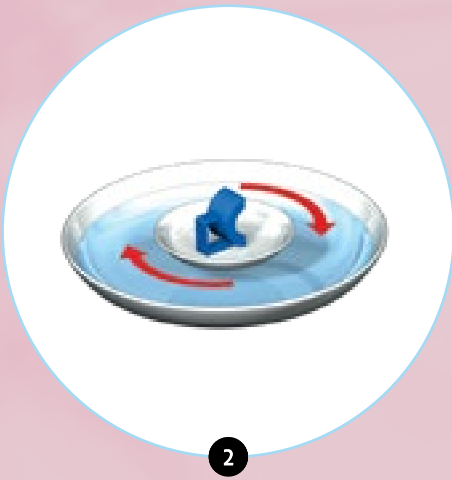

2

→ WHAT'S HAPPENING?

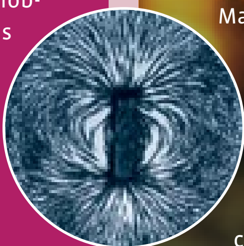
If you move the saucer a little and then let go, it will slowly rotate until the inside of the magnet it pointing north again. So a freely-floating magnet can also point the way north.

Of course, the shape of your magnet isn't exactly what you need for this purpose. After all, it was designed for use with an electric motor. A pointed magnetic needle would work better.

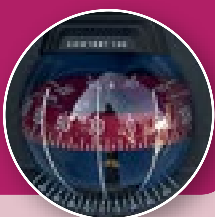
CHECK IT OUT

Navigation Technologies

In spite of the existence of satellite navigation systems, magnetic compasses are still useful. GPS (Global Positioning System) devices can certainly complement navigation by map and compass, but they can't replace it.



GEOCACHING:
GPS devices are also used in electronic treasure hunts. The geographical coordinates of the hidden items are published over the Internet, and the items are then hunted down with the help of a GPS receiver device.



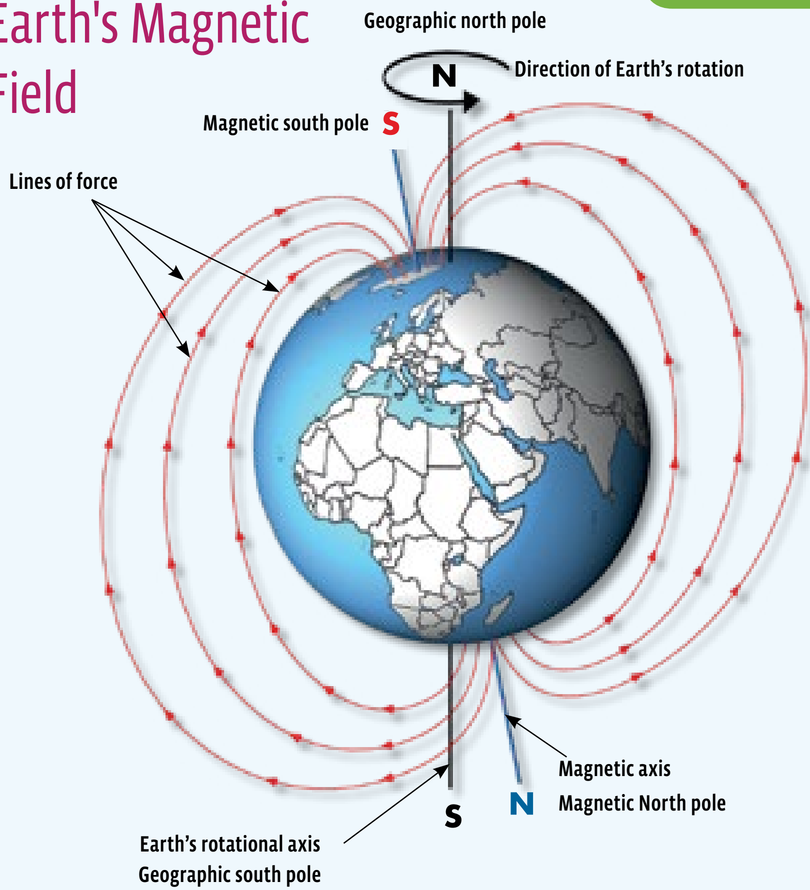
Compass

Magnetic splinters will orient themselves in a north-south direction. People in ancient Greece and China already knew that over two thousand years ago. The Chinese were the first to construct a device with a needle that always pointed to the south — an early form of compass.

The first compasses had floating directional indicators. It isn't completely clear whether Europeans developed a compass on their own, but they certainly improved on the design. The first evidence for a "dry compass," with a magnetic needle mounted on a narrow post, comes from 1269. An Italian seafarer is regarded as its inventor.

