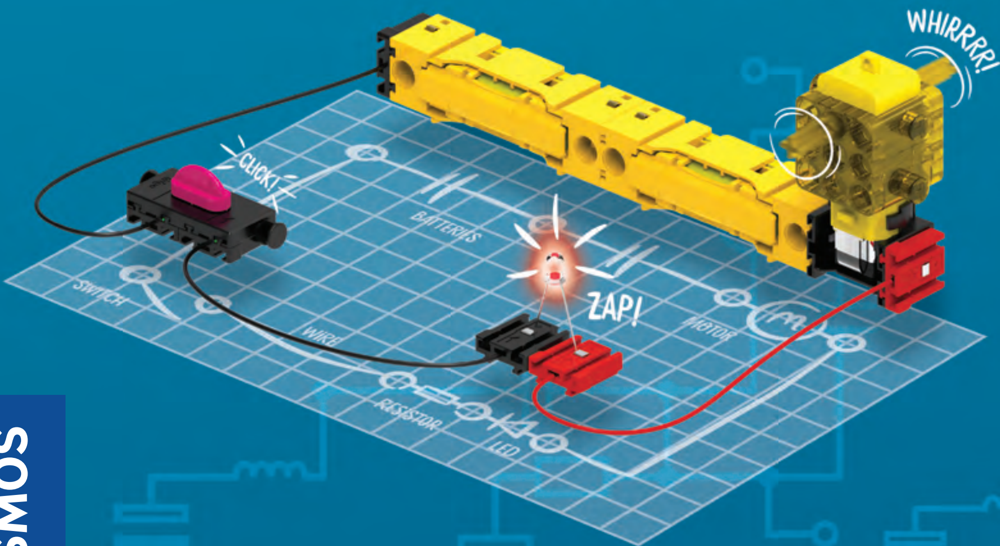
EXPERIMENT MANUAL

Easy Electric Circuits



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
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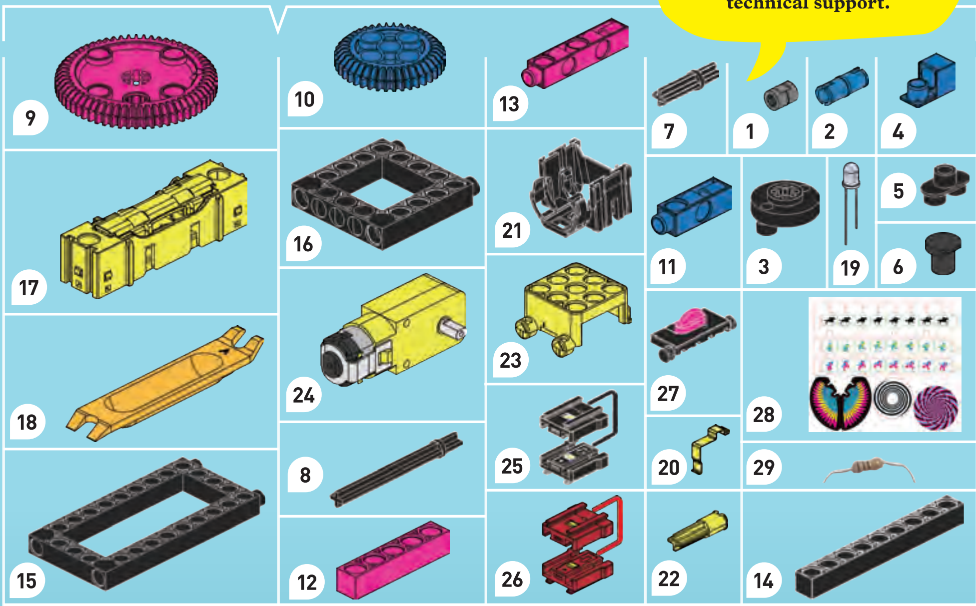
KIT CONTENTS

What's inside your experiment kit:

Good to know!

If you are missing any parts, please contact Thames & Kosmos technical support.



Checklist:

✔	No.	Description	Quantity	Part No.
○	1	Short anchor pin	10	7344-W10-CS2
○	2	Joint pin	6	7413-W10-T1B
○	3	Rod-axle connector	1	7026-W10-L2D
○	4	90-degree converter Y	2	7061-W10-Y1B1
○	5	Two-to-one converter	2	7061-W10-G1D
○	6	Long button pin	4	7061-W10-W2D
○	7	Axle, 30 mm	2	7413-W10-N1D
○	8	Axle, 70 mm	1	7061-W10-Q1D
○	9	Large gear, magenta	2	7026-W10-W5K
○	10	Medium gear, blue	2	7408-W10-D2B
○	11	3-hole dual rod	2	7413-W10-Y1B
○	12	5-hole rod	2	7413-W10-K2P
○	13	5-hole dual rod	2	7413-W10-X1K
○	14	9-hole rod	2	7407-W10-C1D
○	15	Long frame, 5x10	1	7413-W10-I1D
○	16	Square frame, 5x5	2	7413-W10-Q1D
○	17	Battery holder	2	7050-W85-01
		with cover	2	7455-W10-C1Y
○	18	Part separator tool	1	7061-W10-B1Y

✔	No.	Description	Quantity	Part No.
○	19	LED, red	1	E40-04
○	20	Metal contact clip	2	M30#7455-1
○	21	Motor contact cover	1	7455-W10-B3D
○	22	Motor axle	2	7448-W10-B1TY
○	23	Motor housing	2	7448-W10-B3TY
○	24	Motor	1	E10#7455
○	25	Wire, black	2	7455-W85-A1D
○	26	Wire, red	2	7455-W85-A1R
○	27	Switch	1	7455-W85-C
○	28	Die-cut cardboard sheet	1	K16#7455-1
○	29	Resistor, 390Ω	1	E60#7455

The parts not included in the kit are marked in *italics* in the YOU WILL NEED lists.

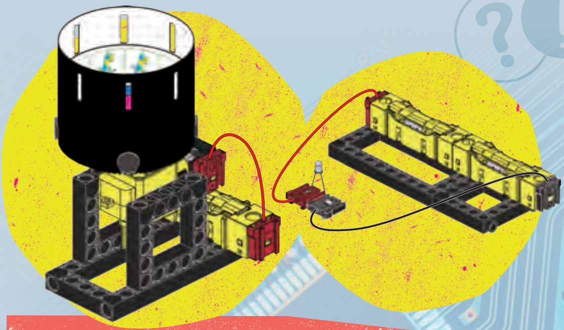
YOU WILL ALSO NEED:

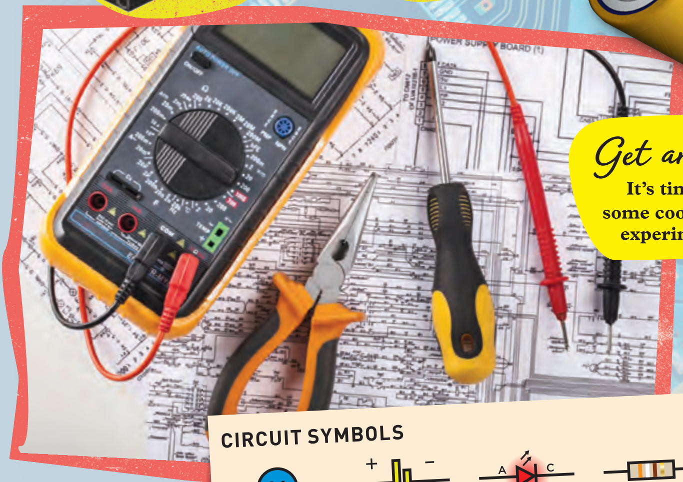
2 AA batteries (1.5-volt, type LR06) and various metallic and nonmetallic objects from around your home for conductivity testing

TABLE OF CONTENTS

TIP

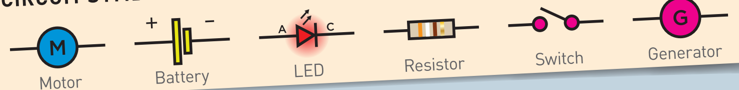
READ THE "WHAT'S HAPPENING" SECTIONS AFTER EACH EXPERIMENT FOR SCIENTIFIC EXPLANATIONS OF YOUR OBSERVATIONS, A CIRCUIT DIAGRAM FOR THE CIRCUIT YOU BUILT, AND DEFINITIONS OF KEY CIRCUITRY TERMS.





Get amped! It's time for some cool circuit experiments!

CIRCUIT SYMBOLS



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WARNING!

Not suitable for children under 3 years. Choking hazard — small parts may be swallowed or inhaled. Strangulation hazard — long cords may become wrapped around the neck.

Warning: This toy is only intended for use by children over the age of 8 years, due to accessible electronic components.

Instructions for parents or care givers are included and shall be followed.

Keep packaging and instructions as they contain important information.

Safety for Experiments with Batteries:

- Never perform experiments using household current! The high voltage can be extremely dangerous or fatal!
- Two AA batteries (1.5-volt, type LR06) are required, which are not included in the kit because of their limited shelf life.
- Avoid short circuiting the battery. A short circuit can cause the wires to overheat and the battery to explode.
- 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.
- Batteries are to be inserted with the correct polarity (+ and -). Press them gently into the battery holders (see page 7).
- Non-rechargeable batteries are not to be recharged. They could explode!
- Rechargeable batteries are only to be charged under adult supervision.
- Rechargeable batteries are to be removed from the toy before being charged.
- Exhausted batteries are to be removed from the toy.
- Dispose of used batteries in accordance with environmental provisions, not in the household trash.
- The supply terminals are not to be short-circuited.
- Avoid deforming the batteries.
- As all of the experiments use batteries, have an adult check the experiments or models before use to make sure they are assembled properly. Always operate the motorized models under adult supervision. After you are done experimenting, remove the batteries from the battery compartments. Note the safety information accompanying the individual experiments or models!
- The wires are not to be inserted into socket-outlets.
- Warning! Do not manipulate the protective device in the battery compartment (PTC). This could cause overheating of wires, eruption of batteries and excessive heating.
- The toy is not to be connected to more than the recommended number of power supplies. Use only the two battery holders, which are included in this kit.

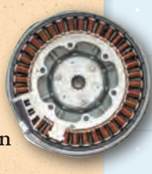
Notes on Disposal of Electric and Electronic Components:

The electronic components of this product are recyclable. For the sake of the environment, do not throw them into the household trash at the end of their lifespan. They must be delivered to a collection location for electronic waste, as indicated by the following symbol:

Please contact your local authorities for the appropriate disposal location.

IMPORTANT INFORMATION

Dear Parents and Adults,



Children want to explore, understand, and create. They want to try new things and do them independently. They want to gain knowledge! They can do all of this with Thames & Kosmos experiment kits. With every single experiment, they grow smarter and develop new, real-world skills firsthand.

With this kit, your children can learn about electricity and electric circuits in a fun, hands-on way. They can learn about many electrical components and principles by building circuits and observing firsthand how they function. They can develop fine motor skills and strengthen their powers of observation and troubleshooting while assembling the circuits and the motorized mechanical models.

The experiments are designed to encourage your children, but they can also be challenging. So please help your children as they experiment and play with this kit. Help your child build and operate the circuits and models with advice and a helping hand — especially with more difficult steps and experiments. For safety, you should supervise the insertion of the two AA batteries (1.5-volt, type LR06) into the battery holders.

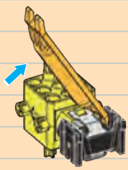
Pay attention to the safety notes on the previous page, and follow the advice provided with the instructions for each experiment. Before setting up and experimenting, read the safety instructions together with your child and discuss them. Please be sure that none of the kit parts get into the hands of young children.

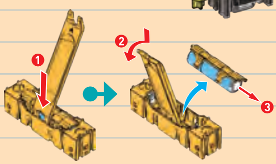
We hope you have a lot of fun with this experiment kit!

Have Fun!

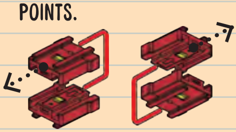
TIPS

USE THE **PART SEPARATOR TOOL** TO REMOVE ANCHOR PINS FROM HOLES, TO OPEN THE BATTERY HOLDER, AND TO REMOVE THE MOTOR CONTACT COVER FROM THE MOTOR.

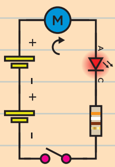




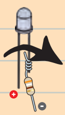
THE ELECTRIC COMPONENTS **SLIDE TOGETHER**. PAY CLOSE ATTENTION TO THE DIRECTION IN WHICH YOU SLIDE THE TERMINALS TOGETHER. MAKE SURE THE **METAL CONTACTS ARE** TOUCHING AT ALL CONTACT POINTS.



