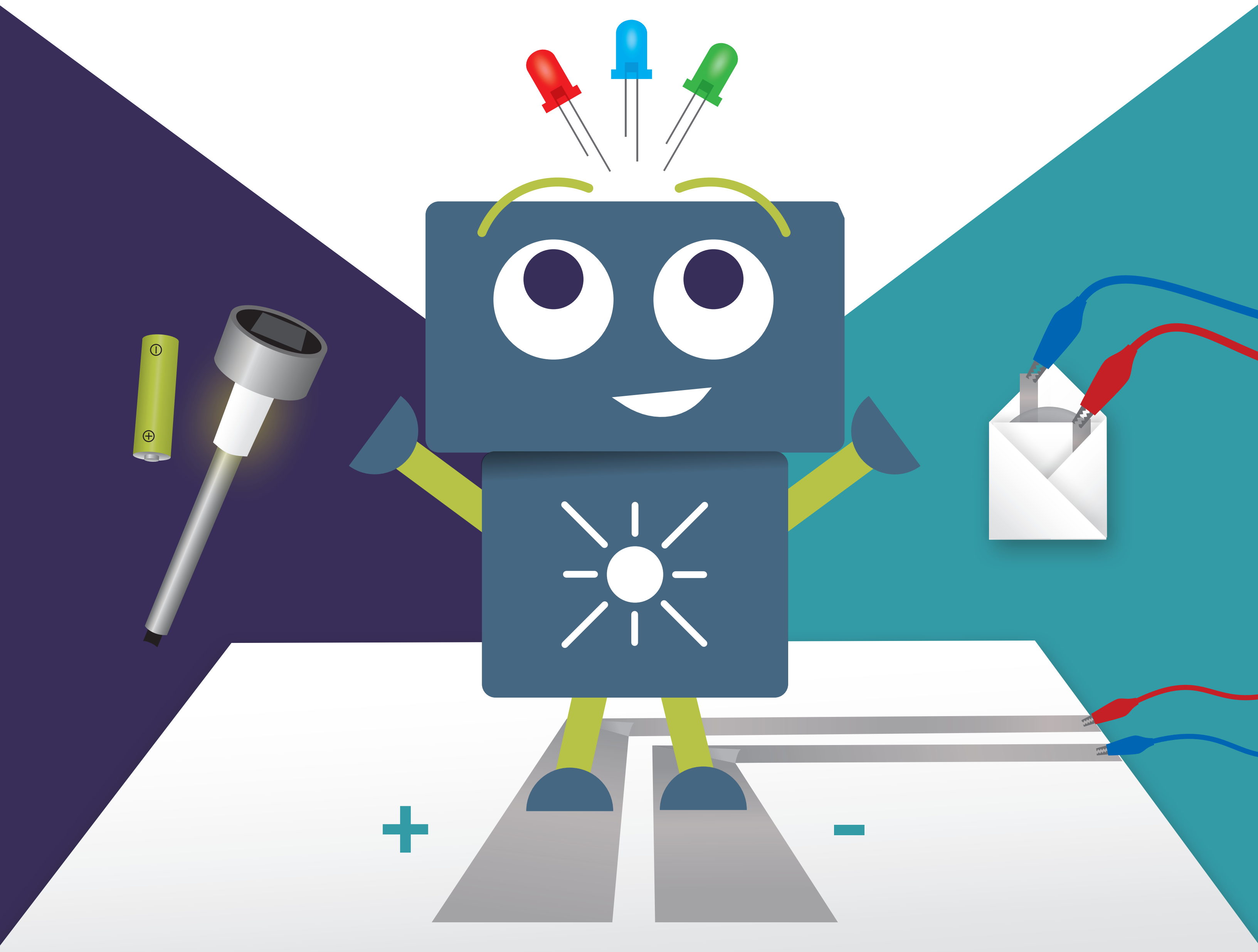
A creative and innovative way for young engineers to explore circuitry

NATIONAL PEER REVIEWED

#1 EXPLORE A POWER PARK:

PAPER CIRCUITS



The activities in this book offer a hands-on introduction to electric circuits using LEDs and conductive tape. The pages are full of opportunities for exploration and challenge young designers to problem-solve and think creatively and critically. Power engineers spend their careers making electricity available to people all over the world and report a thrill every time the lights come on. We want this same thrill, literally and metaphorically, to inspire the next generation of scientists, engineers, and makers.

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ACKNOWLEDGEMENTS

We love to tinker. We thank all of the creative individuals and groups who have brought tinkering into homes and classrooms through more accessible materials, supplies, and activities. We have been inspired by the work done by educators and makers at Adafruit, SparkFun, the Exploratorium, the MIT Media Lab and High-Low Tech group, Chibitronics, the 21st Century Notebooking group, and by many teachers and students who are lighting things up.

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FOR THE FACILITATOR

This circuity curriculum offers a hands-on introduction to electric circuits using LEDs and conductive tape. The pages are full of opportunities for exploration and challenge young designers to problem-solve and think creatively and critically. The activities are meant to ignite a young person's curiosity and imagination, opening the mind to new possibilities and moving him or her to play, tinker, and explore.

Short tutorials and background information accompany puzzles and challenges. The activities build on each other and are designed to allow youth to learn by doing. Each curriculum book becomes a completed workbook full of solved puzzles, met challenges, and creative light-up projects.

As a facilitator of these projects, encourage youth to use their troubleshooting and problem-solving skills and to learn from every situation. Even when there is a "power outage" there is something to be learned. The activities have been designed to promote creative design and encourage empowered learners. The materials offer opportunities for collaboration and encourage redesign.

This curriculum was written for youth in Grades 4-9, but may be used and adapted for younger and older audiences, based on experience.

Each book in the **Power Park** series was written using the International Society for Technology in Education (ISTE) Standards for Students, Next Generation Science Standards (NGSS), and Common Core State Standards (CCSS) for Mathematical Practice as guidance.

STANDARDS EXPLICITLY ADDRESSED:

ISTE Standards For Students:

Innovative Designer

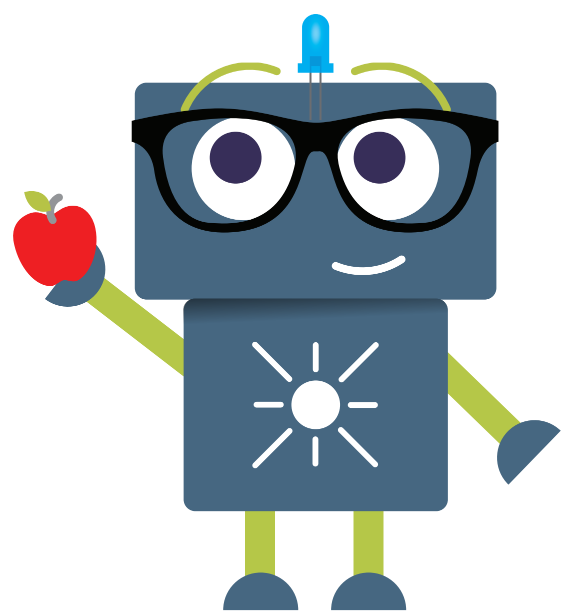
- Students develop, test and refine prototypes as part of a cyclical design process.
- Students exhibit a tolerance for ambiguity, perseverance and the capacity to work with open-ended problems.

NGSS Science and Engineering Practices

- Asking questions *(for science)* and defining problems *(for engineering)*
- Planning and carrying out investigations
- Using mathematics and computational thinking
- Constructing explanations *(for science)* and designing solutions *(for engineering)*
- Obtaining, evaluating, and communicating information

CCSS for Mathematical Practices

- **MP1:** Make sense of problems and persevere in solving them.
- **MP2:** Reason abstractly and quantitatively
- **MP6:** Attend to precision