CHECK IT OUT

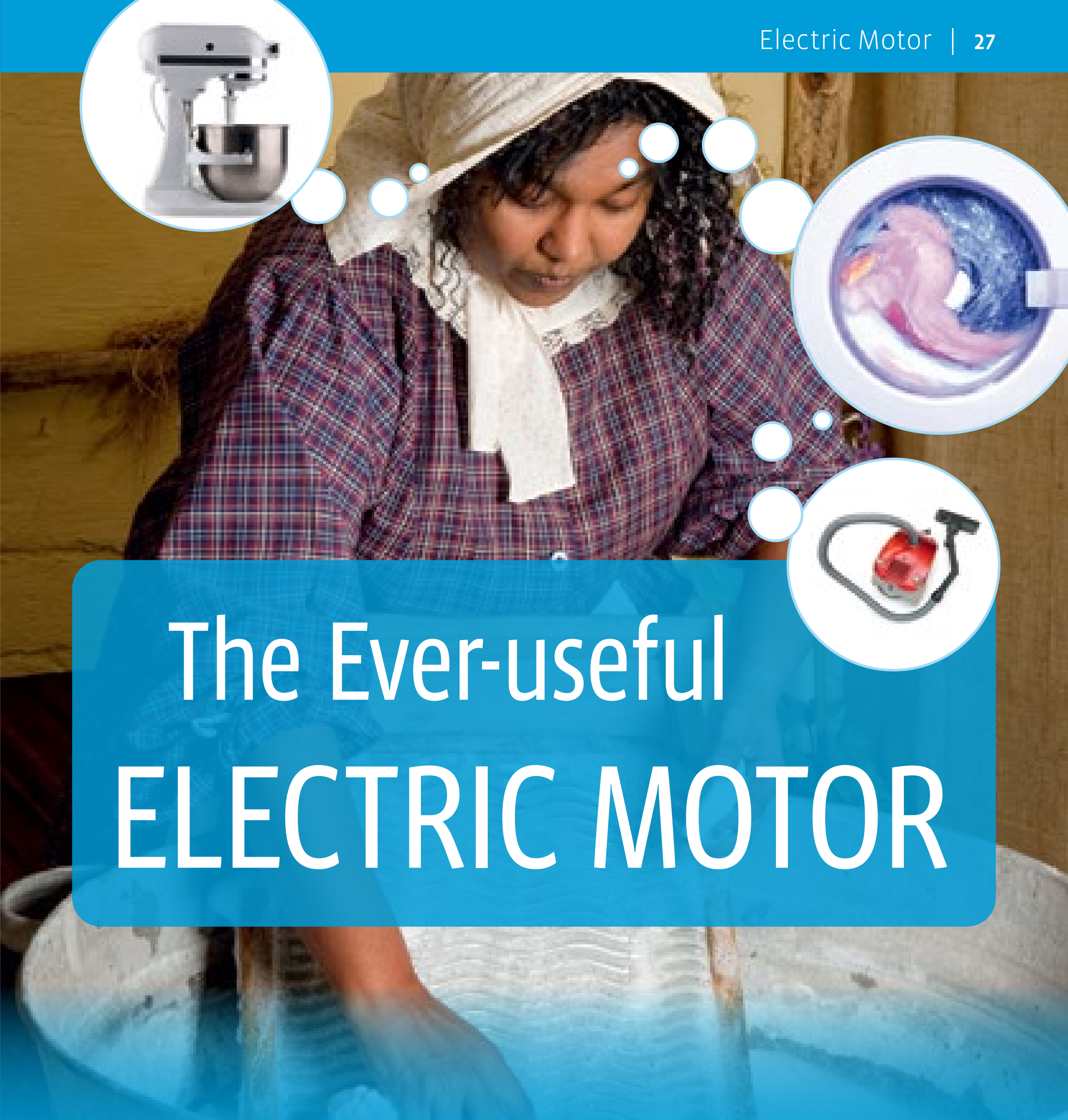
Earth's Magnetic Field



There's an electromagnet inside Earth: In a liquid, electrically conductive region of Earth's interior, powerful circulating electrical currents create Earth's magnetic field, whose lines of force surround the entire globe. It's those lines of force that act on a compass needle, and that have helped seafarers find their direction for hundreds of years.

Earth's magnetic poles are the places where the lines of force penetrate straight down into the ground. If a compass is positioned here, its needle will point downward. Next to the geographic north pole is the magnetic south pole (and vice-versa in the south). There is a historical basis for that: Hundreds of years ago, when magnetism was still quite mysterious, the tip of the compass needle pointing toward Earth's north pole was simply called the north pole of the needle.

Since then, though, people have learned that the compass needle is itself a magnet, and that opposite poles attract each other. The magnetic pole toward which the needle's north pole points is therefore a magnetic south pole.



The Ever-useful ELECTRIC MOTOR

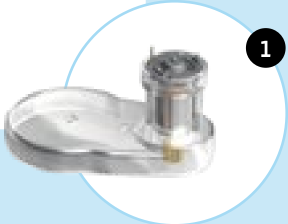
Have you ever tried to imagine how you could get by without electric motors in everyday life? No problem! A hand-cranked washing machine, a foot-powered dentist's drill, a horse-drawn streetcar — all of those things used to exist. As far as a computer hard drive and electric toothbrush go, well, we'd have to think a little more about that. All around you, there are electric motors, and you are about to learn more about them.

EXPERIMENT 13

Electric-powered motor

YOU WILL NEED

→ engine block
→ battery box
with batteries
→ red wire
→ blue wire
→ lamp



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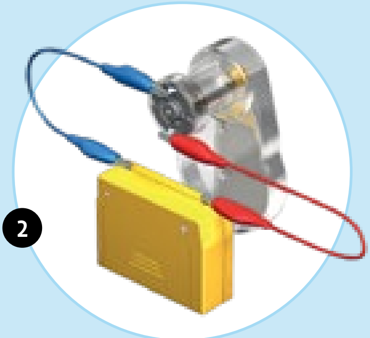

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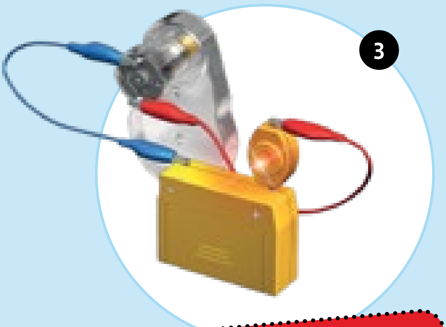


3

→ WHAT'S HAPPENING?

If the lamp lights up, current is flowing. But the motor still won't run. There's something important missing.

HERE'S HOW

1. First, take a careful look at the engine block. Under no circumstances take the motor apart though! You can see that the pin on which the gear is mounted goes all the way through to the plastic insert with the two electric terminals. This pin is called an axle or shaft.

   Inside the transparent tube, you will see three iron pieces with fine wire between them. This component of the electric motor is called the rotor, because it rotates, or turns, when the motor runs — or when you turn the gear.