IF A CIRCUIT DOESN'T IMMEDIATELY WORK, **TROUBLESHOOT** IT BY WORKING YOUR WAY AROUND THE CIRCUIT, **INSPECTING EACH CONTACT POINT** TO MAKE SURE THE METAL CONTACTS ARE ALL TOUCHING. ALSO MAKE SURE THE **BATTERIES ARE SUFFICIENTLY CHARGED.**



IF THE **LED** DOES NOT LIGHT UP, TRY **REVERSING ITS DIRECTION** IN THE CIRCUIT — LEDS ARE DIRECTIONAL!

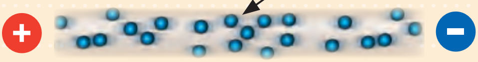


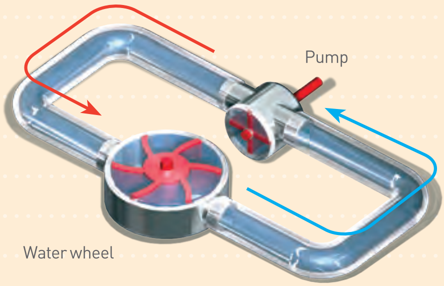
Electricity and Electric Circuits

People have been fascinated by the mysterious and invisible phenomenon of **electricity** for centuries. It is powerful and all around us, but only its effects can be observed by humans without tools. Today, we know that electricity is a "flow of electrons." **Electrons** are found in atoms, which make up all matter. They are smaller and more mobile than atoms, and they have lots of unusual properties.

Going with the Flow

Often, 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 metal 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.

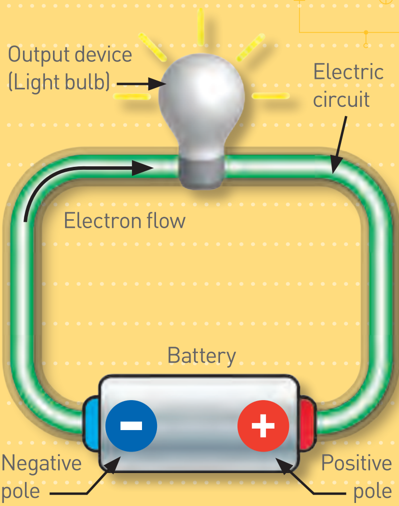
As with pumps in a water pipe, there are things that can cause electrons to flow through a wire — for example, batteries and generators. You can use flowing electrons, called **electrical current,** to do lots of amazing things. The technology of controlling electrons to perform certain goals is called **electrical engineering.** With the help of components like transistors, capacitors, resistors, and LEDs, we can make electrons do what we want them to. A device that provides a path for electrical current to flow is called an **electric circuit.**

Plus and Minus

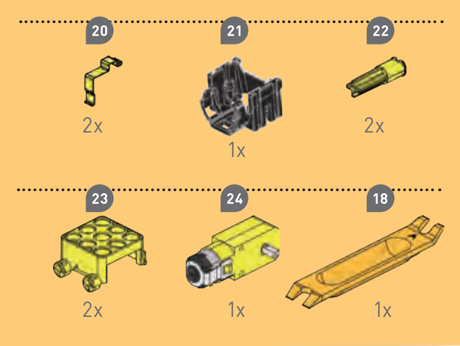
A water pump has two ends: one for suction and one for expulsion. Electrical current sources also have two ends, or **terminals.** At one, called the **positive pole,** they create a sort of electron vacuum. At the other end, the **negative pole,** they produce a sort of electron overload.

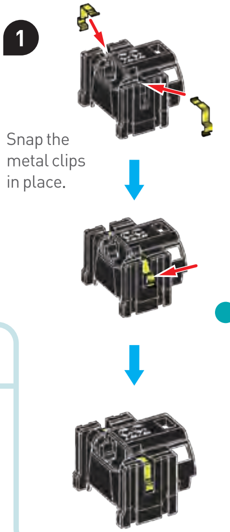
Current only flows when the poles, or terminals, are connected. Then, the electrons flow from the negative pole to the positive pole, and the force of their flow is capable of doing things like lighting a light bulb or spinning a motor. If the circuit is broken at any point, the flow of current immediately stops.

See page 21 for more about the direction of current flow.

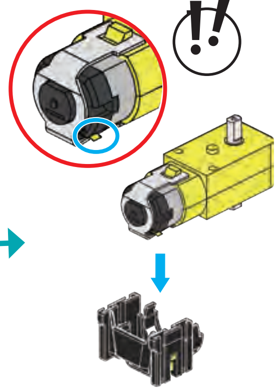


ASSEMBLING THE MOTOR BOX



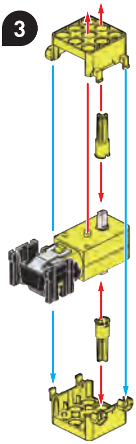


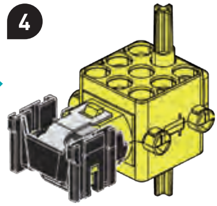
Snap the metal clips in place.



Make sure the metal contact tabs on the motor are facing down.

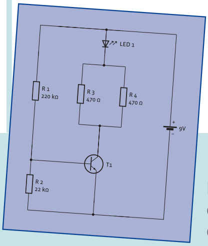
The metal tabs must make contact with the metal clips.





Snap the two sides of the motor housing together.

The Circuit Diagram



Example of a circuit diagram

In order to design and understand how circuits work, electrical engineers use **circuit diagrams.** A circuit diagram uses symbols to represent the individual components and shows how they are connected to one another. This kind of schematic diagram is much easier and faster to draw than a complete circuit board illustration. Each experiment in this manual includes a circuit diagram for the circuit that is built. Here are the symbols for the components used in this kit:

CIRCUIT SYMBOL

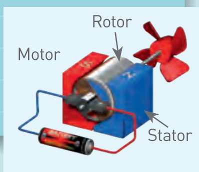
Motor

WHAT'S HAPPENING?

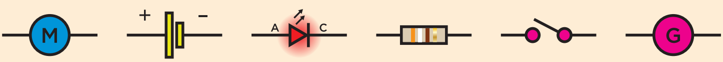
You assembled a motor housing around the **electric motor,** which is a machine that converts electric current into rotating mechanical energy. The housing will help you connect the motor to the other parts in this kit.

You probably already know that similar magnetic poles will repel each other, while opposite ones attract. You also may know that when you run an electric current through a coil of wire, it creates a magnetic field. This is called an electromagnet. When you reverse the direction of the current in the electromagnet, its polarity flips. North becomes south.

These principles are at play in an electric motor, which has a rotating electromagnet (rotor) surrounded by stationary magnets (stator). As the current inside the rotor switches back and forth, the rotor is attracted and repelled by the two sides of the stator. This constant cycle causes the rotor to spin!

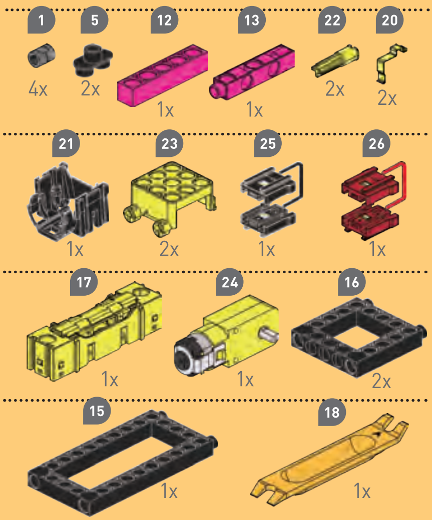


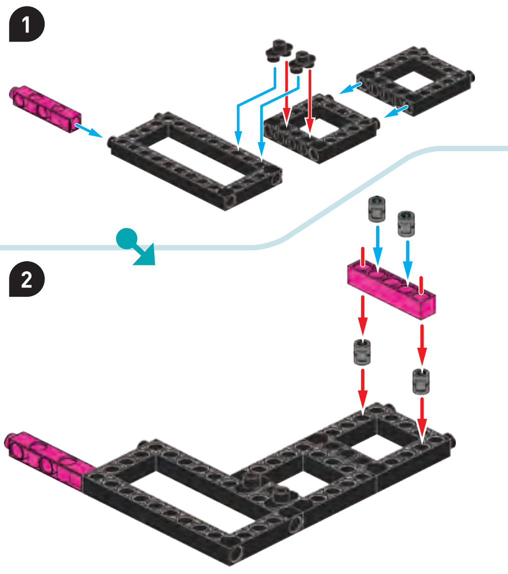
CIRCUIT SYMBOLS

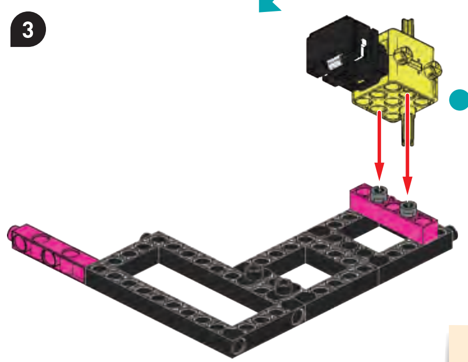


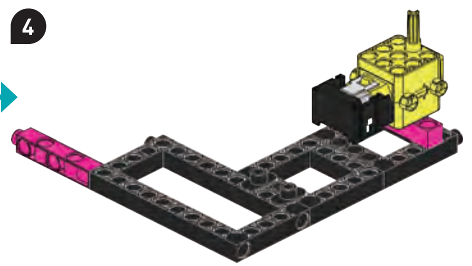
Motor | Battery | LED | Resistor | Switch | Generator

SETUP FOR EXPERIMENTS 1-4



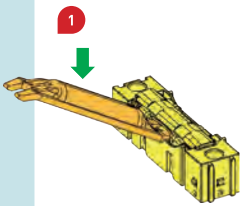




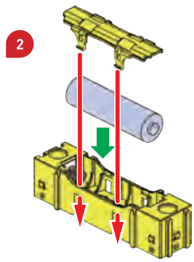


INSTALLING THE BATTERIES

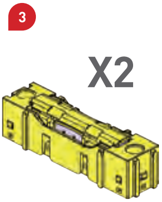
You will need 2 AA batteries.



Remove the cover with the tool.

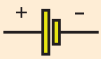


Insert the battery. Follow the polarity markings on the battery holder.



Replace the cover. Install a battery in each holder.

CIRCUIT SYMBOL



Battery

WHAT'S HAPPENING?

In order for your electric circuits to work, you will need to power them with one or two AA batteries (also known as **cells** in physics). A **battery** is a device that stores chemical energy to make it available as electrical energy. In a battery, there are two sides: an **anode** and a **cathode.** A chemical reaction occurs at the anode, causing free electrons to build up there. When the battery is put in a circuit, these free electrons travel from the anode to the cathode. And that's electric current!

EXPERIMENTS 1 & 2

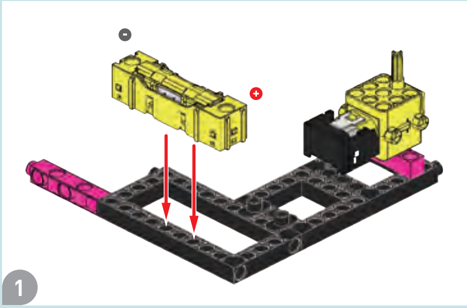
Changing direction

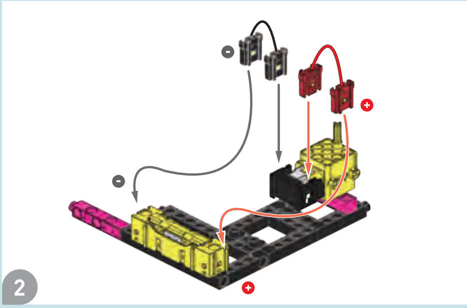
You will need

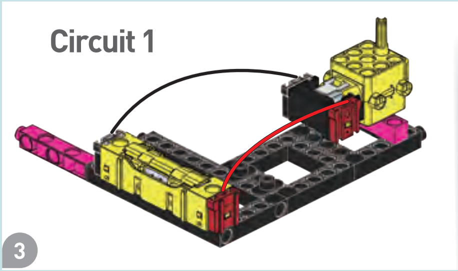
– Parts and Setup Assembly for Experiments 1–4 (see page 7)

Here's how

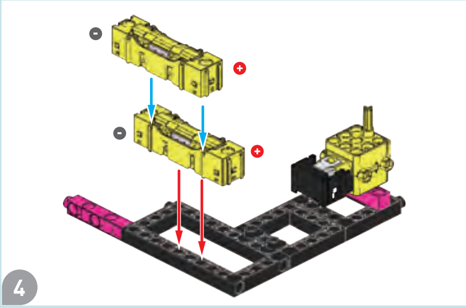
1. Follow steps 1–3 to build your first circuit.
2. Observe what happens when you complete the circuit. How fast and in which direction does the motor turn?