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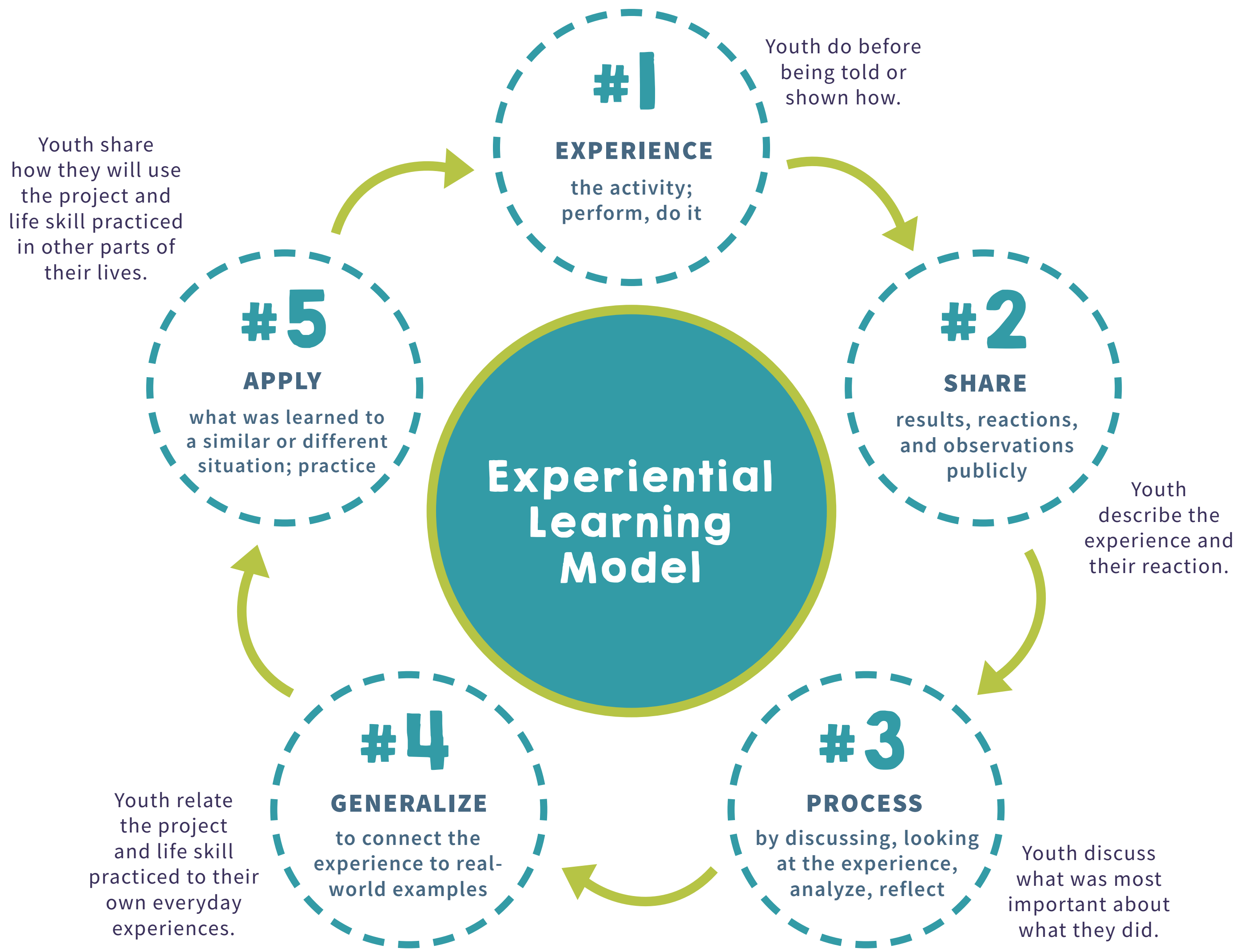
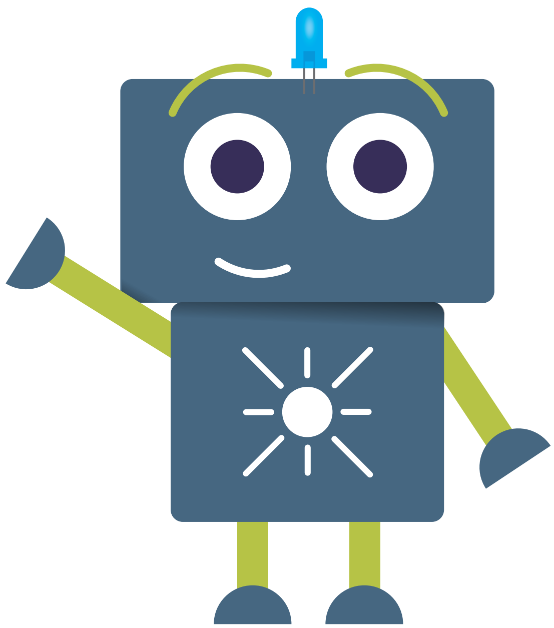
EXPERIENTIAL LEARNING

The **Experiential Learning Model of Instruction** provides learners an opportunity to become familiar with the content (**Experience**), explore a deeper meaning of the content (**Share and Process**), connect the learning to other examples or opportunities (**Generalize**), and apply it in real world situations.

The facilitator will guide youth through this process by helping them to focus on the activities, provide support and feedback for the learning, and debrief with them about their learning experience: what went well, what they could have done differently, what they could do next. This debriefing process fits hand-in-glove with the engineering design process used throughout the curriculum.



WELCOME TO THE PARK



USING THIS BOOK

Welcome to the Power Park! I'm the friendly neighborhood robot.

This is an interactive workbook designed to give you a hands-on experience as you follow along. Use the pages of this book for writing, taping, cutting, drawing, creating, and more!

- Describe your explorations.
- Record your thinking.
- Jot down your questions.
- Challenge what you've learned.
- Create your own projects!

Create circuits in the blue dotted boxes.

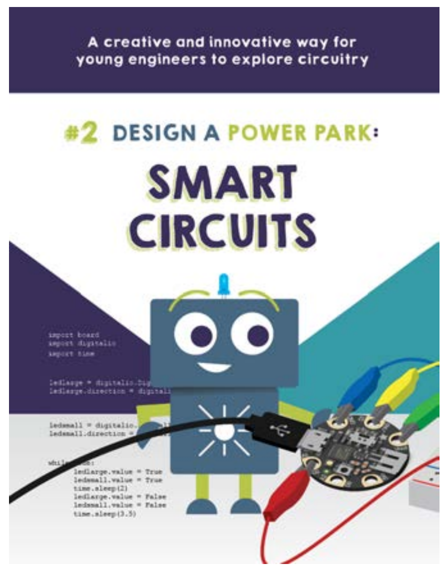
Jot down notes and thoughts in the gray dotted boxes.

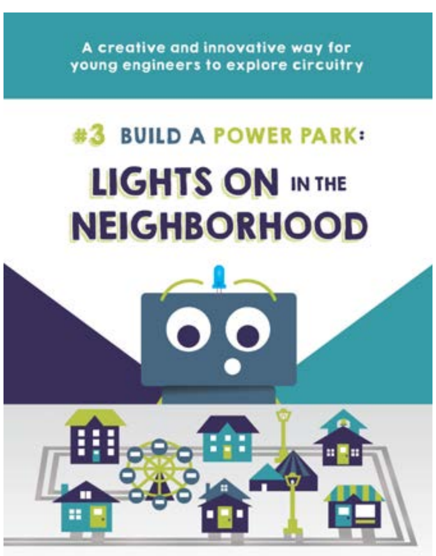
Pay attention to what the green boxes say!

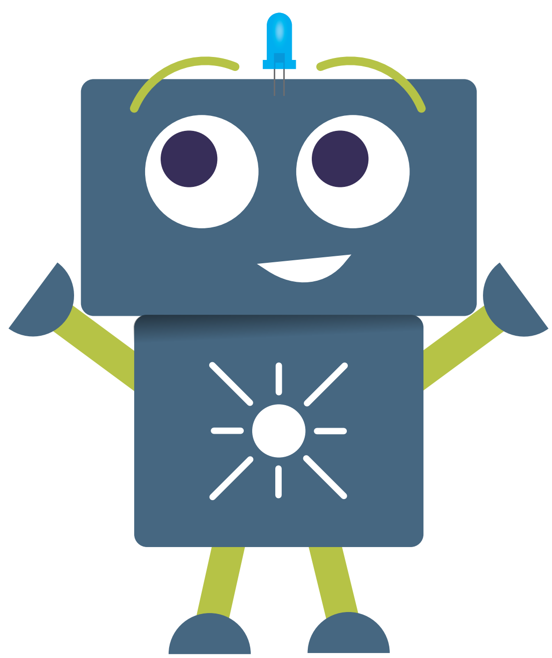
Find interesting challenges in the blue boxes!

ABOUT THE POWER PARK SERIES

This series of three **Power Park** books provides opportunities to explore electrical circuits, power systems, sensors, coding, and microcontrollers. ***Explore a Power Park: Paper Circuits*** is an interactive notebook for investigating conductive tape circuits and alternative power sources. ***Design a Power Park: Smart Circuits*** introduces coding, microcontrollers, and sensors to circuitry projects. ***Build a Power Park: Lights On in the Neighborhood*** adds motors and controls to a three-dimensional neighborhood concluding with a carnival ride design challenge. These books invite you to create, explore, investigate, and tinker as you use science and engineering design to meet a series of challenges.

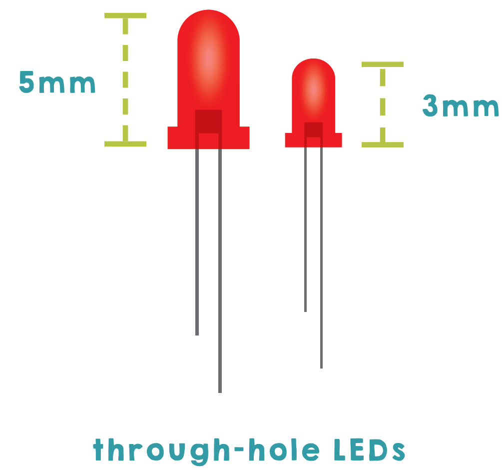






CHOOSING AN LED TYPE

LEDs can be found in a variety of packages of varying shape and size. The part that emits light is very tiny and is enclosed in a case or lens. The case can be clear or colored. Through-hole LEDs have legs that can fit through holes in a breadboard or printed circuit board and come in different sizes. Surface mount LEDs are much smaller and have pads instead of legs.

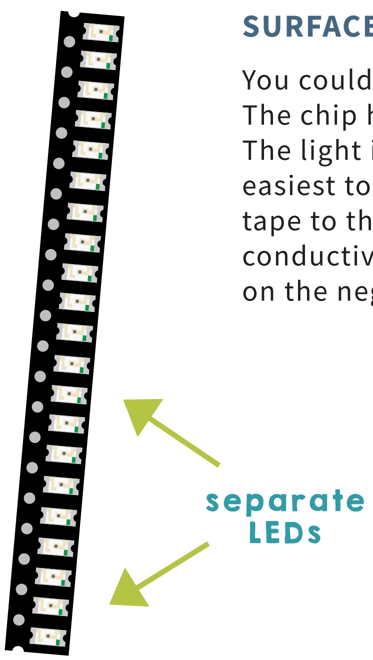


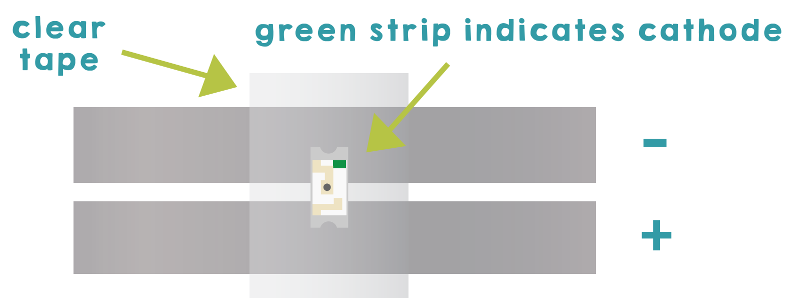
THROUGH-HOLE LEDS

Most of the projects in this book show 3mm through-hole LEDs. This size is big enough so that you can place the LEDs in your projects with your fingers, but small enough so that the pages of your book won't be too lumpy after creating your projects.