   This rotor is made of three electromagnets, with the wire forming three spools. Inside each spool is one of the large iron pieces, which strengthens the effect of the magnet. The iron cores are made of lots of little metal sheets lying on top of one another.

2. Now connect each of the two engine block contacts or terminals with the battery box terminals, using one wire for each connection. Does the motor run? No? Then check to be sure whether any current is actually flowing.

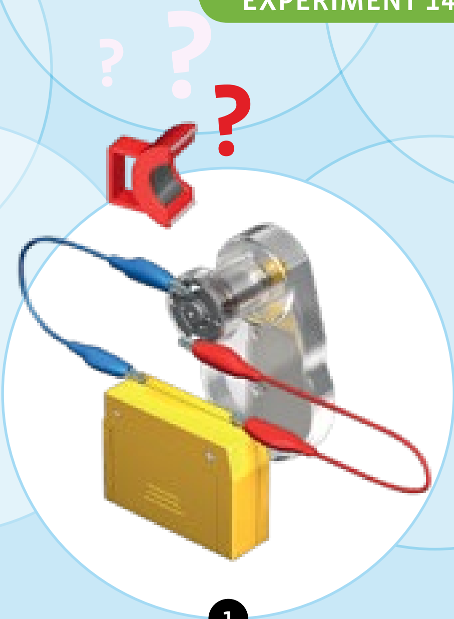
3. Remove the red wire from the battery contact and clamp it to one of the lamp terminals. Tap the other lamp contact against the free battery box contact.

EXPERIMENT 14

It needs a magnet

YOU WILL NEED

- → engine block
- → red magnet
- → battery box *with batteries*
- → red wire
- → blue wire



1

HERE'S HOW

1. Experiment 10 showed how you can use magnets to generate rotational movement. Is the problem that your electric motor lacks magnetic power? Connect the motor terminals to the battery box terminals again. As expected, the motor doesn't run.

2. Now mount the red magnet as shown in the illustration.

2

→ WHAT'S HAPPENING?

The motor starts right up. So that's what was missing — a magnetic field. If you have other magnets, you can try them too. If they are strong enough, the motor will run with them as well. You should only connect the motor to the battery for a short period of time, even if it's not running. Current will still be flowing, and the battery will run out if left connected.

EXPERIMENT 15

Everything in its proper place

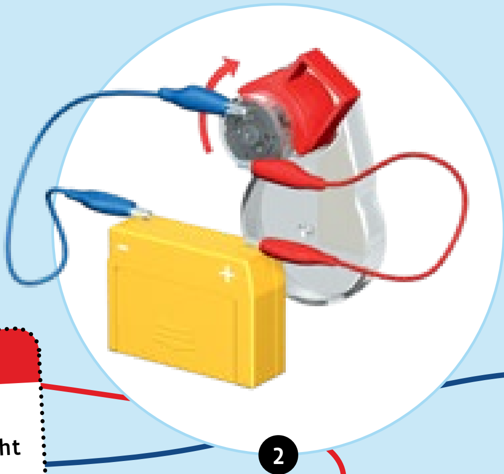
YOU WILL NEED

→ engine block
→ red magnet
→ battery box
with batteries
→ red wire
→ blue wire

HERE'S HOW

1. There are only two places where the red magnet fits onto the transparent housing.
Is there a reason for that?

2. Connect the engine block to the battery box again. Slide the red magnet back and forth against the rotor.
What do you observe?



→ WHAT'S HAPPENING?

The motor gets slower and even stops when the magnet is positioned at a right angle to its original position. This is where there are areas without any current. So the experiment shows that it isn't just a matter of producing a magnetic field, the field has to act on a certain area. Take a look at pages 36–38 to see why that's the case.

EXPERIMENT 16

Adding a second magnet

YOU WILL NEED

→ engine block
→ red magnet
→ blue magnet
→ battery box
with batteries
→ red wire
→ blue wire

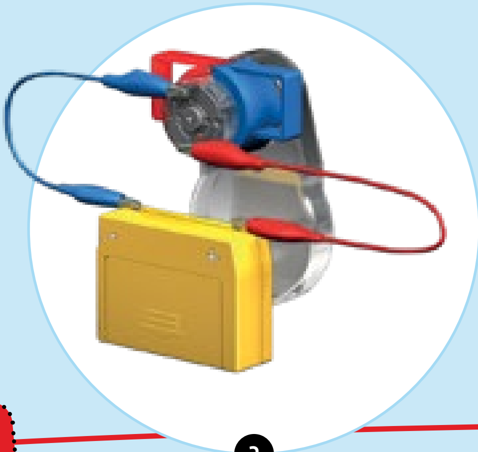
HERE'S HOW

1. While the motor may turn quickly with a single magnet, it doesn't have much power. You can easily stop it just by touching the gear.
   Might the magnet be too weak or too one-sided?

   Now mount the blue magnet as well.

2. Reconnect the motor to the battery box.
   Does anything change?


1


2

→ WHAT'S HAPPENING?