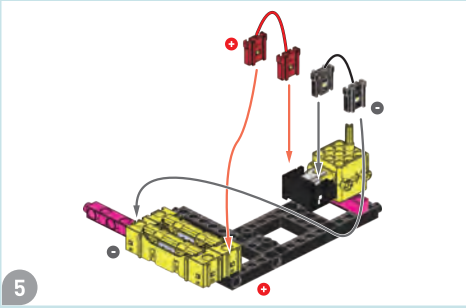


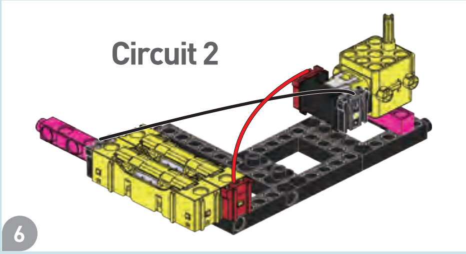




3. Remove the parts you added in steps 1–3. Then, follow steps 4–6.
4. Again, observe what happens when you complete the circuit. How fast and in which direction does the motor turn now?







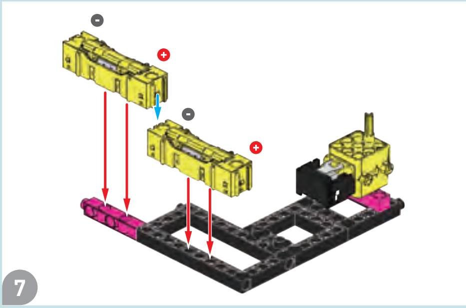
WHAT'S HAPPENING?

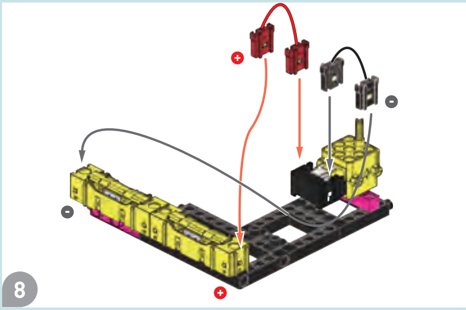
The motor spins at the same speed in both circuits, but the motor in circuit 1 spins in one direction, while the motor in circuit 2 spins in the opposite direction. Changing the direction in which a battery is connected to a motor changes the direction in which the motor turns. Also, circuit 2 will run twice as long as circuit 1 because there are two batteries!

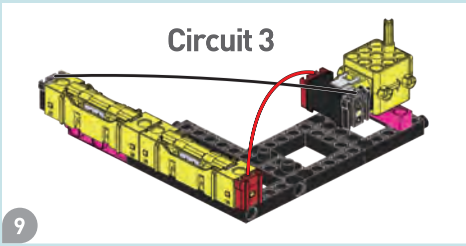
EXPERIMENTS 3 & 4

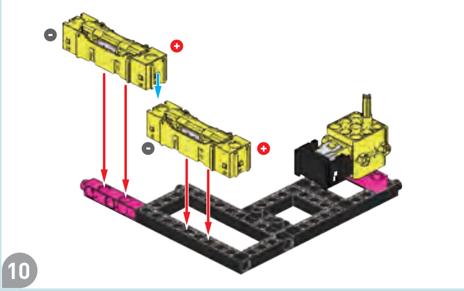
Speeding up

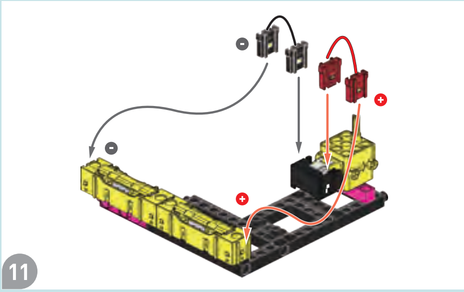
5. Remove the parts you added in steps 4–6 and follow steps 7–9. What happens?
6. Now switch the direction of the wires by following steps 10–12. What happens?

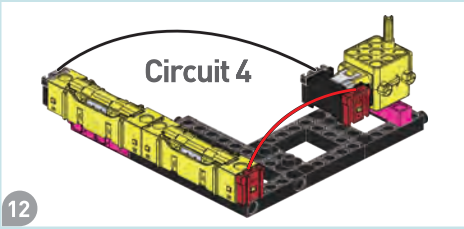










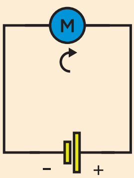


WHAT'S HAPPENING?

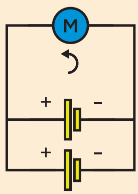
The motor spins twice as fast in both circuits 3 and 4 as it did in circuits 1 and 2. The motor spins in one direction in circuit 3 and the other in circuit 4.

In circuit 2, the batteries are connected in **parallel,** while in circuits 3 and 4, the batteries are connected in **series.** You can easily see the effect this has on the motor: When two batteries are connected in series, it doubles the voltage, which makes the motor spin faster.

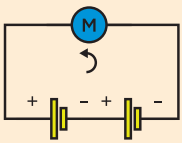
CIRCUIT DIAGRAM 1



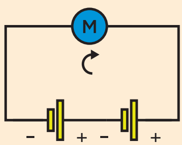
CIRCUIT DIAGRAM 2



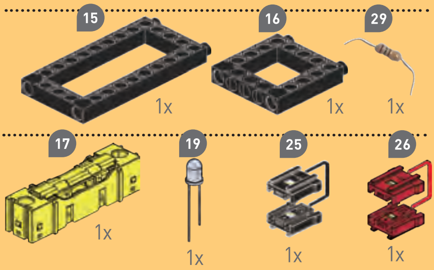
CIRCUIT DIAGRAM 3



CIRCUIT DIAGRAM 4



EXPERIMENT 5



Will it light up?

You will need

– Parts shown above, with battery installed

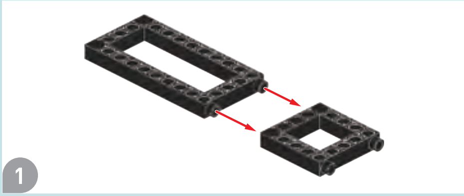
Here's how

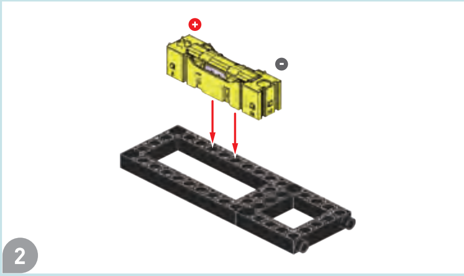
1. Assemble the circuit following steps 1–6. In step 4, you must wrap one end of the resistor around the shorter leg (the negative pin) of the LED. Whenever you use the resistor in the circuit, please wrap one end of the resistor three times around the LED. You will use this LED+resistor subassembly every time you use the LED in this kit.

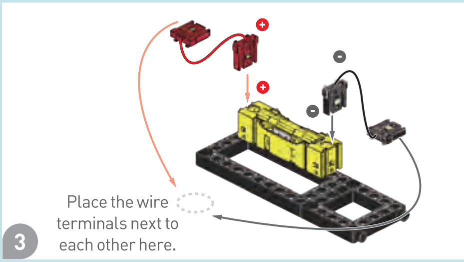
2. When the circuit is complete, what happens?

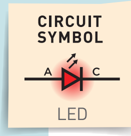
WHAT'S HAPPENING?

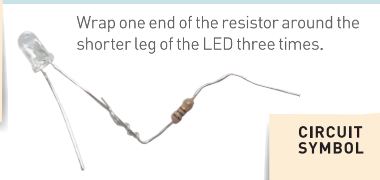
You didn't do anything wrong! The battery is not providing enough voltage for the **LED** to light up. LEDs are made of a semiconductor material that emits energy in the form of light when current flows through it. Depending on the material used, LEDs can emit any color of visible light, or invisible infrared or ultraviolet light. The LED's shorter leg is called a **cathode (C),** and the longer one is an **anode (A).** LEDs only work in one direction. When turned the wrong way, they won't let current through and they won't light up.

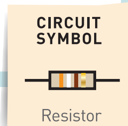


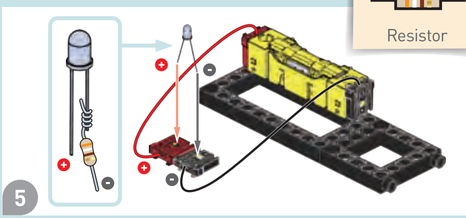


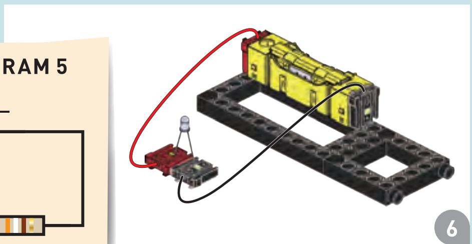


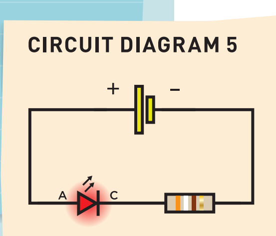




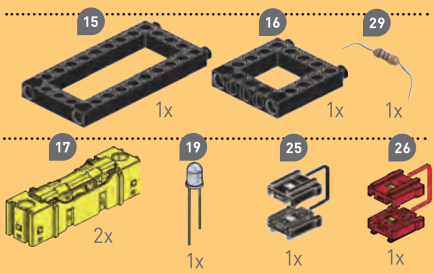








EXPERIMENT 6



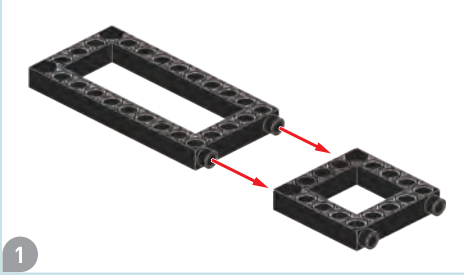
Lighting the way

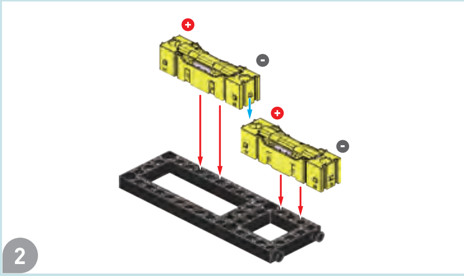
You will need

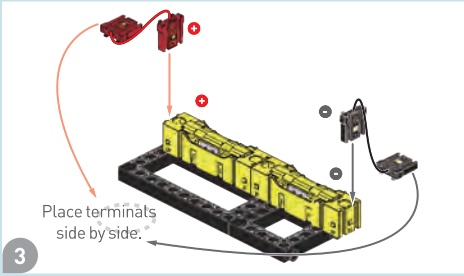
– **Parts shown above, with batteries installed**

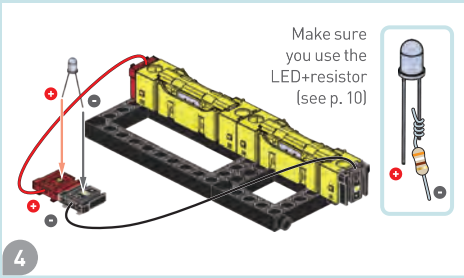
Here's how

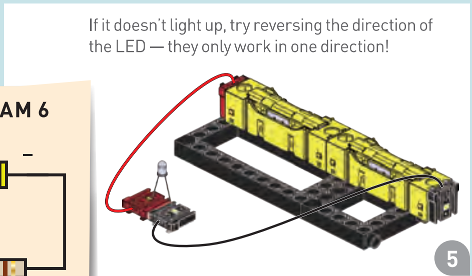
1. Follow the steps to assemble the circuit and observe what happens this time!











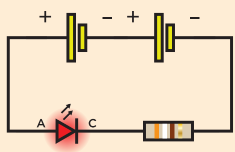
WHAT'S HAPPENING?

This time, with two batteries in a series circuit, there is enough voltage for the LED to light up. The voltages are added together, yielding twice the voltage. But what is voltage?