SURFACE MOUNT LEDS

You could also use surface mount LEDs (SMD LEDs) in any or all of the projects. The chip holding the LED is a small rectangle with copper pads on the ends. The light is bright and they barely rise above the page in your book. It's easiest to place these in a project using tweezers. You can also stick clear tape to the top and hold the tape to place it. Just remember to place the conductive tape strips close together, but not touching, so one copper pad is on the negative trace and the other is on the positive trace.





CIRCUIT STICKERS

Circuit stickers are another option. These are SMD LED circuits pre-mounted on stickers with larger copper pads that you can place in a project with your fingers. These LED stickers are easy to use, but they are more expensive than the other options.

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NOTES

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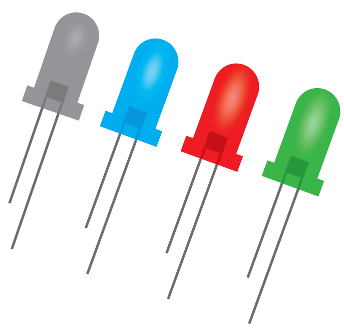
Circuits with LEDs

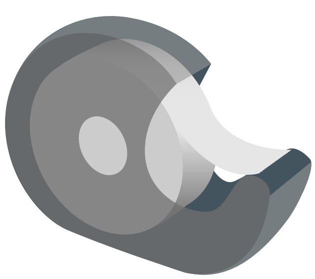
MATERIALS NEEDED

Scissors



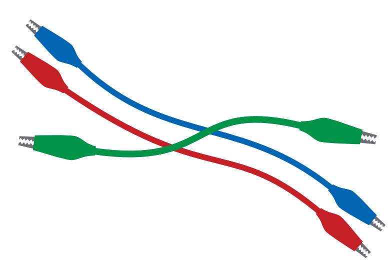
LEDs

Roll of Conductive Tape



Clear Tape

2 Coin Cell Batteries



3 Alligator Clip Test Leads

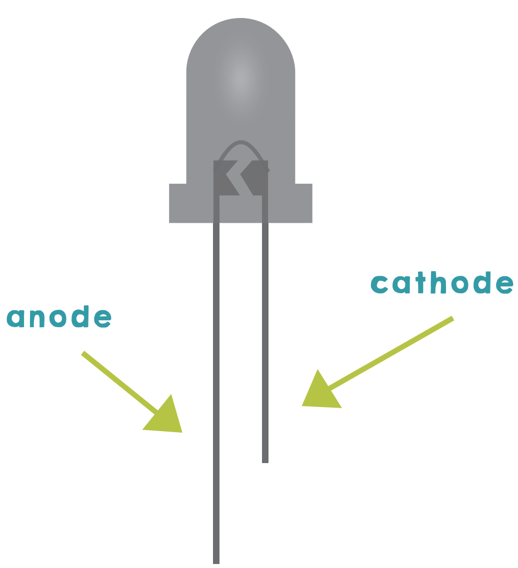
EXPLORING LEDs

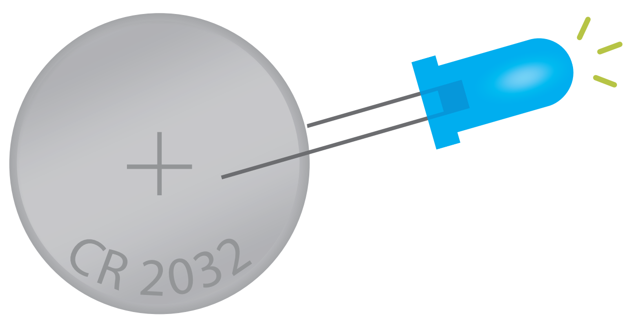
Light up this book with LEDs! Inside a light emitting diode (LED) is a tiny two-layer crystal. Two semiconductor materials are layered together so that electrons can flow in only one direction. When a power source pushes electrons through the layers of the crystal, they release energy that we see as colored light. The color of light we see is determined by the type of semiconductor material that makes up the LED crystal.

In this book, we use LEDs to shed some light on our understanding of circuits, and illuminate our pages in color!

POWERING AN LED

A battery stores energy and pushes it through a circuit when there is a path between the positive and negative terminals (sides). Let's create a path through the LED to see it light. Touch the **anode** (longer leg) to the positive (+) side of the coin cell battery and the **cathode** (shorter leg) to the negative (back) side of the battery.





LEDs are diodes and diodes have polarity, which means current flows through the diodes in only **one** direction. This is why we make sure the anode touches the positive side of the battery and the cathode touches the negative.

What happens when the anode touches the negative and the cathode touches the positive? *(Answer: nothing lights up!)*

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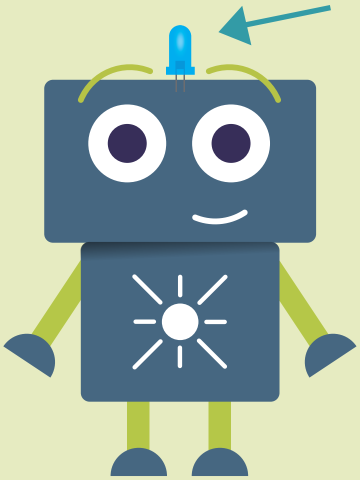


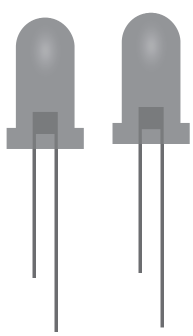
ABOUT LEDS

LEDs don't create much heat so they are more efficient and last longer than traditional light bulbs. You see them as indicator lights on appliances and your electronic devices. LEDs are used to light supermarket freezer sections, streetlights, traffic lights, automobile taillights, and outdoor signs like the giant signs in Times Square in New York City.

The first visible light LED was red. It was developed by Nick Holonyak, Jr and demonstrated on October 9, 1962 at General Electric. In 1963, Holonyak returned to his alma mater, the University of Illinois, as a professor. One of his students, M. George Craford, went on to create the first yellow LED in 1973. Over the years other colors followed with the first patent for a blue LED issued in 1991. In 2014, the Nobel Prize in Physics was awarded to three scientists for their work on the blue LED.

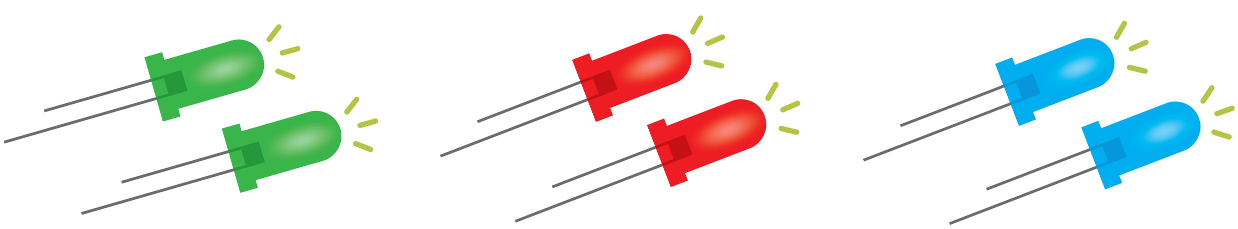
COLOR SORT LEDS

Some LEDs may have clear cases and others may have colored cases. Use a coin cell battery to determine the colors of clear-cased LEDs.



1. Gather any clear LEDs to determine their colors.

2. Connect each LED to the coin cell battery one by one.

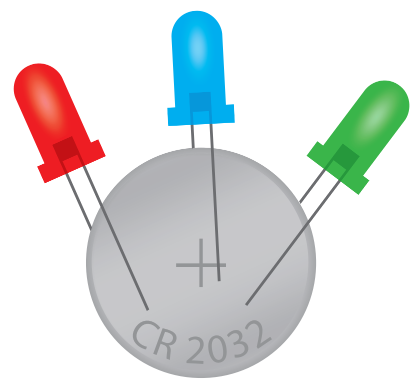


3. Organize the clear LEDs by their light color.

POWERING MORE THAN ONE LED

Connect several LEDs of the same color to a battery at the same time. How many blue LEDs can you light at one time? How many green? How many white or red?

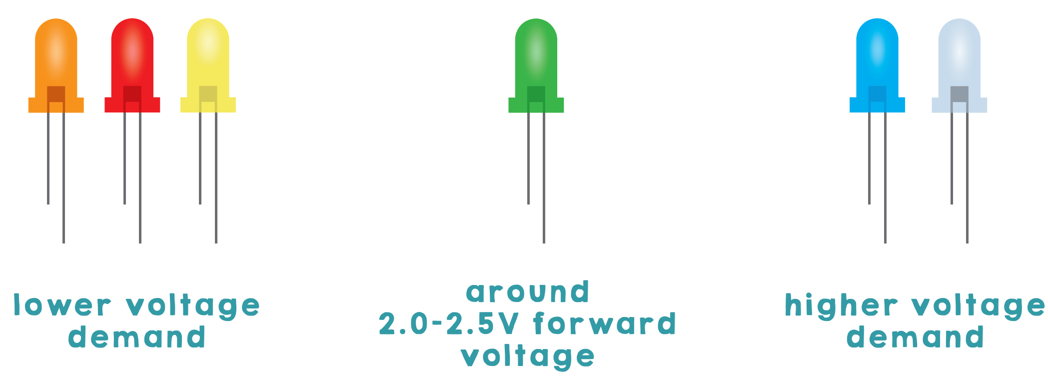
Connect different colored LEDs to a battery at the same time.