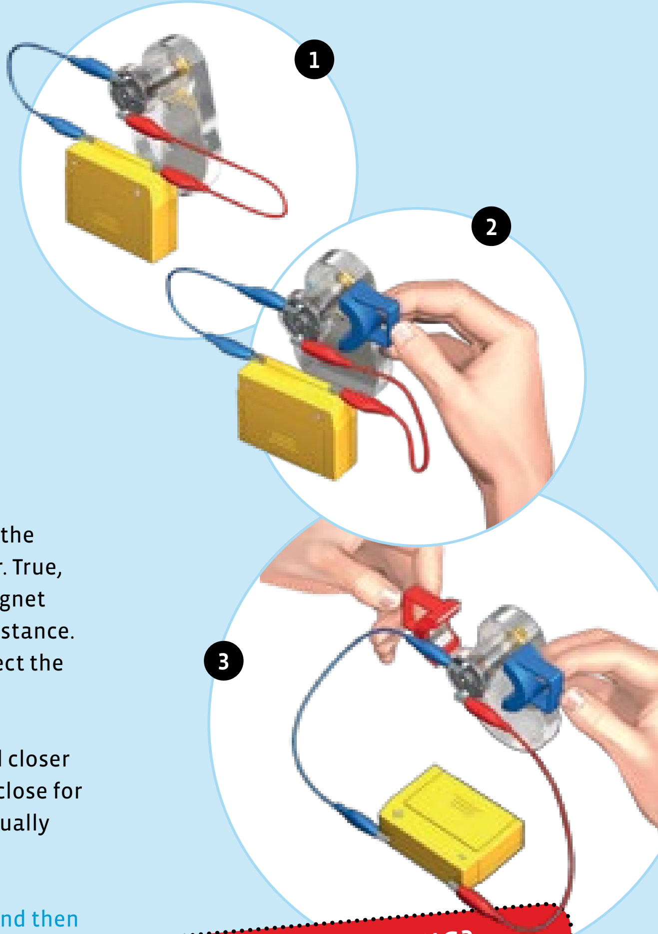
In fact, the motor really does get more power now. It runs better because of the much stronger magnetic field from the two magnets.

EXPERIMENT 17

It all comes down to power

YOU WILL NEED

→ engine block
→ red magnet
→ blue magnet
→ battery box *with batteries*
→ red wire
→ blue wire



HERE'S HOW

1. Investigate how the strength of the magnetic field affects the motor. True, you can't make a permanent magnet weaker, but you can adjust its distance. Pull off both magnets and connect the motor to the battery box.

2. Hold the blue magnet closer and closer to the rotor. It has to get pretty close for the motor to start up. Then gradually move it away again.

   The machine will keep running and then stop when the magnet is a few centimeters away.

3. Leave the blue magnet far enough away that the motor doesn't turn, and then approach from the other side with the red magnet.
   When does the motor start to run?

→ WHAT'S HAPPENING?

As you bring the red magnet closer, the motor will start running even when it's five or ten centimeters away.

By adjusting the distance of the magnets, you can also regulate the rotation speed of the motor. When it runs too slowly, though, it gets a little jerky. So the magnetic field has to be strong enough, and the motor will run better and more quietly when the field is coming from both sides.

EXPERIMENT 18

What the gear system does

YOU WILL NEED

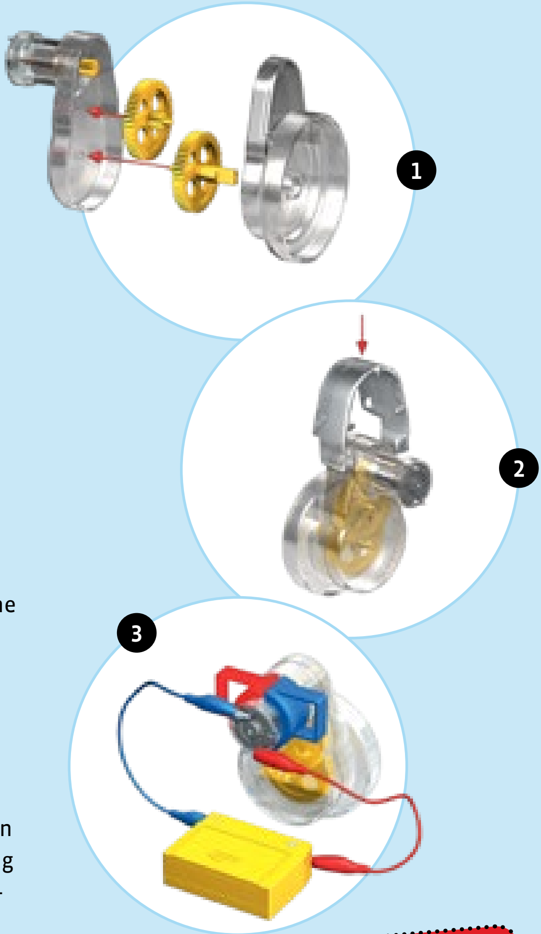
→ engine block
→ both gears
→ cover
→ stabilizer
→ red magnet
→ blue magnet
→ battery box
with batteries
→ red wire
→ blue wire

HERE'S HOW

1. You can use a gear system to increase the motor's power even more. Insert the two yellow gears. Mount the cover on the engine block as shown in the illustration.

2. Now you have a double transmission: The gear system converts the motor's high rotation speed into a slow rotation of the second shaft. Now, before setting the motor in motion, slide on the stabilizer. That will secure the mounting of the gear shafts.

3. Connect the motor to the battery box and mount both magnets.
What strikes you about the shaft protruding from the cover?



→ WHAT'S HAPPENING?

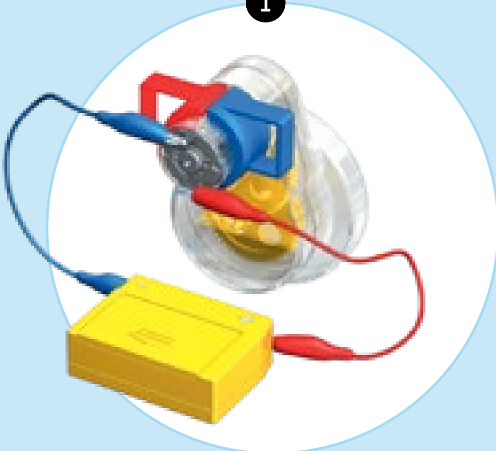
The thicker shaft rotates a lot slower than the rotor. But when you try to brake it with two fingers, you will also notice that there's a lot more power behind it. So a gear system isn't merely something that converts rotation speeds, it is also a power converter. When the rotation rate is reduced, the power on the shaft is increased.