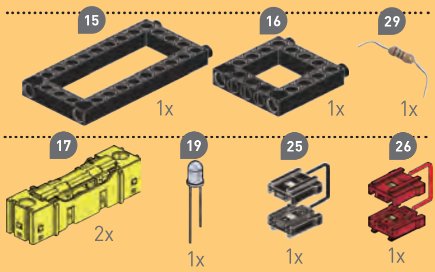
You can think of **voltage** as the pressure with which something like a battery pushes electrons out of one of its terminals, and with which it sucks up the electrons at the other terminal. Electrical voltage is measured in **volts (V).**

And what is a resistor? **Resistors** are components that have a certain constant electric resistance. They reduce the current and voltage in a circuit. They usually look like small barrels with two terminal wires. The resistance value is indicated by a color code printed on the barrel. The LED in your circuit will burn out after some time without the resistor, because it is designed for lower voltages than the batteries provide.

CIRCUIT DIAGRAM 6



EXPERIMENT 7



Lights off!

You will need

– **Parts shown above, with batteries installed**

Here's how

1. Assemble the circuit following steps 1–5.
2. Observe the LED. What do you see?

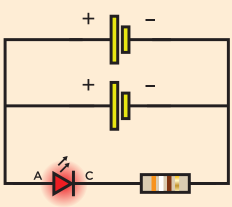
WHAT'S HAPPENING?

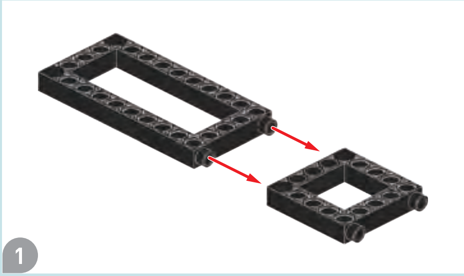
There are two batteries in the circuit, but because they are connected in parallel, the voltages are not being added together. There is not enough voltage for the battery to light up, just like in experiment 5.

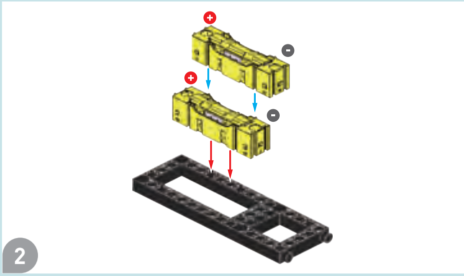
Each of the batteries produces a voltage of 1.5 volts. When they are connected in series, they deliver 3 volts. That's not much: A car battery has 12 volts, and current from a wall socket has 110 volts.

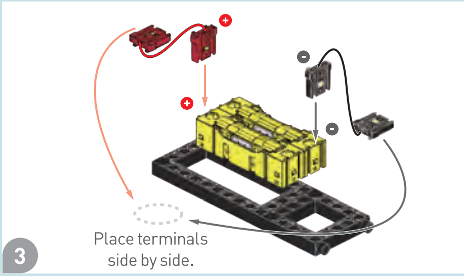
Similar to how high water pressure is able to push more water per second through a pipe than low water pressure can, a higher voltage sets more electrons in motion per second, producing a higher **current.** A high current can accomplish more than a low one, although it can also be more destructive. The unit of measure for current is the **ampere (A).**

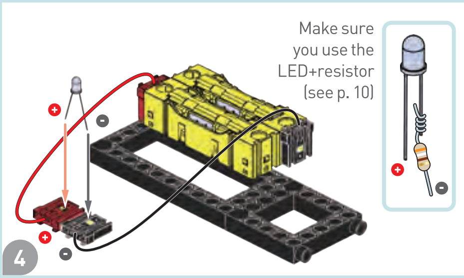
CIRCUIT DIAGRAM 7

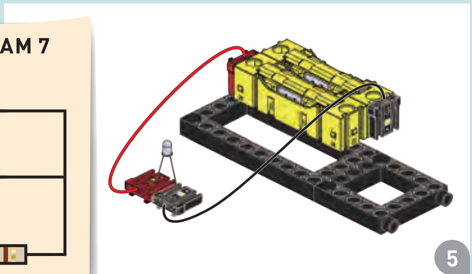




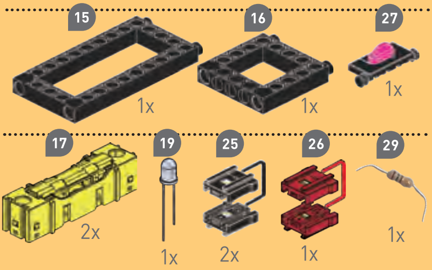








EXPERIMENT 8



Light switch

You will need

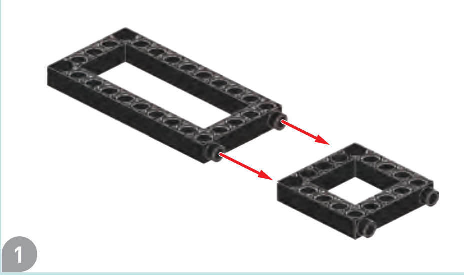
– **Parts shown above, with batteries installed**

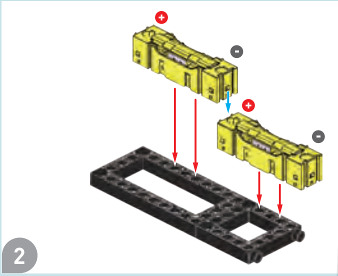
Here's how

1. Follow the steps to assemble the circuit as shown. In step 3, make sure that you insert the wire terminals into the switch in the correct direction. The metal contacts must be touching each other. Align the arrows on both components.
2. Turn the switch to its off position, with the knob vertical and the metal contacts showing. What happens?
3. Turn the switch to its on position, with the knob horizontal. What happens now?

WHAT'S HAPPENING?

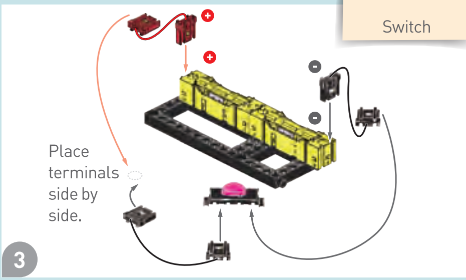
You have added a switch to your circuit. A **switch** is an electrical component that can connect or disconnect the conducting path in a circuit, breaking the circuit or diverting the current from one conductor to another. When the switch is open, the circuit is broken, no electric current flows, and the LED does not light up. When the switch is closed, the circuit is complete, electric current flows, and the LED lights up!

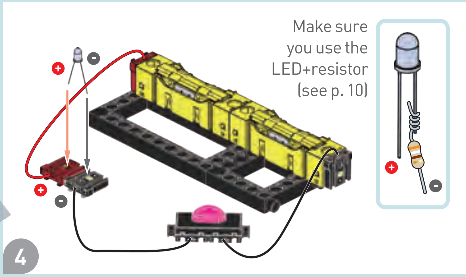


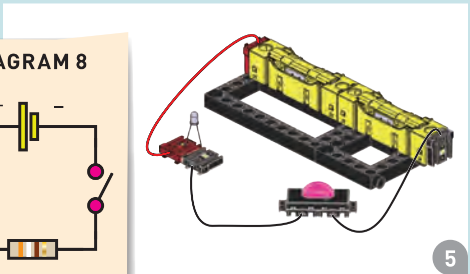


CIRCUIT SYMBOL

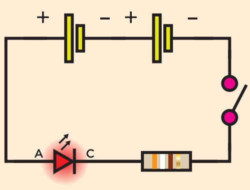
Switch



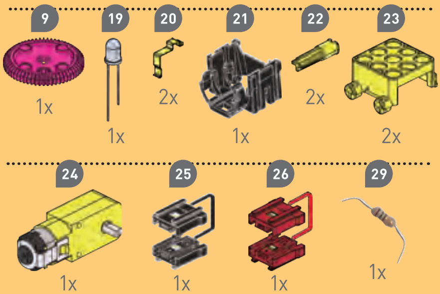




CIRCUIT DIAGRAM 8



EXPERIMENT 9



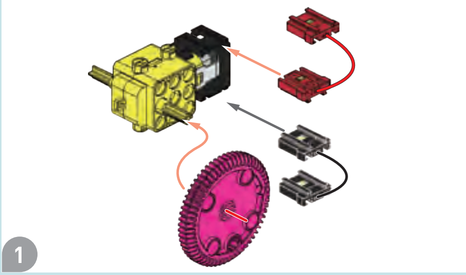
Simple generator

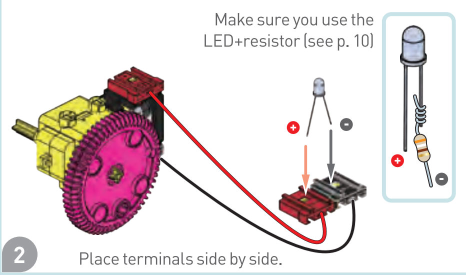
You will need

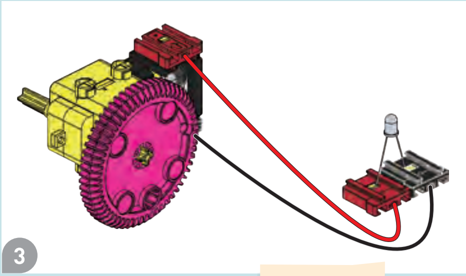
– Parts shown above

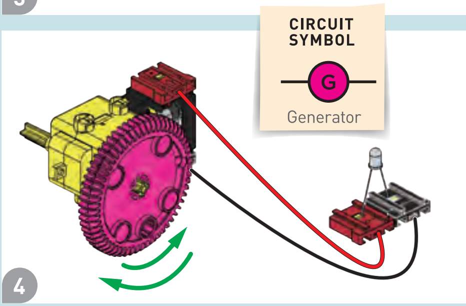
Here's how

1. Assemble the circuit as shown.
2. Turn the large gear wheel quickly with your hand. What does the LED do?
3. Now turn the large gear wheel quickly in the opposite direction. What happens to the LED?



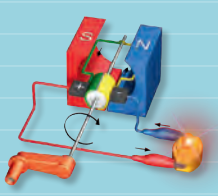




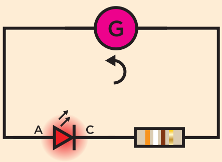


WHAT'S HAPPENING?

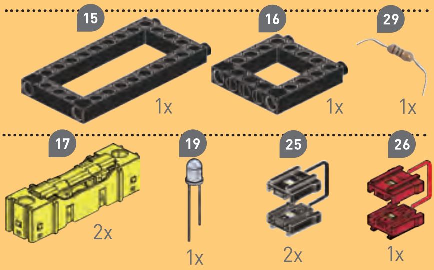
You made the LED light up without a battery! The motor operating in reverse becomes an **electric generator.** When you turn it, it creates an electric current. But it only works when you spin the generator in one direction and not the other. That is because the LED is directional. If you hold a wire 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.



CIRCUIT DIAGRAM 9



EXPERIMENT 10



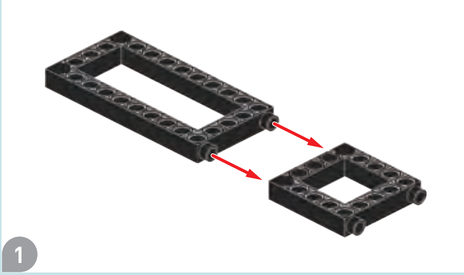
Conductors

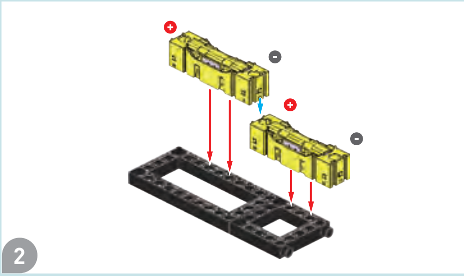
You will need

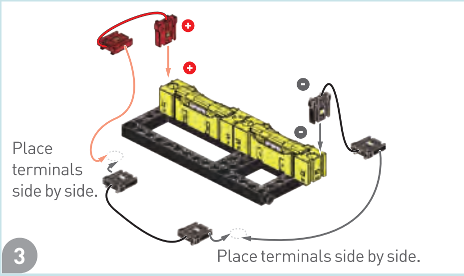
- **Parts shown above, with batteries installed**
- *Various metallic objects from around your home. For example: coins, paper clips, silverware, nails, and so on.*

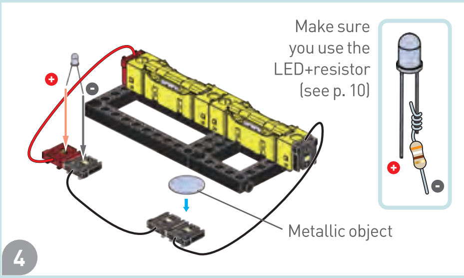
Here's how

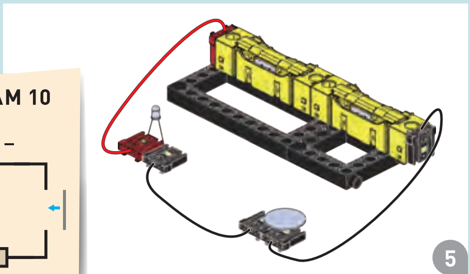
1. Follow steps 1–5 to assemble the circuit.
2. One at a time, use the metallic objects to connect the two free terminals of the black wires. Make sure the metallic object is touching both of the metal contacts on the ends of the wires.
3. For each object you test, observe what happens to the LED.