In which color combinations do all of the LEDs light? In which color combinations do some or all of the LEDs not light?

Different LEDs need different amounts of power to light. This depends on the LED color and how it is manufactured. The manufacturer usually includes information about how much voltage and current is needed to make the LED light.

The information for a typical green LED reads, **2.0-2.5V** Forward Voltage, at **20mA** current. The voltage demand is usually lower for red, orange, and yellow LEDs and higher for blue and white.



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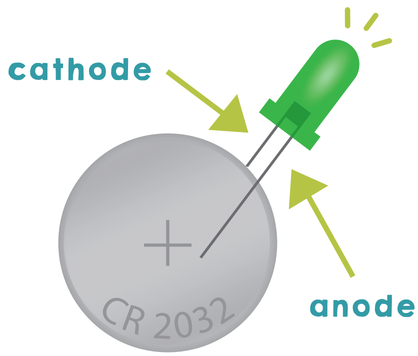
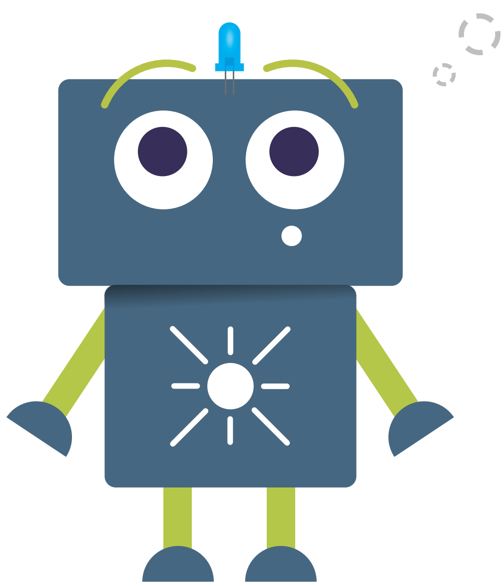
LED **forward voltage** is a measure of the battery pressure needed to move current forward through the diode from the anode to the cathode.



The **3V** CR2032 coin cell battery has enough voltage to light an LED and not so much that the LED could burn out.

How might these differences in voltage demand explain what you see when you connect several LEDs to a battery?

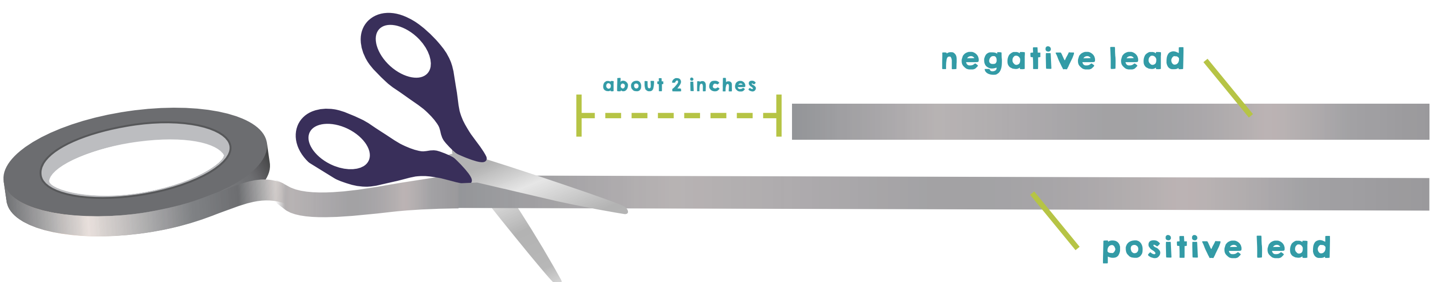


CONDUCTIVE TAPE

Let's connect! Conductive tape is metal foil tape or metal-infused fabric tape. Metals are good conductors of electricity. That means the metal in this tape allows current to move through it when the tape is part of a complete electric circuit. Conductive tape makes it easy to create circuits on paper because it's sticky on one side and conductive on the other. The illustrations in this book show nylon conductive tape, which is also conductive on the sticky side. Conductive tape circuits are functional and look cool!

USING CONDUCTIVE TAPE TO CREATE CIRCUITS

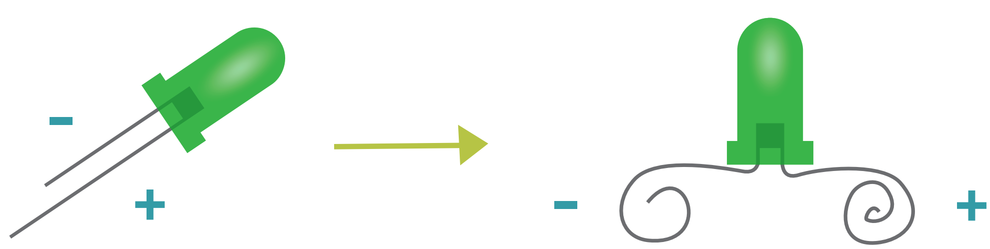
1. Place a strip of conductive tape along the line inside the blue dotted box below. Peel off the white backing and stick the tape to the page. Place a battery on the strip with the positive side facing up so that the strip is touching the negative side.
2. Without taping it down, cut a second piece of conductive tape about 2 inches longer than the first strip.



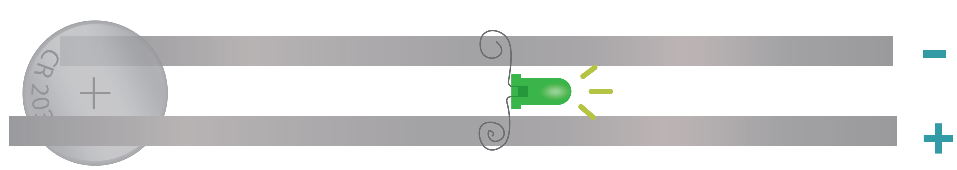
3. Starting from the right, begin placing the second strip of conductive tape about half an inch below the first. Stop and cut the tape just past the battery as shown.

4. About an inch from the battery, fold the conductive tape sticky-side-to-sticky-side so that the non-sticky side of the tape touches the positive side of the battery.

5. Use fingers to bend each leg of an LED so that more of each LED leg touches the conductive tape. The shape of the bend isn't important, as long as it increases the LED leg's surface contact with the tape. Be sure to remember which leg of the LED is longer. We'll show the anode as the **tightly wound** leg, and the cathode as the **loosely wound** leg.



6. Attach the LED on top of the conductive tape. Make sure that the cathode is touching the negative lead conductive strip and that the anode is touching the positive lead. Tape the LED legs down so they are secure. Press on the positive lead to see the LED light up!



TIP: Peel away a small (1/2 inch) piece of the white backing on the conductive tape roll. Cut a tiny piece of conductive tape off the roll leaving the white backing on the roll. Leave a little backing on the roll so next time it won't be so hard to peel the backing away.

EXPLORING CONDUCTIVE TAPE CIRCUITS

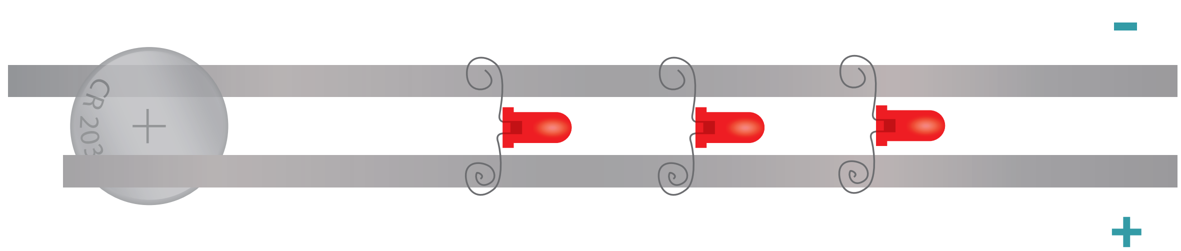
Practice creating and observing paper circuitry with these conductive tape circuit puzzles!

CONDUCTIVE TAPE CIRCUIT PUZZLE #1

Place conductive tape and a battery in the blue dotted box below. Add the red LEDs one at time.

Do all three LEDs light? Do the LEDs get brighter or dimmer when adding more? Can there be more than three?

Predictions:



Observations:

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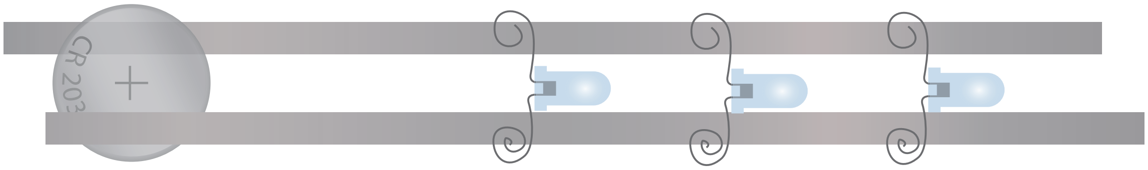
CONDUCTIVE TAPE CIRCUIT PUZZLE #2

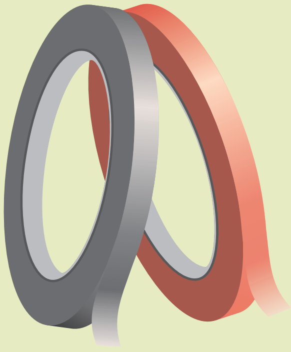
Place conductive tape and a battery in the blue dotted box below. Add white LEDs one at time.