EXPERIMENT 19

Polar reversal

YOU WILL NEED

→ engine block
→ both gears
→ cover
→ stabilizer
→ red magnet
→ blue magnet
→ battery box
with batteries
→ red wire
→ blue wire

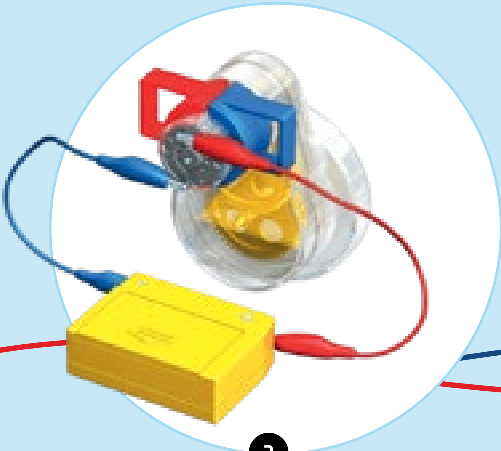
1


HERE'S HOW

1. Have you been paying attention up to now exactly how the motor is connected to the battery contacts?

   Take a look at the motor contact where the blue wire clamp is mounted and note the rotation direction of the motor: clockwise or counterclockwise?

2. Reverse the red and blue wire clamps on the motor.


2

→ WHAT'S HAPPENING?

The direction of rotation changes. This is an example of how — unlike with the lamp — the polarity of the wires can make a difference.

EXPERIMENT 20

Magnetic reversal

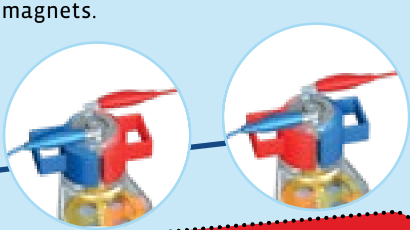
YOU WILL NEED

- → engine block
- → both gears
- → cover
- → stabilizer
- → red magnet
- → blue magnet
- → battery box *with batteries*
- → red wire
- → blue wire

HERE'S HOW

Does it make any difference how the magnets are placed on the motor — that is, whether the red one is on the right and the blue one on the left?

Take a look at the direction of rotation and then reverse the positions of the magnets.



→ WHAT'S HAPPENING?

The motor starts right back up again, but it turns the opposite direction. So, if the shaft turned in a clockwise direction when viewed from above, now it will turn in a counterclockwise direction.

EXPERIMENT 21

When you reverse both, they cancel out

YOU WILL NEED

- → materials from Experiment 20

HERE'S HOW

Of course, you could switch both the polarity and the magnets at the same time.

Note the direction of rotation, reverse the terminal clamps, and reverse the positions of the magnets as well.

→ WHAT'S HAPPENING?

The motor runs, but in the original direction. The two reversals cancelled each other out.

Note

An electromagnet has a north and a south pole, just as a permanent magnet does. By switching the direction of current, you can also switch the poles in the blink of an eye.

Electric Motor History

If you want to get picky about it, the history of the electric motor started a long time ago. A lot of knowledge and experience were needed before such a ground-breaking invention could even be conceivable.

It's impossible to name a single person who thought of the entire invention. It was mainly in the 19th century that a lot of inventors and scientists really started experimenting with electrical current.

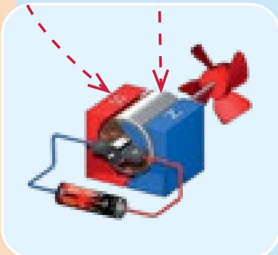
As so often happens, each discovery and each new idea was the basis for further developments. No matter how you look at it, it was an exciting bit of technological history. You will find more on the topic on pages 46-48.

ROTOR AND STATOR

Equal magnetic poles will repel each other, while opposite ones attract. In Experiment 20, you made a suspended permanent magnet start spinning by alternating the magnetic force of another.

That's similar to the way an electromagnet works. It is basically composed of two parts, the rotor or armature and the stator. The rotor is the rotating part, while the stator is the fixed part that encloses it.

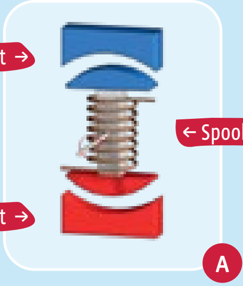
Both the rotor and the stator are magnets. In your motor, the stator consists of two permanent magnets, one with its north pole toward the rotor, the other its south pole.



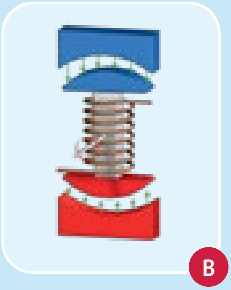
The rotor, on the other hand, is an electromagnet. It gets its electrical current through the motor terminals. It has a ring on its shaft with a piece of electrically conductive carbon pressing against it. This sliding contact carries the current when the ring rotates.

CHECK IT OUT

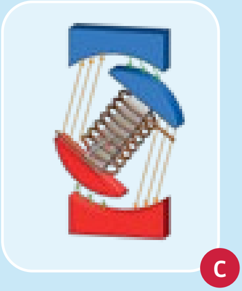
Imagine that you have a simple rotating spool with an iron core inside it, mounted between two permanent magnets (A). As soon as current flows, it becomes a magnet, with a north and a south pole and its own magnetic field. But this magnetic field also senses the magnetic field of the permanent magnets.



This creates a force that pushes each of the poles of the rotor sideways, indicated by arrows in the drawing (B). It is this force that makes the rotor turn (C).

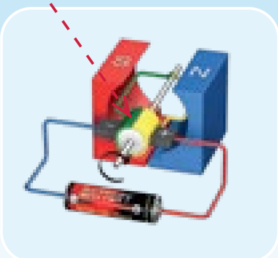


The turning direction depends on the position of the permanent magnets and the direction of current flow. The force weakens as the poles get farther away from each other.