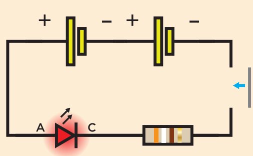




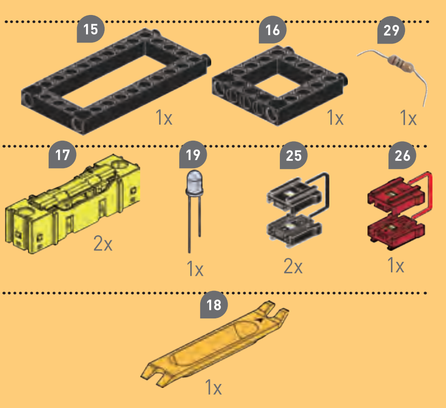
WHAT'S HAPPENING?

The LED should light up in most of your tests. Most metals are **electrical conductors,** meaning they transmit electrical current well. Electrons are able to move easily through them. The wires in your kit are all conductors with an insulated plastic coating. In the circuit diagrams, the conductive wires are indicated as lines, while breaks in the circuit — any non-conductive areas, including air — are empty spaces.

CIRCUIT DIAGRAM 10



EXPERIMENT 11



Insulators

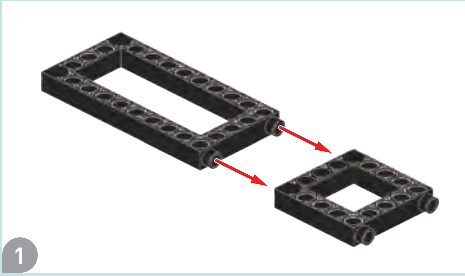
You will need

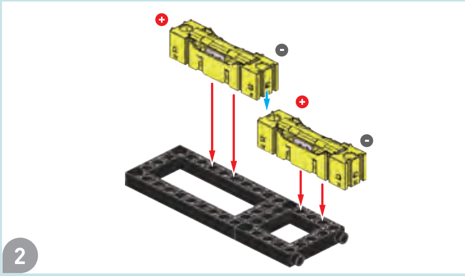
– Parts shown above, with batteries installed

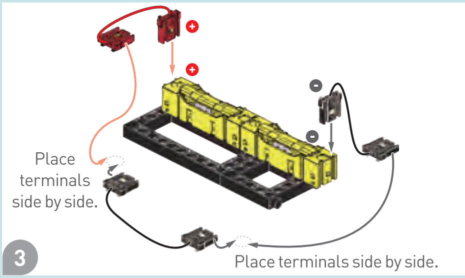
– Various nonmetallic objects from around your home. For example: paper, fabric, plastic, rubber, wood, and glass.

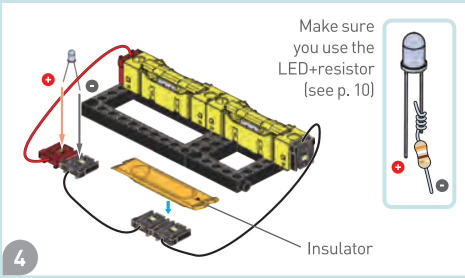
Here's how

1. Follow steps 1–5 to assemble the circuit.
2. One at a time, use the objects to connect the two free terminals of the black wires.
3. For each object you test, observe what happens to the LED.





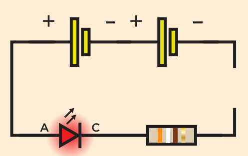


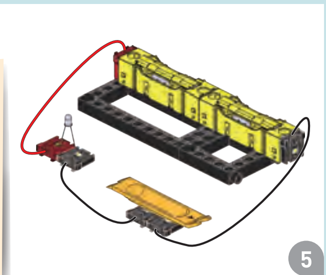


WHAT'S HAPPENING?

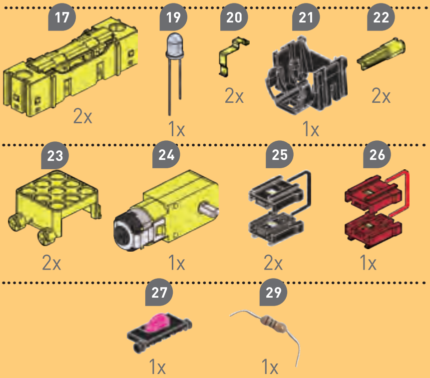
The LED will probably not light up for most of your tests. The part separator tool is plastic, which is an insulator. Insulators are materials that conduct current poorly. Plastics, air, glass, and other materials belong to this group. With these materials, the electrons hold tightly to their atoms and can't be set into motion so easily.

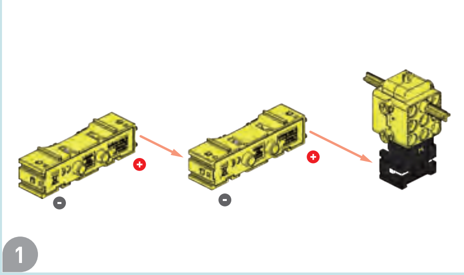
CIRCUIT DIAGRAM 11

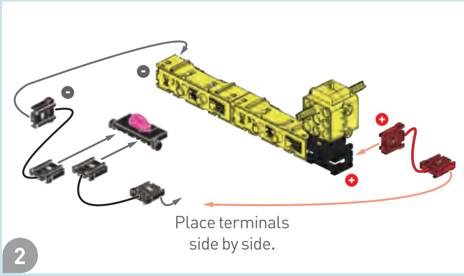


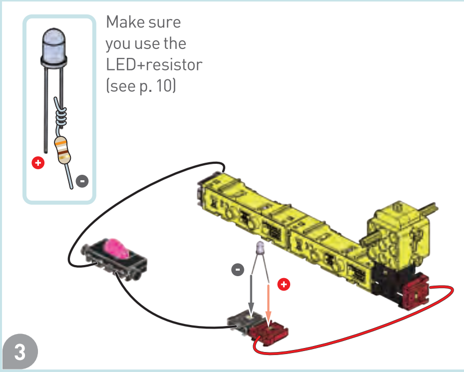


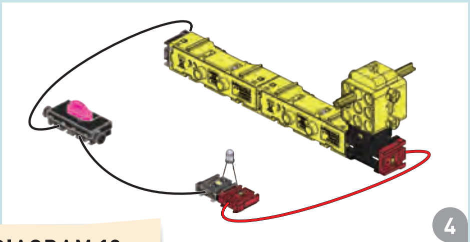
EXPERIMENT 12











Putting it all together

You will need

– **Parts shown above, with batteries installed**

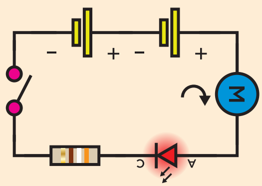
Here's how

1. Follow the steps to assemble the circuit as shown.
2. Use the switch to turn on the motor and the LED.

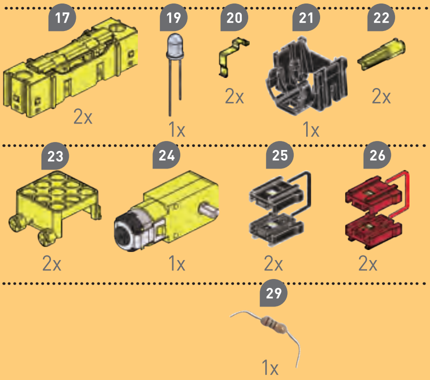
WHAT'S HAPPENING?

In this experiment, you assembled a more complex circuit than the others you have assembled so far. There are five different types of electrical components in this circuit. The electric current is capable of lighting the LED and turning the motor in the same circuit — but just barely. The motor does not turn very fast, or maybe doesn't turn at all depending on your battery. The motor, switch, LED, and resistor are all in series.

CIRCUIT DIAGRAM 12



EXPERIMENT 13



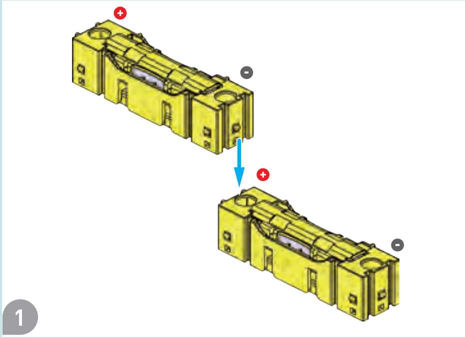
Parallel paths

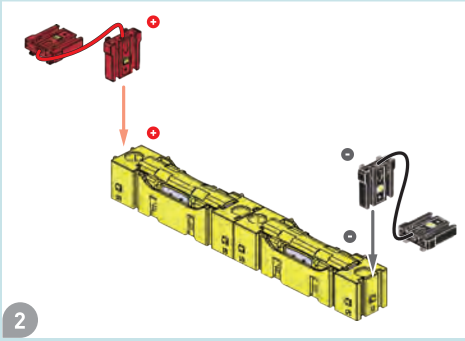
You will need

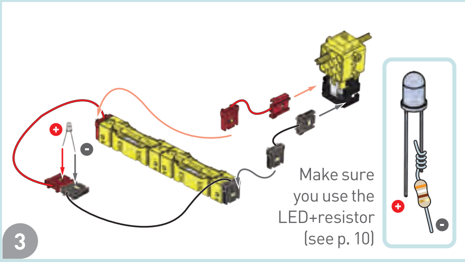
– **Parts shown above, with batteries installed**

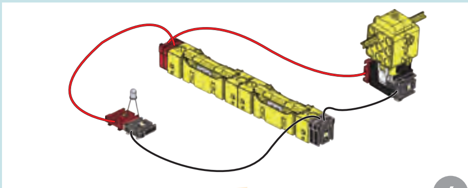
Here's how

1. Follow the steps to assemble the circuit as shown.
2. Observe what happens.
3. Remove the LED. What happens now?





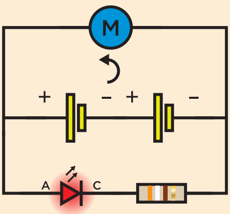




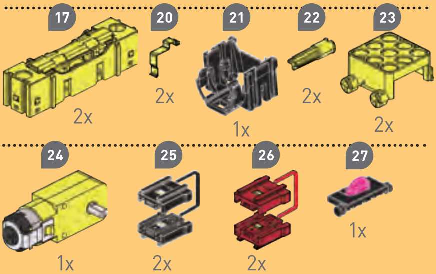
WHAT'S HAPPENING?

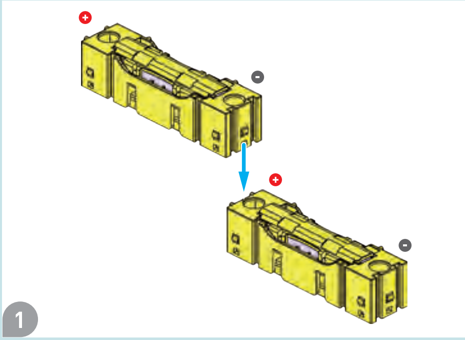
The motor and LED are connected in parallel. The LED lights up and the motor turns. Compare this to the previous experiment. This circuit has the same power supply (3 volts) as circuit 12, but because the motor and LED are connected in parallel, they are both receiving 3V. The current is being divided between the two components based on their resistances. When you disconnect the LED, the motor gets more current, so it speeds up. The sum of the currents through each path is equal to the total current that flows from the battery.