Do all three LEDs light? Do the LEDs get brighter or dimmer when adding more? Can there be a fourth LED?

Predictions:



Observations:



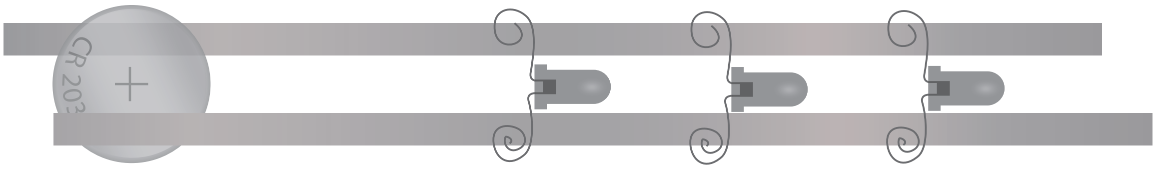
TYPES OF CONDUCTIVE TAPE

The circuit diagrams in this book use **nylon** conductive tape, but there are other kinds of conductive metal foil tape to use such as **copper** and **aluminum**.

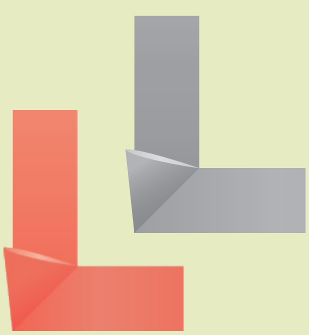
Each type of tape has its own advantages and disadvantages in terms of conductibility and ease of use. Copper and aluminum tape are usually conductive on one side, whereas nylon tape is conductive on both sides.

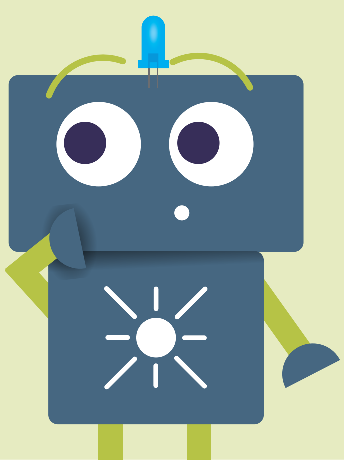
CONDUCTIVE TAPE CIRCUIT PUZZLE #3

Place conductive tape and a battery in the blue dotted box below. Add LEDs of **different** colors so that all light.



What do you see? What are you curious about? What combinations work? What did you try?



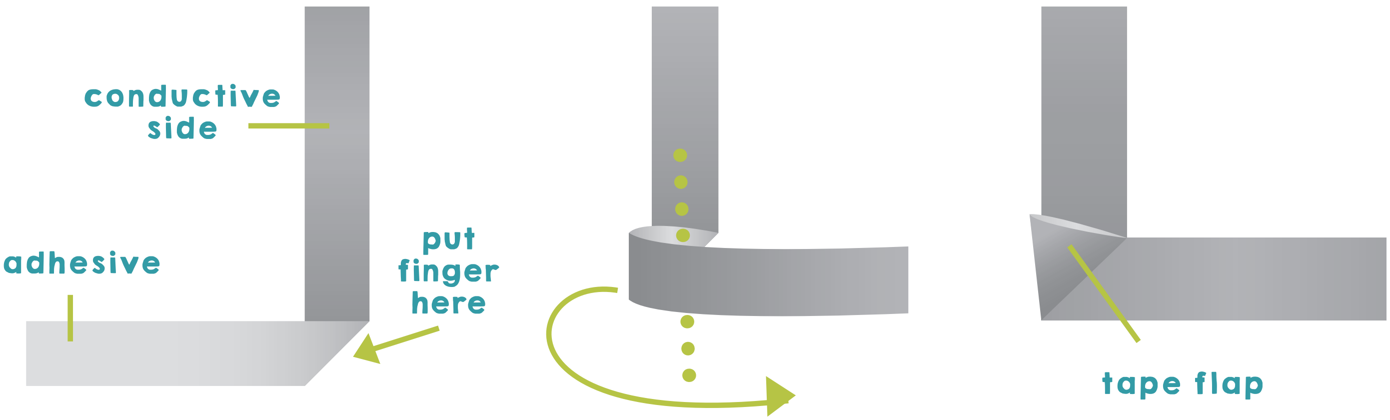


When using **copper** or **aluminum tape**, fold your tape when turning a corner. Don't cut the tape, or you'll lose conductivity!

When using **conductive nylon tape**, you're able to cut up pieces and tape them together without losing conductivity.

TURNING CORNERS WITH CONDUCTIVE TAPE

Place conductive tape and a battery in the blue dotted box below. Turn corners with conductive tape without cutting the tape.



1. When folding a corner, pull the tape in the opposite direction you want to turn. Put your finger on the diagonal.

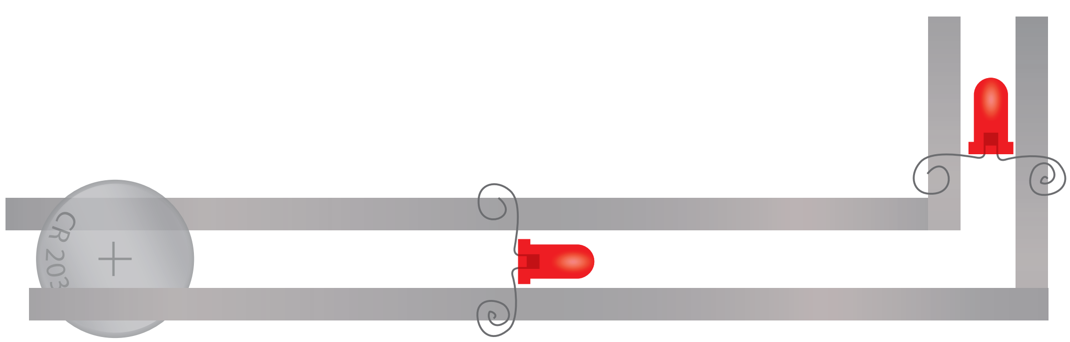
2. Pull the tape over your finger to the direction you want to turn. Remove your finger and press down the corner.

3. When you're done, you'll have a small triangular flap with copper on both sides and a folded corner.

CONDUCTIVE TAPE CIRCUIT PUZZLE #4

Place conductive tape and a battery in the blue dotted box below. Turn corners with conductive tape without cutting the tape.

Add LEDs so that they all light.



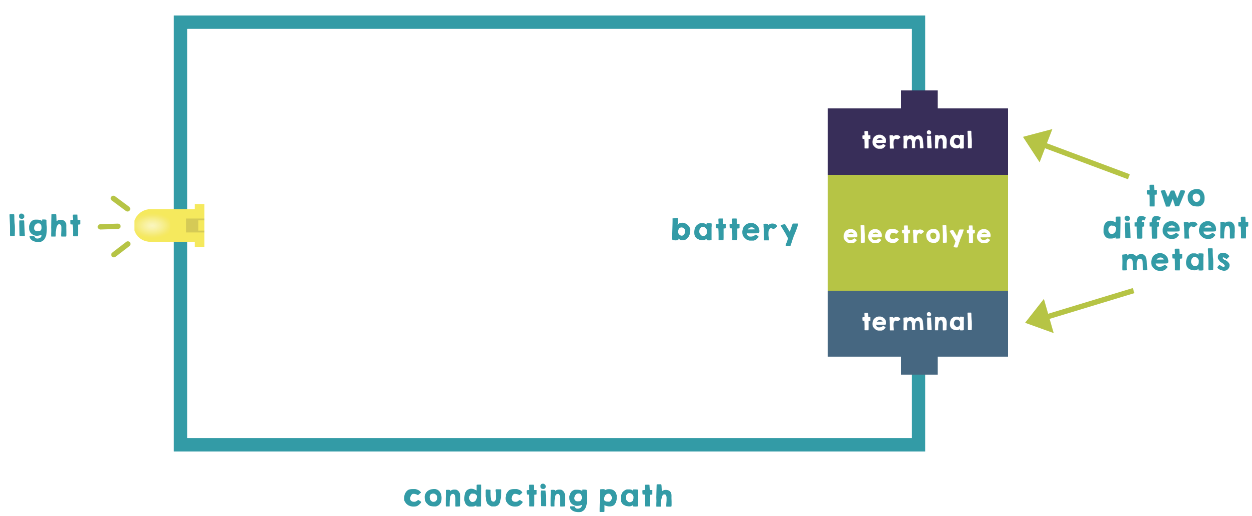
NOTES

BATTERIES & CIRCUITS

Let's give it some juice! As we explore more circuit activities and use more LEDs, the batteries we use can restrict the number or types of LEDs we can use in our circuits. In this section, we'll investigate the relationship between coin cell batteries and different types of circuits. We're going to start off using a coin cell battery, a paper holder, and alligator clips that allow us to easily switch power sources.

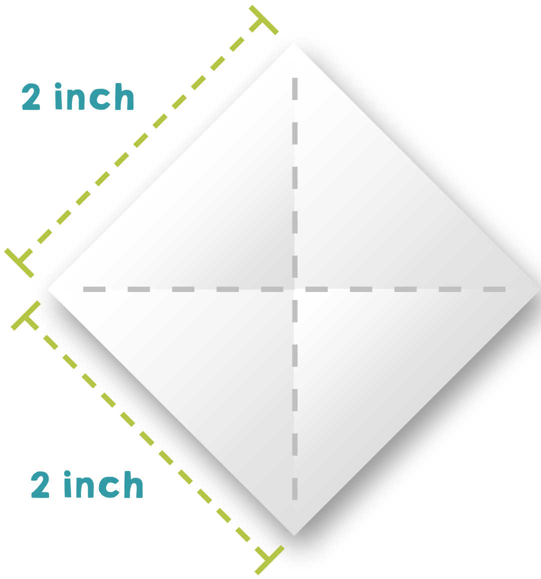
WHAT IS A BATTERY?