To keep the motor moving, you have to use a trick: At the moment that the rotor is turned crossways, the direction of current through the rotor spool is reversed. This switch is performed by a **commutator.**

The illustration shows how it works. The commutator is usually made of plastic with small copper ring elements embedded in it at just the right locations, against which the two carbon pieces press.



CHECK IT OUT

THE TRIPLE-T ARMATURE

Now you also know why the position of the magnet was so important in Experiment 15: The switch has to occur when the poles are oriented toward each other in just the right way, which might not happen if the magnet is moved.

Because the armature looks like a double T, it is also called a double-T armature. In fact, though, it isn't very practical, since it can't run all by itself — the poles won't always happen to be in the best position.

More reliable is the triple-T armature, which runs well in any position. As you have probably noticed, this is the kind of rotor your motor has, so it also has a commutator with three segments.

Stronger motors often have a more complicated armature with a lot of spools, all of which contribute a portion of the motor's power. Also, instead of permanent magnets in their stator, they will have much more powerful electromagnets.

Carbon

Applications in industry and transportation

At first, electric engines replaced steam engines in powering individual pieces of equipment. Later, they powered conveyor belts and, thus, entire branches of industry.

In transportation, electric engines were first used for electric trains. Good reasons for using them in automobiles include their high degree of efficiency and their small size and weight compared to combustion engines. In addition, electric engines are exhaust-free.

Turning Movement into Electricity

Electric motors and a lot of other things that are electrically powered — such as electric lights — are very important in modern life. But first, of course, you have to get the electricity for them. A considerable portion of our electricity consumption goes to electric motors. If your electric motor can convert electricity into a rotational movement, could you maybe do things in reverse and turn the rotor to produce electric current? If your bicycle came to mind just now, you'd be right on target.

EXPERIMENT 22

Can the motor produce electricity too?

YOU WILL NEED

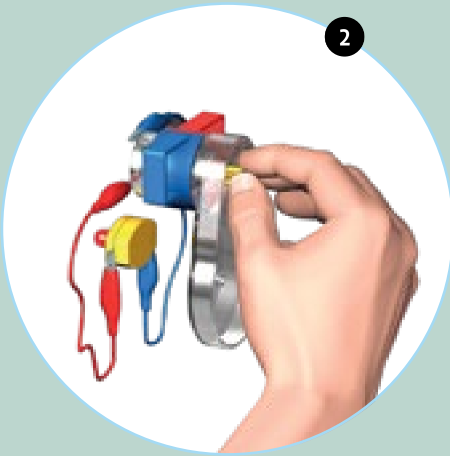
→ engine block
→ red magnet
→ blue magnet
→ red wire
→ blue wire
→ lamp

1

HERE'S HOW

1. Take the engine block, but without the gear system. Of course, you can't see it produce electricity. That's why you will need the lamp for proof. Wire it up and place the magnets on the motor.

2. Turn the small gear with your thumb and forefinger.



2

→ WHAT'S HAPPENING?

If you turn it slowly, nothing happens. But if you turn it quickly, the light bulb will also shine weakly, at least for a moment.

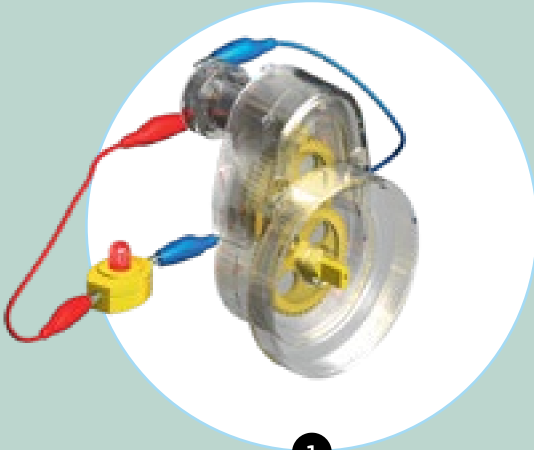
So it really is possible to produce electricity in this way. The rotation speed of the rotor is apparently important: The faster it turns, the more current is produced.

EXPERIMENT 23

Increasing rotation speed

YOU WILL NEED

→ engine block
→ both gears
→ cover
→ stabilizer
→ red magnet
→ blue magnet
→ crank
→ red wire
→ blue wire
→ lamp



1

HERE'S HOW

1. You already know one way to increase rotation speed: use a gear system. So re-install the two gears, attach the cover, and clamp the cover to the engine block with the stabilizer.

2. And now, quickly set the two magnets onto the engine block. It won't be easy to turn the thick yellow shaft with your finger. But once you mount the orange-colored crank, you can turn it easily.

2

→ WHAT'S HAPPENING?

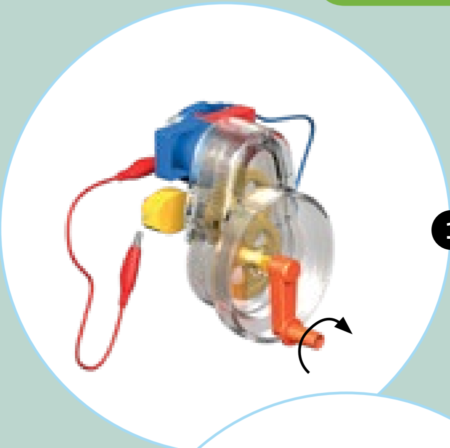
Now when you turn the crank, the bulb lights up steadily — and the faster you crank, the brighter it gets.