CIRCUIT DIAGRAM 13



EXPERIMENT 14





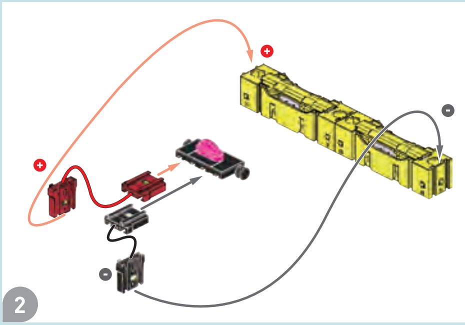
Taking a shortcut

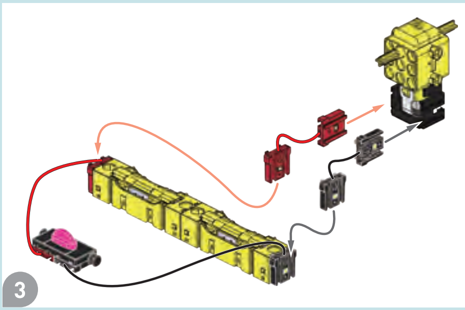
You will need

– **Parts shown above, with batteries installed**

Here's how

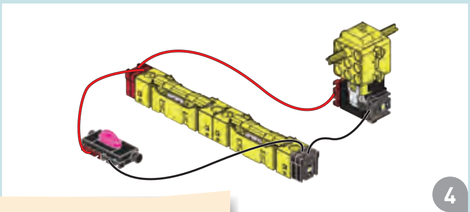
1. Assemble the circuit as shown.
2. **CAUTION! Leave the switch on for only a brief moment.**
   You are essentially creating a short circuit. The battery holder has a fuse in it to prevent an actual short circuit in the battery, thus preventing the battery from heating up. But you could burn out the fuse in the battery holder if you leave the switch on too long.



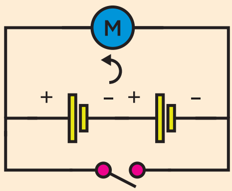


WHAT'S HAPPENING?

You are essentially short-circuiting the circuit momentarily. A **short circuit** is an electrical circuit in which the current flows along a path with no or very low electrical impedance. Electricity takes the path of least resistance, so the current will flow through the switch side when the switch is on, because the switch side has almost no resistance compared to the motor side. Short circuits can be very damaging to electrical components, which is why fuses and circuit breakers are used to protect them.

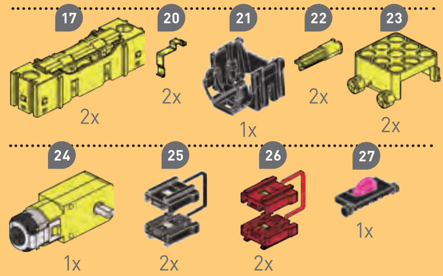


CIRCUIT DIAGRAM 14



CAUTION! Leave the switch on for only a brief moment.

EXPERIMENT 15



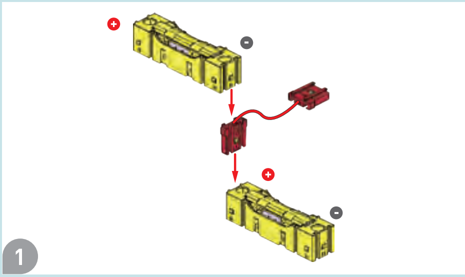
Two circuits in one

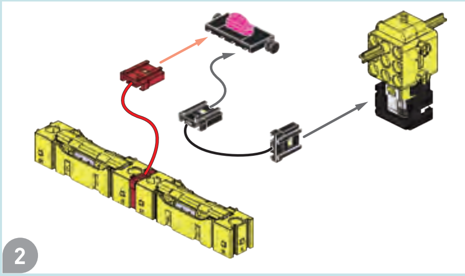
You will need

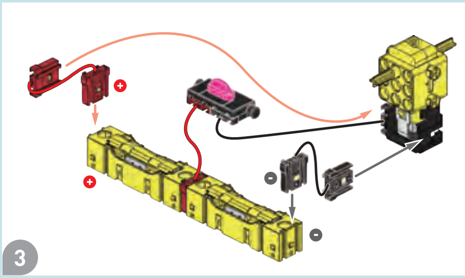
– Parts shown above, with batteries installed

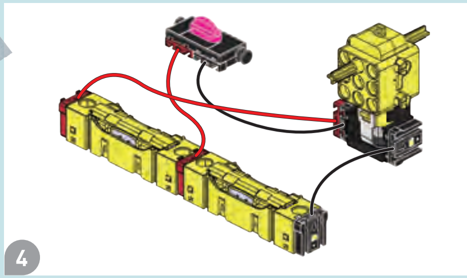
Here's how

1. Assemble the circuit as shown.
2. Turn the switch to its off position. What happens to the motor?
3. Turn the switch to its on position. What happens to the motor?







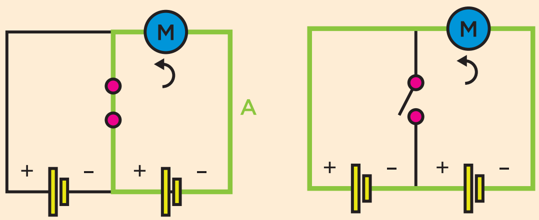


WHAT'S HAPPENING?

When the switch is off, the motor will turn faster than when the switch is on. This is because when the switch is on, circuit A (see diagram below) is active, and it only has one battery. When the switch is off, circuit B is active, and it has two batteries.

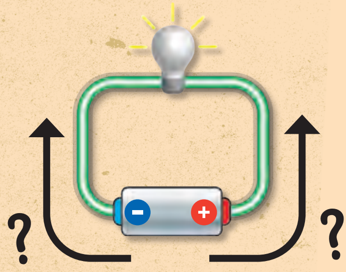
Now imagine if the switch were controlled not by a twist of your fingers, but by the electrical output of another circuit. For example, at a high voltage, the switch is on, and at a low voltage, the switch is off. One circuit would be controlling the other. This is the basis of all computing as we know it today!

CIRCUIT DIAGRAM 15



CHECK IT OUT

WHICH WAY DOES IT GO?



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**. 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.

But, around 100 years ago, 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.**

Thus it is very important to distinguish between the direction of conventional current flow — from positive to negative — and the direction of movement of the electrons — from negative to positive.

KEYWORDS

Voltage vs. Current

As you learned, the driving force for electrical current is known as **electric voltage,** which is measured in units called **volts.** In our water-pipe example, voltage would correspond to the water pressure produced by the pump.

You have to distinguish carefully between voltage and **current,** which is measured in **amperes,** or **amps** for short. 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 turning a motor or lighting up a lamp.

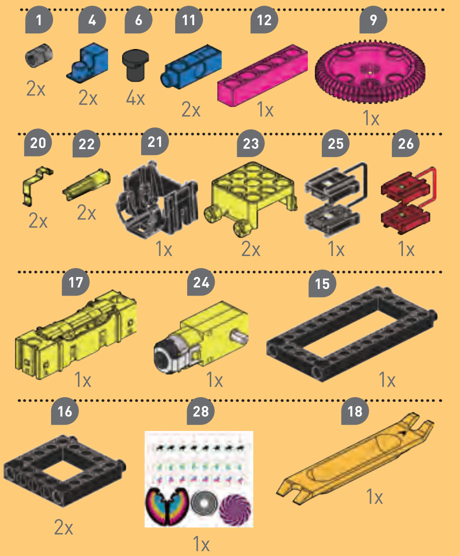
A multimeter is used to measure voltage and current in a circuit.

The motor in a washing machine

Motorized DEVICES

Have you ever tried to imagine how you could get by without electric circuits and electric motors in everyday life? Without electric devices, we would need things like a hand-cranked washing machine, a foot-powered dentist's drill, and a horse-drawn car — all of which existed not too long ago. As far as your smartphone, computer hard drive, microwave, and lamp go — those things would never be possible without electric circuits. Circuits with lights and motors are all around you. In this section, you can use what you learned in the first 15 experiments to build five motorized devices that use electric motors to perform interesting tasks!

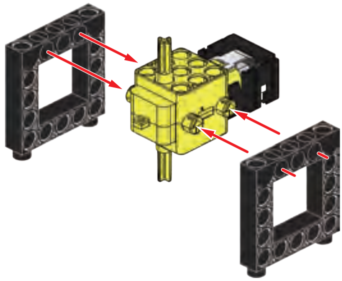
EXPERIMENT 16



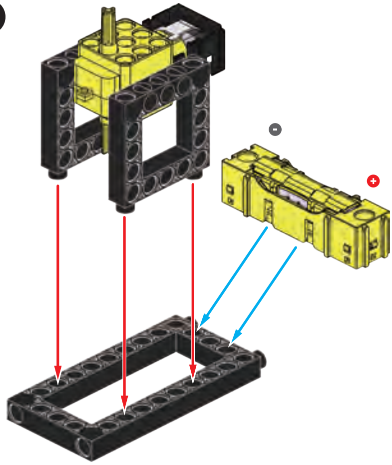
For experiments 16–20, use the parts shown in the parts lists for each experiment, with the battery already installed in the battery holders, to assemble the models. Then, observe how each model moves.

Movie Zoetrope

1



2



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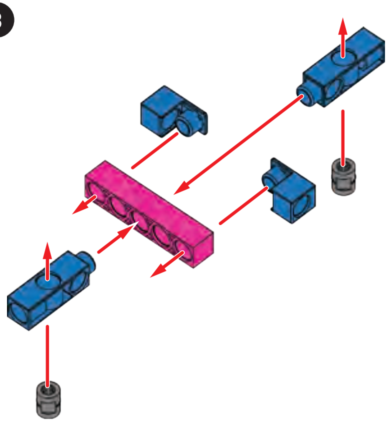

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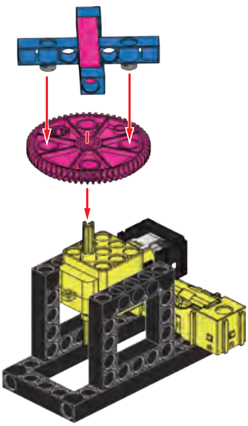

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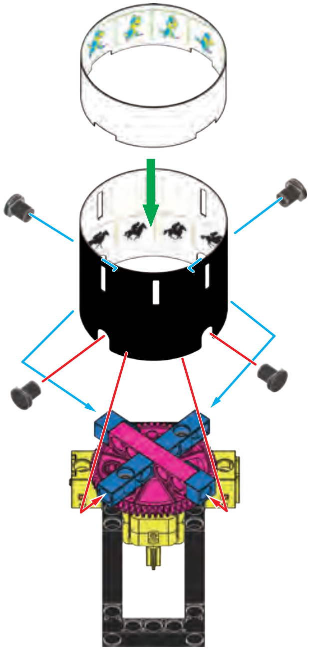
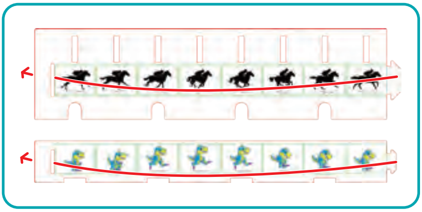
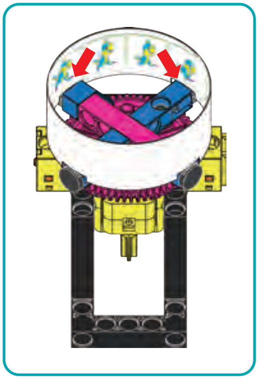


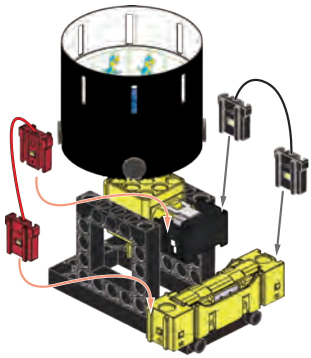


Use the film strip printed on the inside of the cylinder, or cover it with one of the other two film strips.

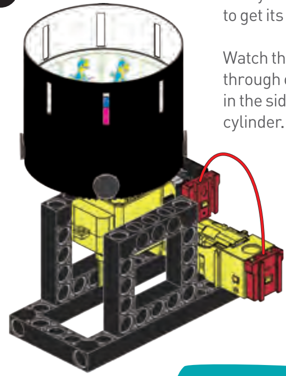


Align the notches in the film strip with the four button pins in the ends of the four rods.

6



7



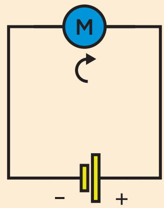
You might need to give the cylinder a little push to get its rotation started.

Watch the animation through one of the slits in the side of the spinning cylinder.

WHAT'S HAPPENING?

The circuit you built is actually the same as circuit 1. The battery powers the motor, which turns the cylinder. When your eye views the series of images through the slit, your brain blends them together and you perceive a single moving object. This is basically how animation and movies work!