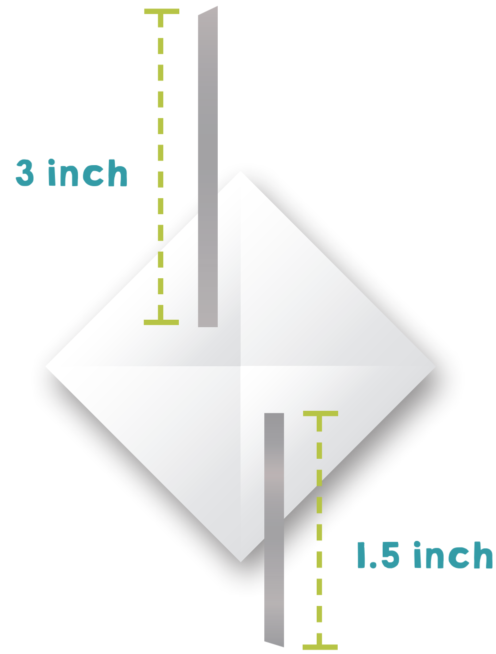
Batteries store energy in a chemical form. There are many different shapes and sizes, but all batteries have the same three basic parts: two terminals (also called electrodes, made up of two different types of metal) and an electrolyte (a liquid or a gel) between them. The electrolyte chemically reacts with the metals, releasing extra electrons at one terminal, which causes the electrons to flow to the other terminal. When there is a conducting path between the two terminals, current flows!



CREATING A BATTERY HOLDER

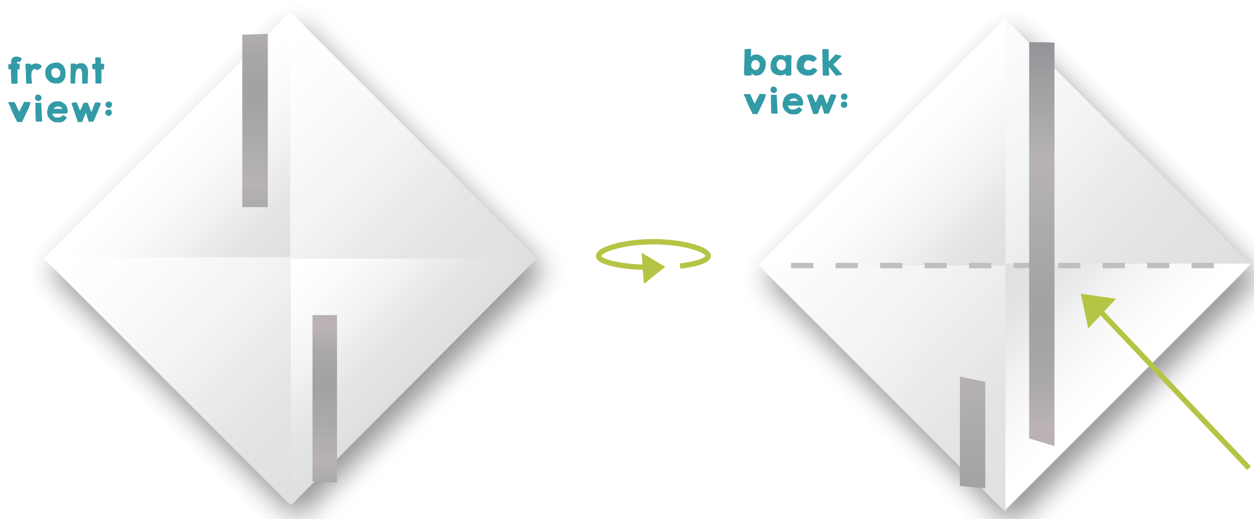
Create a paper holder for the coin cell battery. Attach alligator clips to conductive tape on the holder and power your circuits.





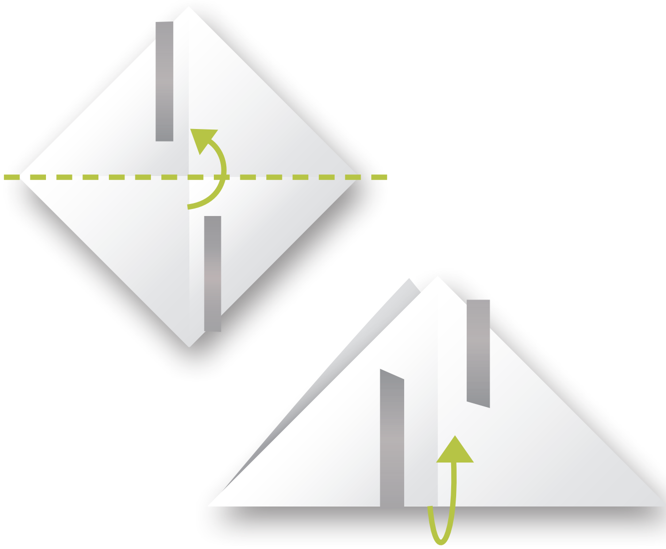
1. Cut out a 2x2 inch piece of paper or use a 2x2 inch sticky note. Rotate it so that it looks like a diamond, and fold in half twice diagonally as shown.

2. Cut two pieces of conductive tape, one 1.5" long and one 3" long. Place these pieces of tape on opposite sides of the center fold, but close to the center.



3. Fold excess tape onto the back of the paper. Flip the piece of paper around to make sure that the longer piece of tape reaches past the horizontal fold along the back.

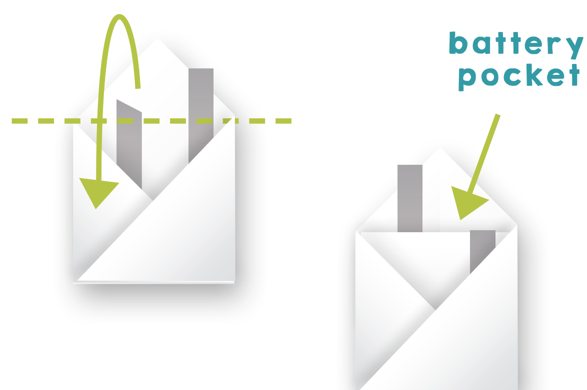
Flip the paper around to the **front** before moving on to step 4!



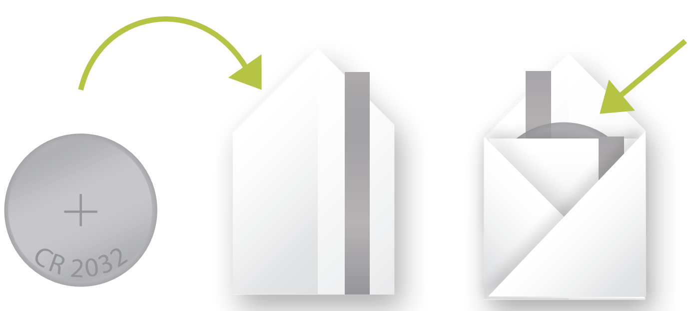
4. Fold in half on the horizontal fold line.

5. Measure and draw vertical fold lines on each side 1/2” from the center line. Fold the right corner over.

6. Notice that the folded right corner creates a pocket. Open up the right corner, fold the left corner over, and fit the left corner **inside** the right corner.