EXPERIMENT 24

Power you can feel

YOU WILL NEED

- → engine block
- → both gears
- → cover
- → stabilizer
- → red magnet
- → blue magnet
- → crank
- → red wire
- → blue wire
- → lamp



1

2

HERE'S HOW

1. Remove the wire from the lamp contact and turn the crank.

2. Reconnect the lamp. Turn the crank again.
   Can you feel the difference?

   And now try short-circuiting the generator by connecting the blue wire to both motor contacts. Crank again!
   What do you notice now?

→ WHAT'S HAPPENING?

Your generator can only do any real work if the lamp or some other current consumer is hooked up to it. You can feel it when you turn the crank: When it's doing some kind of work, the crank is harder to turn.

If the terminals are short-circuited, turning the crank gets really hard. Now, the generator is sending a lot of current through the wire, which would even start to heat up after a while. You are supplying the energy for this with your muscle power.

EXPERIMENT 25

Power transmission

If you have a friend with another Motors & Generators experiment kit, you can assemble a miniature power transmission system.

YOU WILL NEED

- → 2x engine block
- → 2x both gears
- → 2x cover
- → 2x stabilizer
- → 2x red magnet
- → 2x blue magnet
- → 2x crank
- → 2x red wire
- → 2x blue wire
- → *scissors*
- → *optionally, a few meters of insulated wire*

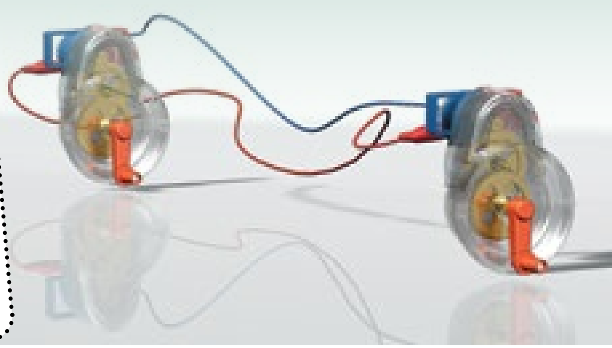
HERE'S HOW

1. With your two kits, assemble two motors, each with a gear system. Equip both motors with a crank.
2. Use the wires to interconnect the two units' terminals, and then try using one and then the other as a power generator. Now when you turn the crank on one motor, the other motor will start up.
3. It will also work if you insert a few meters of insulated wire between the two devices.
4. You just have to use a pair of scissors to remove a bit of insulation from the ends of the wires, and then attach them with alligator clips.

→ WHAT'S HAPPENING?

If everything works right, you will have an electric power plant connected to an electric motor to supply mechanical energy a certain distance away.

This is exactly the way that people take the energy produced by, say, a hydropower plant and send it hundreds of kilometers away to factories for powering electric motors and a variety of machines.

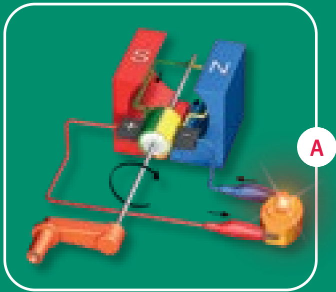


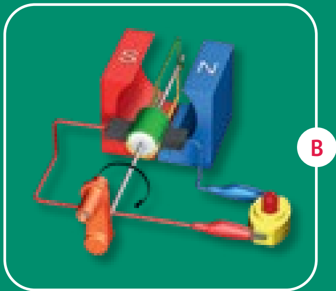
Hand-crank phone call

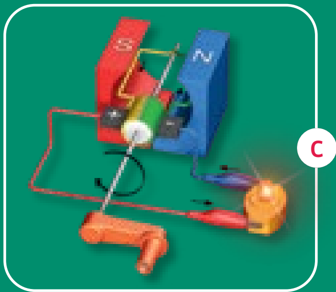
Have you ever puzzled over one of those ancient giant telephones on which, instead of dialing a number, people turned a crank before starting to talk? You sometimes see them in movies portraying a time period between around 1885 and 1930.

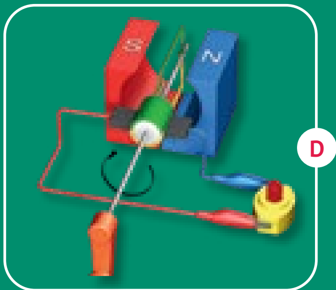
In those days, telephone lines had no electrical current running through them most of the time. If someone wanted to make a phone call, he or she had to crank a small generator to send a signal to the switchboard.

Then, the gentlemen at the local telephone switchboard office received a signal that someone wanted to make a call, and they connected the person placing the call with the person receiving it by manually inserting plugs onto the relevant jacks.









CHECK IT OUT

Generator

If you hold a wire in the magnetic field of a permanent magnet, nothing happens. But if you move the wire through the magnetic field, it creates electrical voltage. This is the principle underlying the electrical generator. Illustrations A through D show how a generator works.

In Figure A, the green region of the conductor loop moves upward through the magnetic field at the south pole. When that happens, current flows toward the positive terminal as indicated by the little black arrow. In the yellow region at the magnet's north pole, the current flows away from the negative terminal. The current flows through the terminals and the wire toward the lamp, closing the electrical circuit.

In Figure B, no current is being produced at the moment, so the bulb is dark.

But in Figure C the current is flowing again. The directions of current flow in the yellow and green conductor loop are reversed relative to A, because each is moving through the region of the opposite magnetic pole.

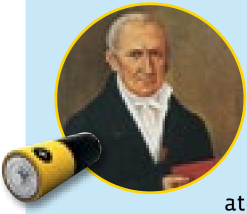
Nevertheless, the direction of current flow through the lamp remains the same, because the commutator ensures that the current still flows toward the positive terminal and away from the negative terminal on the other side.

In position Figure D, once again, no current is flowing.

Even though the direction of current flowing through the conductor loop changes with each rotation, it remains constant at the terminals, even if the current strength fluctuates quite a bit (which is why the light flickers when you turn the crank slowly).