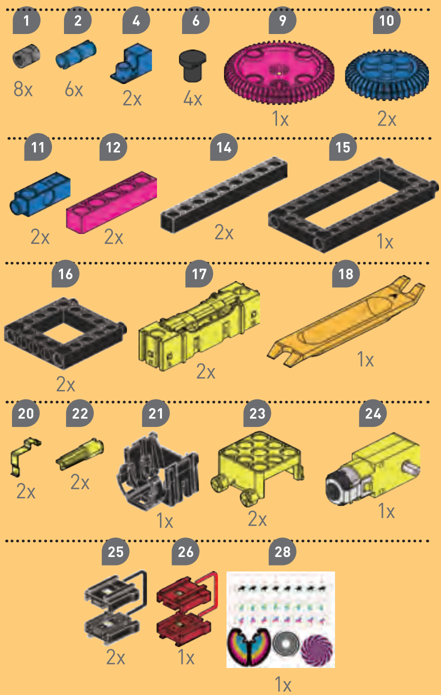
CIRCUIT DIAGRAM 16



Oh yeah!
It's the same as circuit 1 !

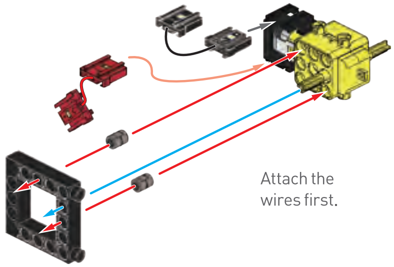
Additional ideas: Can you add a light to the circuit to light the movie? Can you change the gearing to make it spin slower or faster?

EXPERIMENT 17



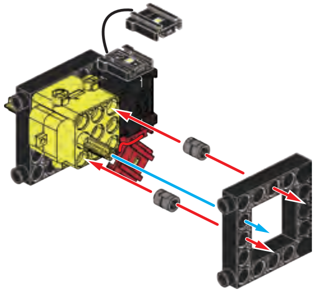
Walking Lion

1



Attach the wires first.

2



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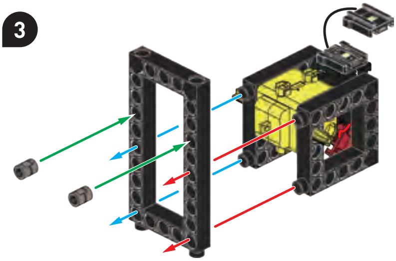
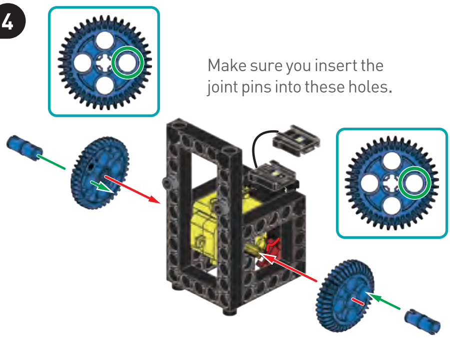
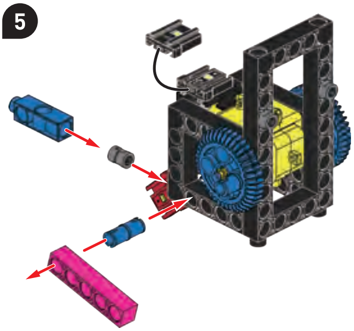


4



Make sure you insert the joint pins into these holes.

5



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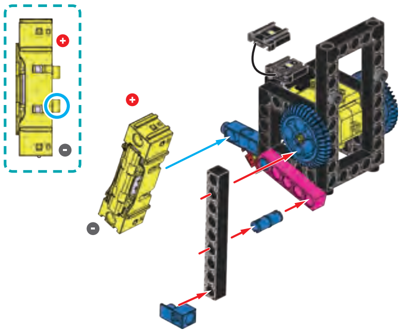
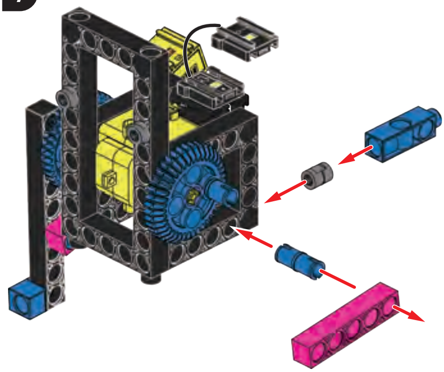


EXPERIMENT 17

7



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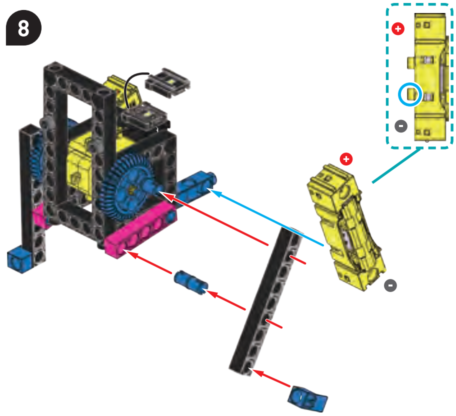

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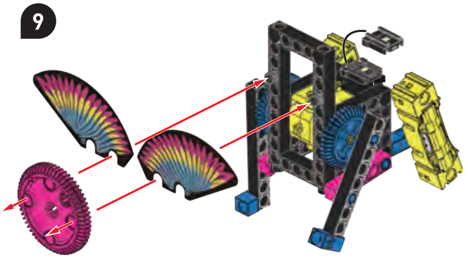

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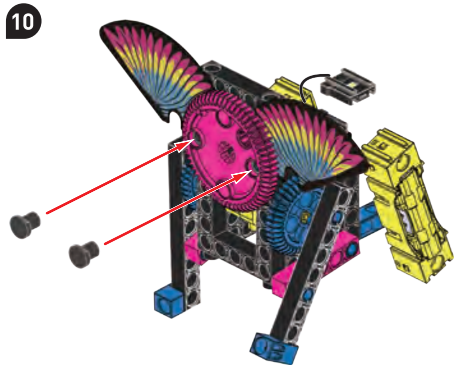

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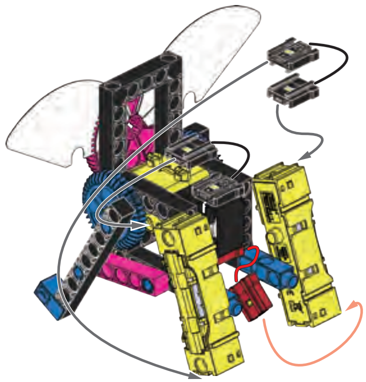
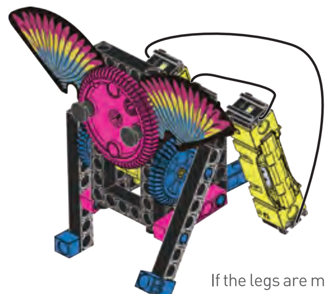


12

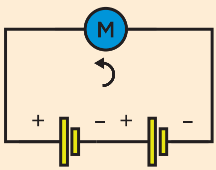


If the legs are moving in the wrong direction and your model is not walking forward, reverse the direction of the wires. See experiment 4.

WHAT'S HAPPENING?

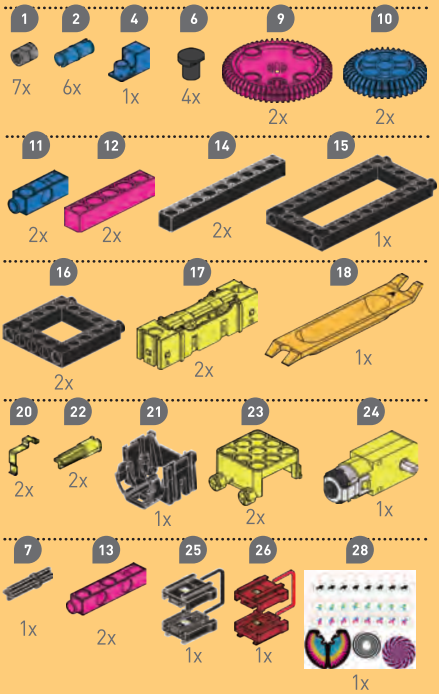
You built a model that uses the same circuit as in experiment 3 to power the motor. The motor turns the medium gear wheels, which move the legs back and forth. This causes the model to walk forward!

CIRCUIT DIAGRAM 17



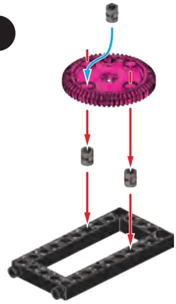
Neato!
It's the same as circuit 3!

EXPERIMENT 18



Flapping bird

1



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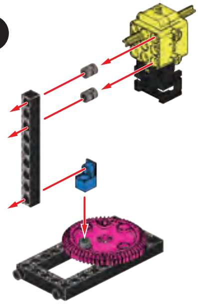

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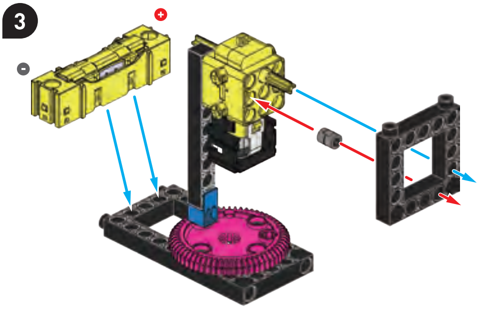

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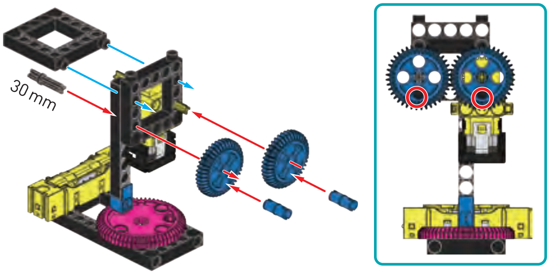

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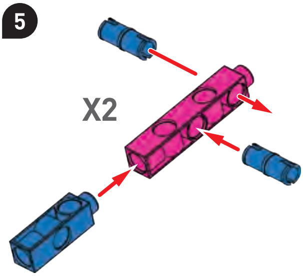

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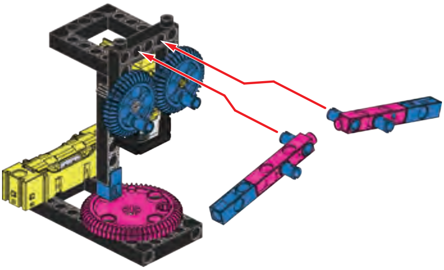

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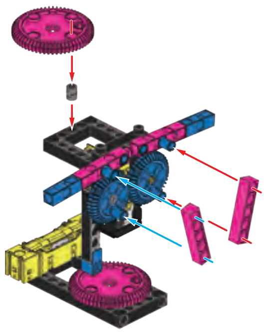

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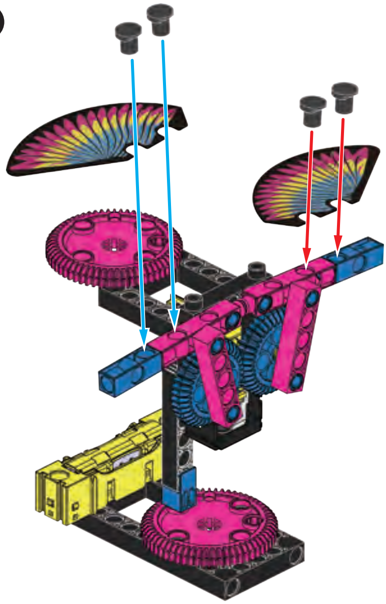

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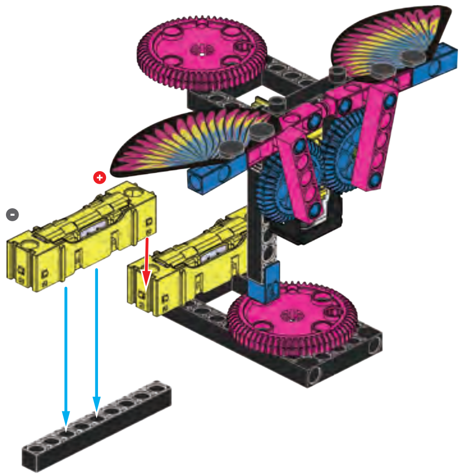

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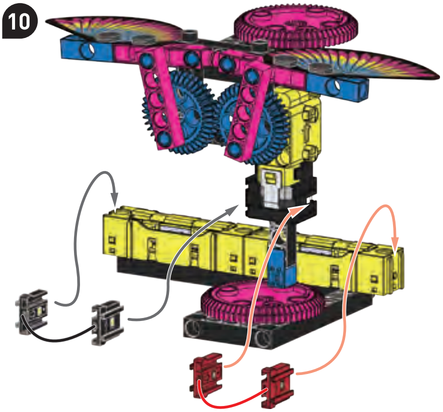
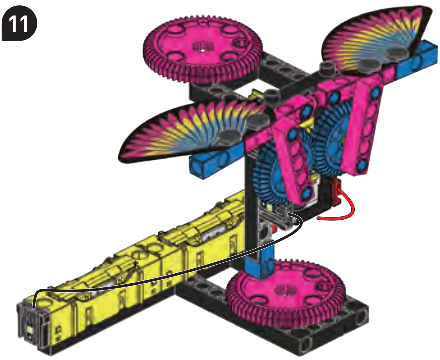


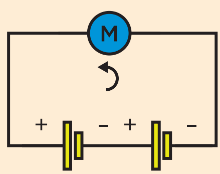
11



WHAT'S HAPPENING?