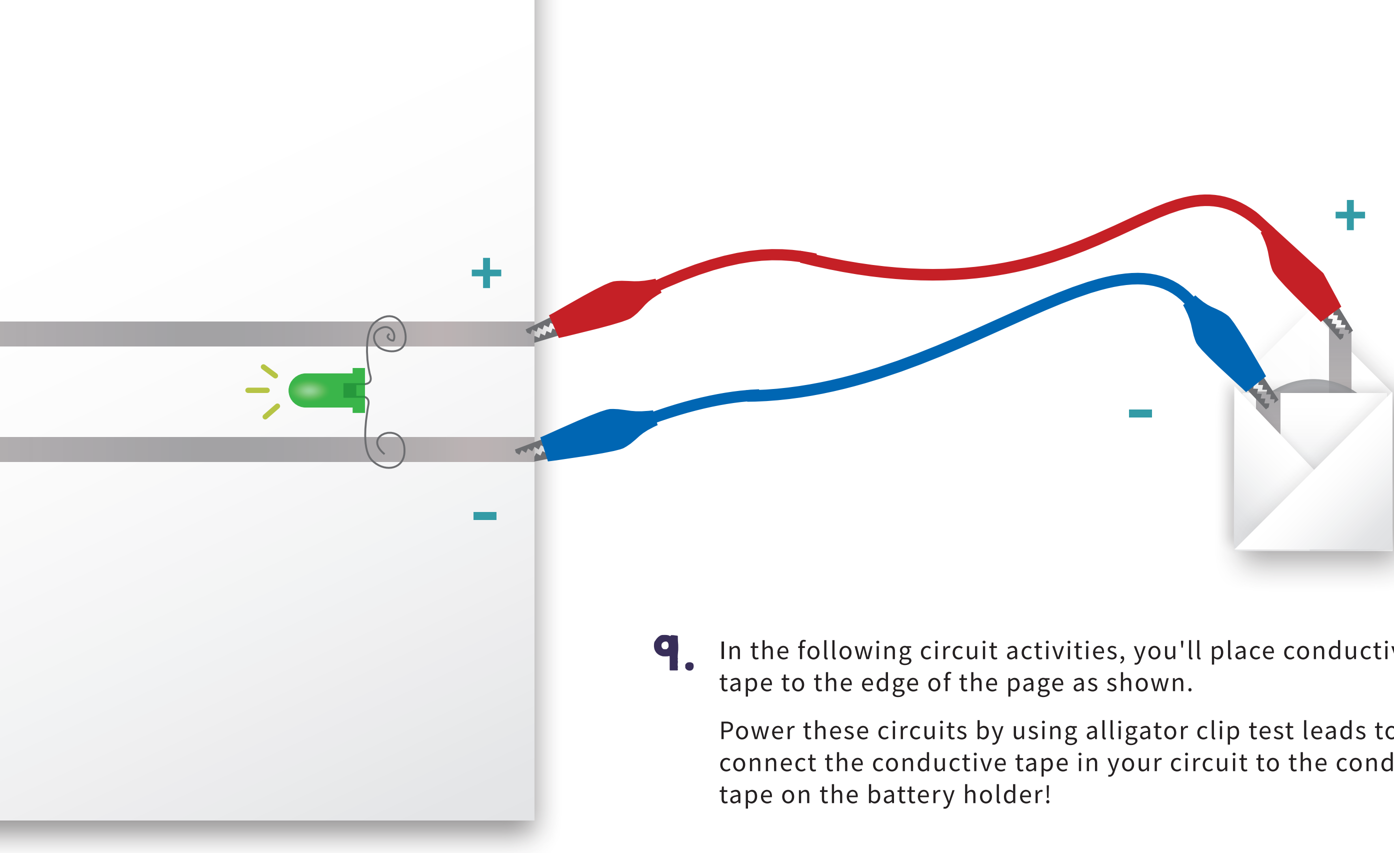


7. Fold the tip of the first layer of paper over the green dotted line and into the folds along the bottom. This creates a pocket for the battery.



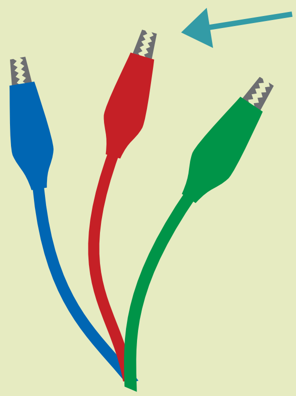
place battery **negative** side up

8. Place the battery into the battery holder **negative side up** so that the negative side of the battery is touching the front layer of paper folded down in step 7.



9. In the following circuit activities, you'll place conductive tape to the edge of the page as shown.

Power these circuits by using alligator clip test leads to connect the conductive tape in your circuit to the conductive tape on the battery holder!



USING ALLIGATOR CLIPS

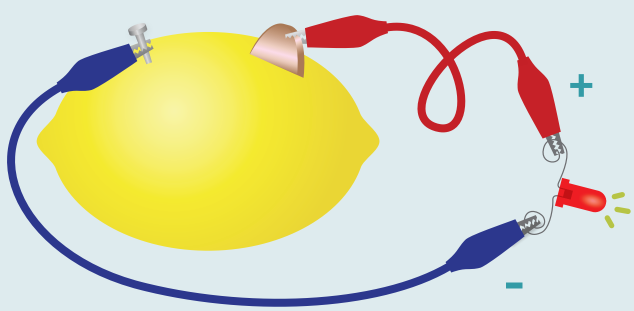
Alligator clip test leads allow us to connect different parts of a circuit easily. These are just wires with clips that look like alligator teeth on each end. The colors of the outer insulation make it easy to organize your circuit. It's customary to use red to designate positive leads (wires) and black and blue are often used for negative leads.

The alligator clips can easily attach to our conductive tape circuits and connect them to different power sources or other circuits.

CHALLENGE

Create a battery with a penny, a galvanized nail, and a lemon (or a cup of vinegar) as shown.

How many lemons are needed to light an LED?

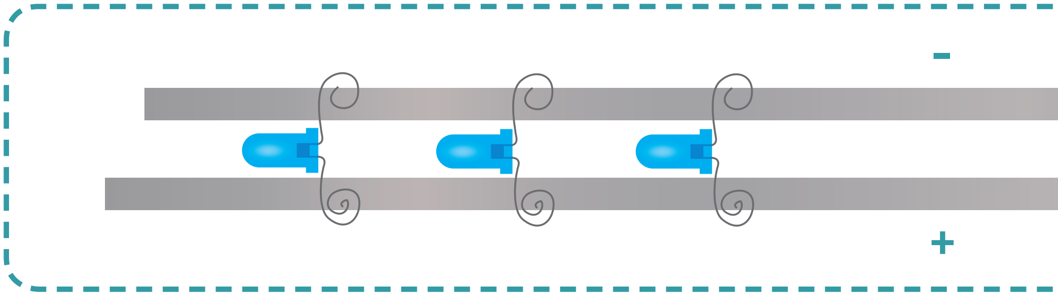


 ILLINOIS

LEDS IN PARALLEL AND SERIES CIRCUITS

Make the circuit in the blue dotted box adding blue LEDs one at a time. Power your circuit with a battery using alligator clips and your new battery holder.

This circuit and the circuits you made in the previous puzzles are **parallel circuits**.

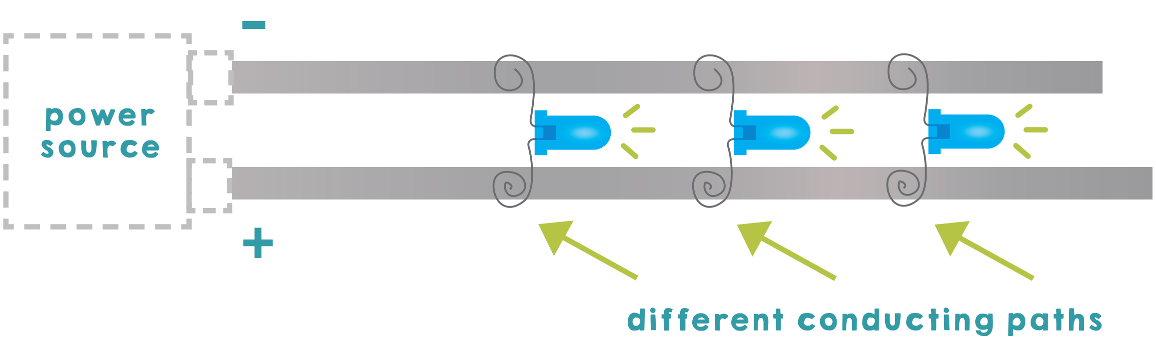


Connect to alligator clips and your new battery holder! →

Do the LEDs get brighter or dimmer as you add more? What happens when you add fourth and fifth LEDs? What happens when an LED is removed? Does it matter which LED or how many are removed?

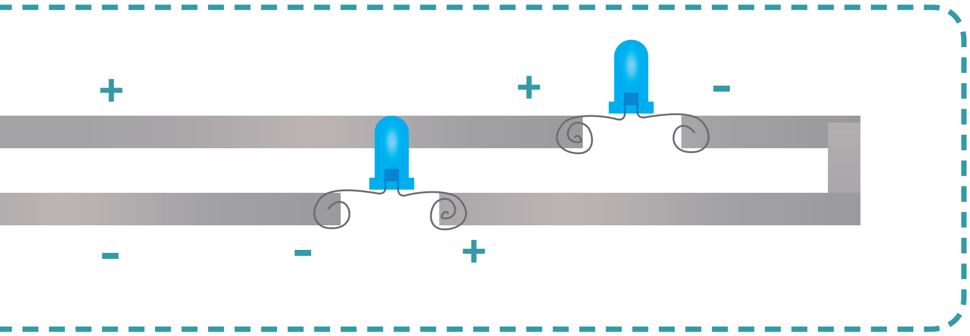
In a parallel circuit, the current has more than one path, or branch, that it can flow through. Start at the positive terminal -- how many paths can the current take between the positive and negative terminals?

If you said "3" you're right! Each LED in this circuit is completing its own conducting path between the positive and negative terminals (sides) of the battery. When you remove one LED, there are still two complete conducting paths in the circuit.



Make the circuit in the blue dotted box. One coin cell battery cannot power both LEDs in this circuit.

Stack two batteries on top of each other so that the positive side (top) of one is touching the negative (bottom) side of the other, put them in your battery holder, and power the circuit.

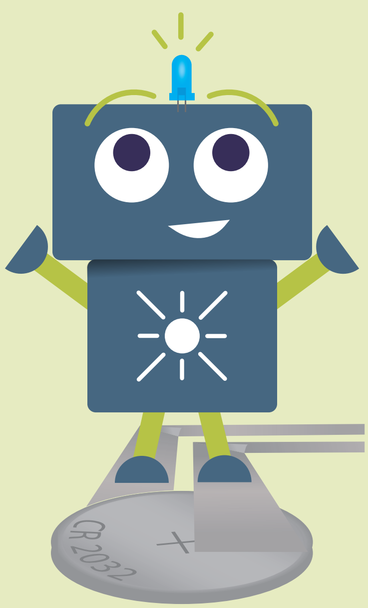


This circuit is a **series circuit**.

In a series circuit, the current has only one conducting path.

When we remove one LED from this circuit, we create a break in the conducting path and the current cannot flow.

What happens in this circuit? What happens when you remove an LED? Does it matter which LED is removed?



MEASURING ELECTRICITY

The energy stored in a battery is measured in terms of electric charge, often with units of milliamp-hours (mAh). When there is a path between the positive and negative battery terminals, current travels through the path. The pressure moving the current is measured in volts (V) and the amount of current is measured in milliamps (mA). A typical CR2032 coin cell battery provides 240 mAh at 3 volts.