Note

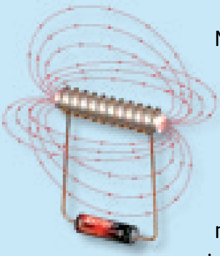
An electrical generator is constructed like an electric motor — except that it works in reverse, by converting movement into electric current.



Electricity only became really useful in 1800, when the Italian physicist **Alessandro Volta** invented the battery and thus created the first flowing current source.

A few years later, in 1819, the Danish physics professor **Hans Christian Ørsted** made an exciting discovery: Just by accident, he placed a wire on a compass and noticed that the needle moved when current was flowing though the wire.

This discovery caused quite a sensation among the natural scientists of the time. It showed that the two apparently entirely different fields of electricity and magnetism were in fact related.



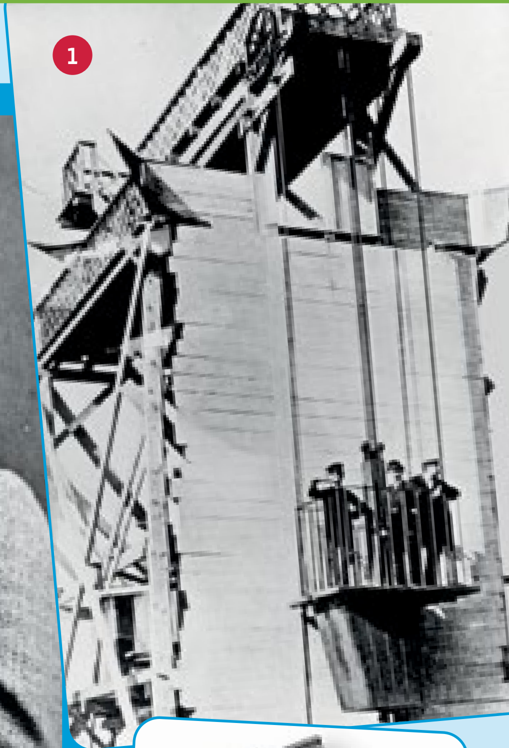
Now you know how Ørsted's observation can be explained: The flow of current creates a magnetic field around the wire, and the compass's needle reacts to it. Physicists of that time needed a few more years to figure it out, though. It wasn't until 1825 that the English physicist **William Sturgeon** built the first electromagnet.

Shortly thereafter, the brilliant English physicist and chemist **Michael Faraday** (1791-1867) discovered so-called electromagnetic induction, the name given to the phenomenon that an alternating magnetic field in a wire will produce electrical current.

This kind of induction is also the reason your motor can act as a power generator. A lot of researchers used this as a basis for all sorts of power-generating devices.

In 1833, the English professor **William Ritchie**, was the first to generate electricity by spinning an electromagnet between the poles of a large permanent magnet.

A lot of inventors tried to improve on these devices, since it was obvious that batteries were not adequate long-term current sources if large quantities of electricity were needed. Even so, the performance of these little machines remained quite modest until the late 19th century. They were nevertheless sometimes used to generate the electricity needed to power lighthouses.

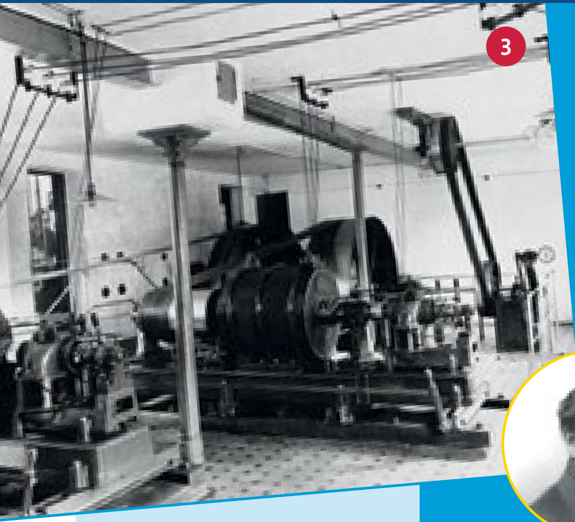


The first inventor to construct a truly high-performance electrical generator was the German **Werner von Siemens** (1816-1892). He is therefore considered to be the founder of electrical engineering. In his version of the generator, he replaced permanent magnets with much more powerful electromagnets powered by a portion of the electricity generated by the device.

As soon as it starts up, this kind of Siemens generator produces a little current, which immediately supplies energy to the electromagnets. As they get going, the current production quickly rises. The Siemens generator was so powerful that the electricity gauge burst the first time Siemens tried using it. →

1 The world's first electric elevator, Mannheim, Germany

2 A dynamo built by Werner von Siemens



→ This was the first invention to make electricity cheap and available in large quantities, and it was only now that electric light and electric motors were really cost-effective. Generators operating by this same principle are still at work in all electric power plants today.

By that time, it had already been a long time since the invention of the electric engine. In 1838, the researcher **Moritz Hermann Jacobi** had constructed a machine that used a total of eight electromagnets to set battery current flowing in a circular motion. He was even able to use it to power a small boat. And then Werner von Siemens got to work on the task of developing and using high-performance, efficient engines for the production of electric power.

For the Berlin Trade Exhibition, for example, he built the first electric railroad engine, and in 1881 he constructed Berlin's first electric streetcar.

He also suggested the use of electric rapid transit trains to ease the clogged city streets of his day. Soon thereafter, electric motors of all sizes moved into factories and households, and they have been lightening workloads ever since.

3 Three-phase generators at a three-phase power plant

4 First electric railroad engine, 1879

5 First electric streetcar, 1881

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Revision: Dr. Heike Herrmann
Project management: Ita Meister, Kristin Albert
Product development: Elena Ryvkin
Design and layout: Atelier Bea Klenk, Klenk/Riedinger
Illustrations: Claus Rayhle, Rayhle Designstudio, Bietigheim

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