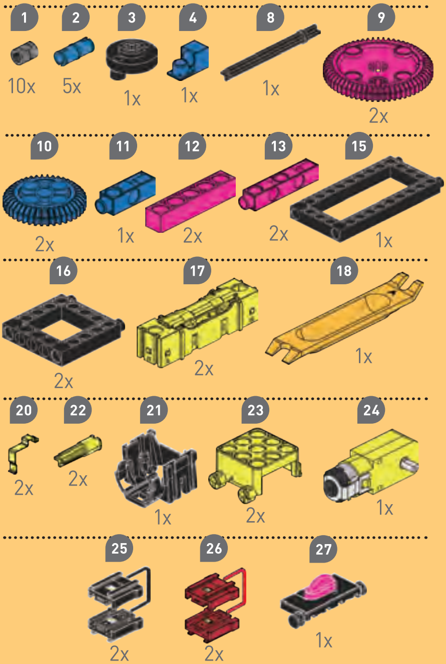
Again you used circuit 3 in a motorized device. This time, the batteries power the motor, the motor turns the gears, and the gears turn to make the wings flap up and down. The **cranks** attached to the gears convert the rotating motion of the gears into the up and down motion of the rods holding the wings.

CIRCUIT DIAGRAM 18



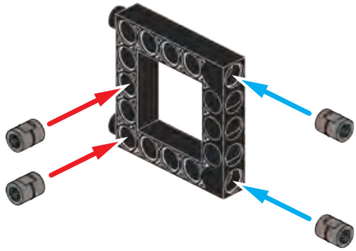
Neato!
It's the same as circuit 3 !

EXPERIMENT 19



Electric Car

1



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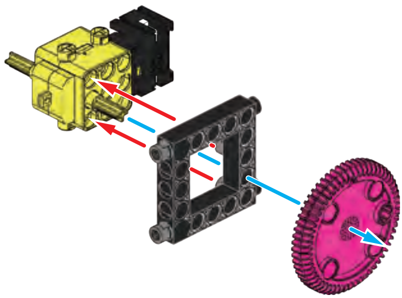

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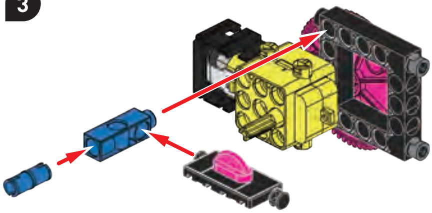

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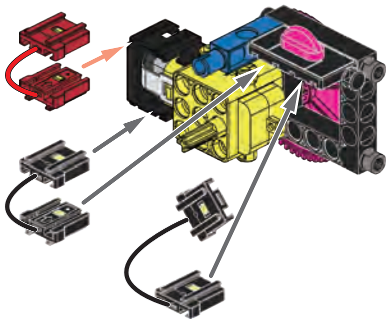

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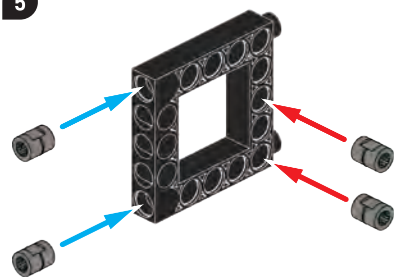

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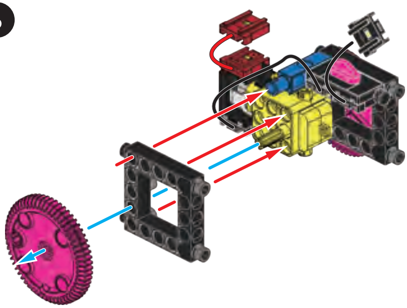
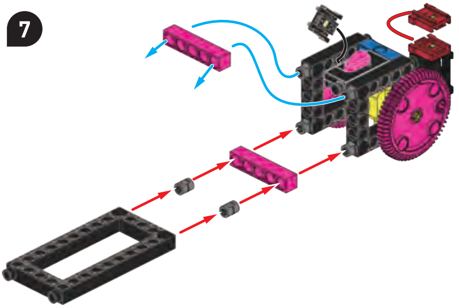


EXPERIMENT 19

7



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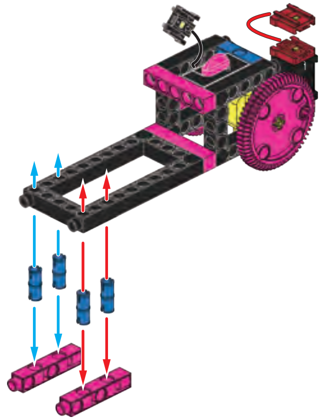

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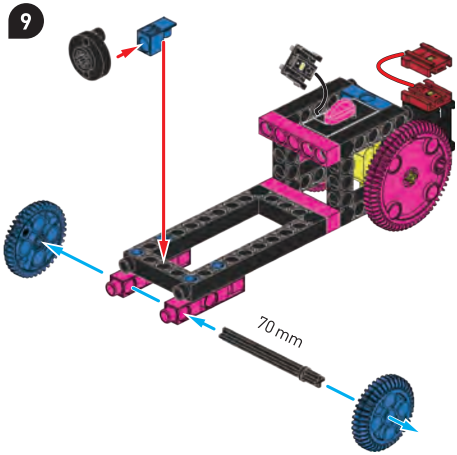

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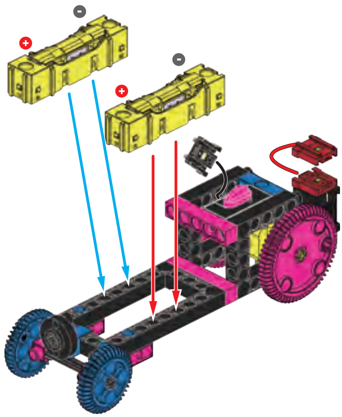

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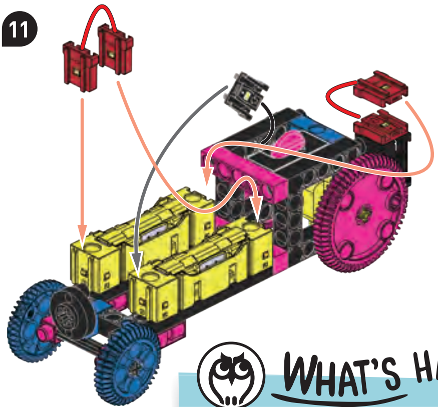

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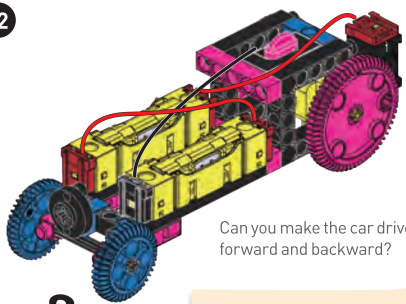
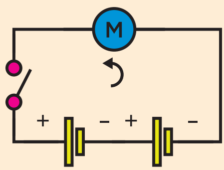


Can you make the car drive forward and backward?

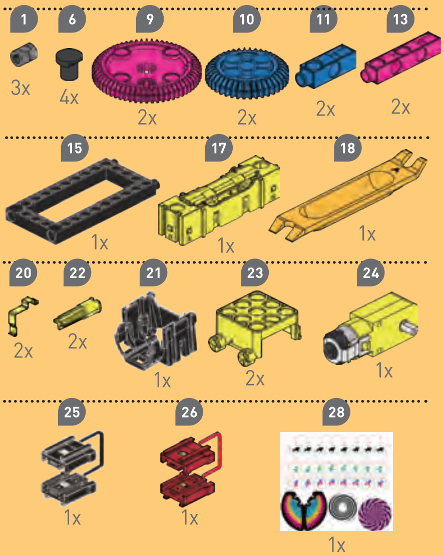
WHAT'S HAPPENING?

You built a new circuit with two batteries, a switch, and a motor to turn the wheels of a model car. When you turn the switch on, the car moves forward or backward, depending on the direction in which the wires are connected to the batteries.

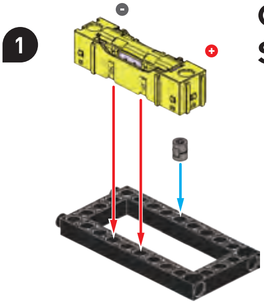
CIRCUIT DIAGRAM 19

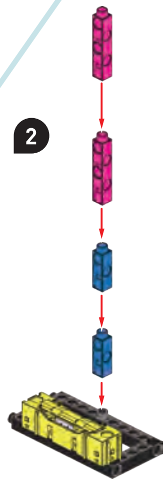


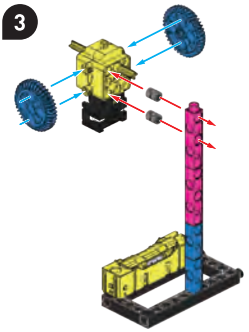
EXPERIMENT 20

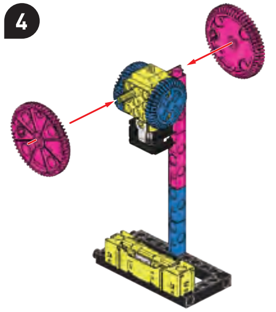


Optical Illusion Spinner

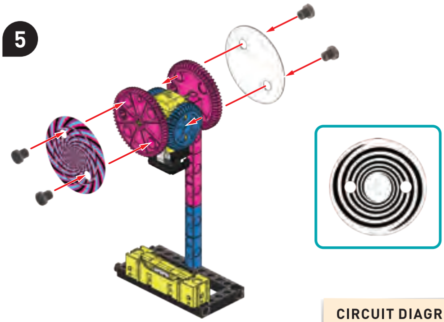


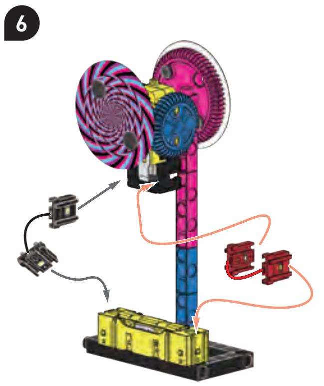


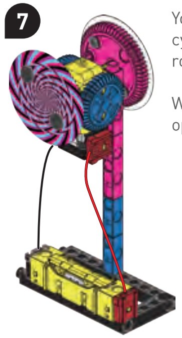




The shaft does not go through.



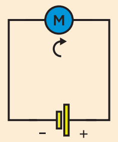




You might need to give the cylinder a little push to get its rotation started.

Watch the spinning disks. What optical illusions do you see?

CIRCUIT DIAGRAM 20



WHAT'S HAPPENING?

The motor makes the optical illusion disks spin. When you stare at the spinning spiral disk for a while and then look at another object, the object will appear to shrink or grow.

CHECK IT OUT

An exploded view of an electric motor

Who invented the electric motor?

The history of the electric motor started a long time ago. A lot of scientific knowledge and experience were needed before such a ground-breaking invention could even be conceivable to humankind.

It's impossible to name a single person who thought of the entire invention. As early as the 1740s, the British physicist Andrew Gordon and the American scientist Benjamin Franklin experimented with electrostatic motors. In the 1800s, dozens of inventors and scientists perfected the electric motor through countless experiments with electric current, magnets, and circuits.

As so often happens, each new discovery was the basis for further developments. No matter how you look at it, it was an exciting bit of technological history.

Motors 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 sectors of industry.

In transportation, electric engines were first used for electric trains. Recently, electric cars have started to gain popularity. Good reasons for using electric motors 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.

An electric car at a charging station

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Text and Editing: Ted McGuire
Layout: Mark Geary
Graphics: Dan Freitas
Additional technical support: Franckh-Kosmos Verlags-GmbH & Co. KG (Kosmos), Stuttgart, Germany

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