Imagine a circuit with one blue LED operating at a voltage of 3V and a current of 20 mA. In theory this battery can light this LED for 12 (240mAh/20mA) hours, but in reality LEDs can vary a little. As a battery gets near the end of its stored energy the voltage is lower, which may make the LED dimmer. Conductive tape and wires use some of the power too. When two batteries are connected in series, the voltage is increased. One coin cell battery supplies 3 volts. A stack of two supplies 6 volts.

EXPLORING PARALLEL CIRCUITS

In a parallel circuit, each branch is connected to the battery's positive and negative terminals, and gets the battery's full voltage.

PARALLEL PUZZLE #1

Create a circuit that has two blue LEDs in parallel.

Each branch needs 3V to light its LED. We can still use just one 3V battery, but now the circuit uses two times as much current and the stored energy in the battery is used twice as fast. How much current is needed for two LEDs in a parallel circuit?

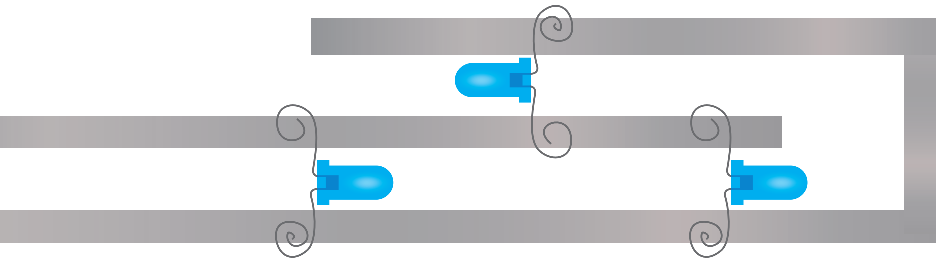
Add a third blue LED. How much voltage is needed in this circuit now? How much current?

PARALLEL PUZZLE #2

Create a circuit that has three red LEDs in parallel.

A typical red LED operates at a voltage of 2V and a current of 20 mA. Will one CR2032 battery light all three red LEDs in this circuit? How much voltage is needed? How much current?

For approximately how long will a CR2032 battery light 6 red LEDs in a parallel circuit?



PARALLEL PUZZLE #3

Create the circuit in the blue dotted box. Label the negative and positive leads.

Will one CR2032 battery light all three LEDs in this circuit? How much voltage is needed? How much current?

PARALLEL PUZZLE #4

Create the circuit in the blue dotted box. Label the negative and positive leads.

Place four LEDs so they all light. Use at least two different colors.

Will one CR2032 battery light all four LEDs in this circuit? How much voltage is needed? How much current?

EXPLORING SERIES CIRCUITS

In a series circuit, there is only one path connecting the positive to the negative terminal of the battery, and so the LEDs in the circuit must share the battery's voltage.

SERIES PUZZLE #1

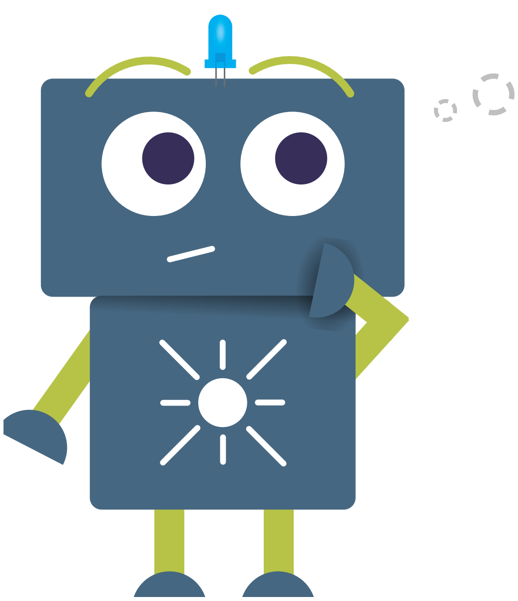
Create a circuit that has two white LEDs in series.

The circuit needs only 20mA of current, because there is only one path for it to flow. However, 3V are needed for each LED. In this circuit, the first LED needs 3V and then the second LED needs 3V, a total of 6V.

One CR2032 battery is too weak and the LEDs won't light. Two batteries stacked on top of each other (in series) can produce 6V and light the two white LEDs.

SERIES PUZZLE #2

Create a circuit that has one red LED and one blue in series.



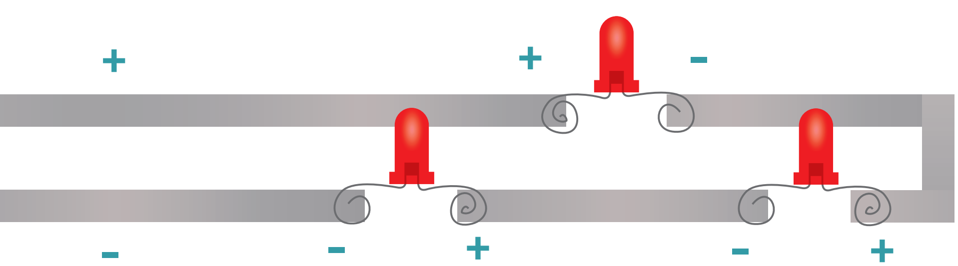
How many CR2032 batteries are needed to light both? How much voltage is needed? How much current?

SERIES PUZZLE #3

Create a circuit that has two red LEDs in series.

How many CR2032 batteries are needed to light both? How much voltage is needed? How much current?

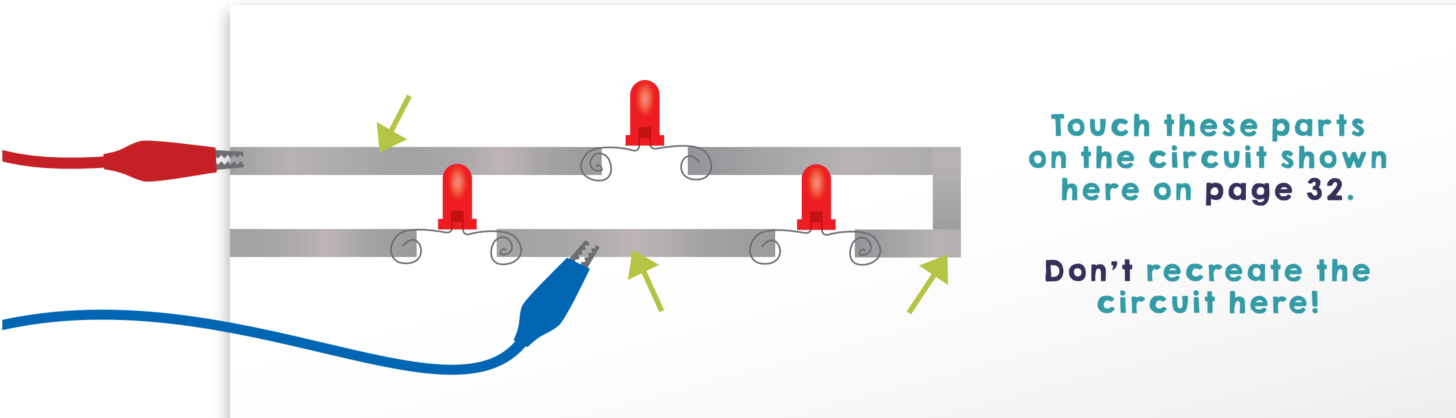
SERIES PUZZLE #4



Make the circuit in the blue dotted box. Power your circuit with two stacked batteries in your battery holder.

What do you notice about the LEDs? Are the LEDs in this circuit brighter or dimmer than those in the series circuit above? What happens as the number of LEDs in a series circuit increases?

Detach the alligator clip connected to the negative lead and touch it to various parts of the conductive tape in the circuit at the arrows as shown.



What do you notice about the lights? What do you wonder about? What do you try?

Why do you think most circuits in this book are parallel circuits?

COMMON GROUND

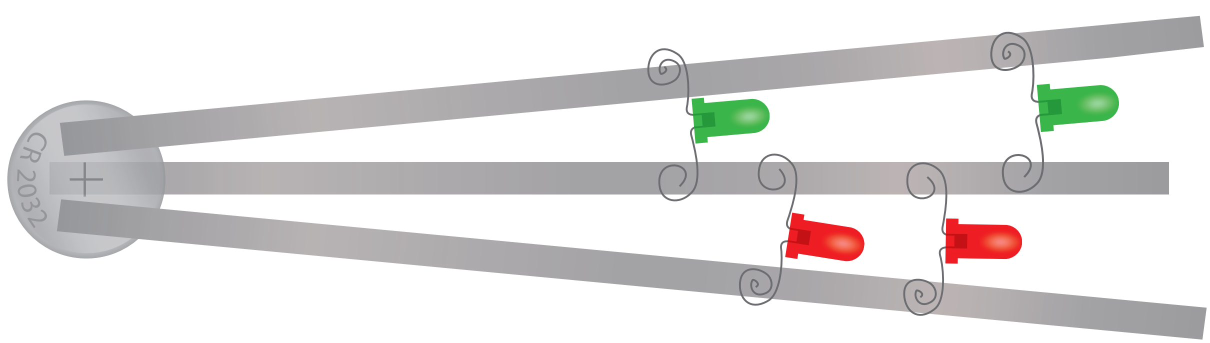
Let's branch out! In the previous puzzles, we've had one positive lead and one negative lead. But circuits are rarely this simple. We might need an LED in a position that isn't part of a straight line. In these next puzzles, we're going to explore using a common ground to be able to create more complex circuits!

USING A COMMON GROUND

Place conductive tape and a battery in the blue dotted box below. The outer strips of conductive tape touch the positive side of the battery and the center tape strip touches the negative side of the battery. This center strip is the negative lead or **ground**.

Add green and red LEDs to the circuit. The current to the green LEDs flows through the two upper paths and the current to the red LEDs flows through the two lower paths. All of the paths share one negative lead. They share a **common ground**.

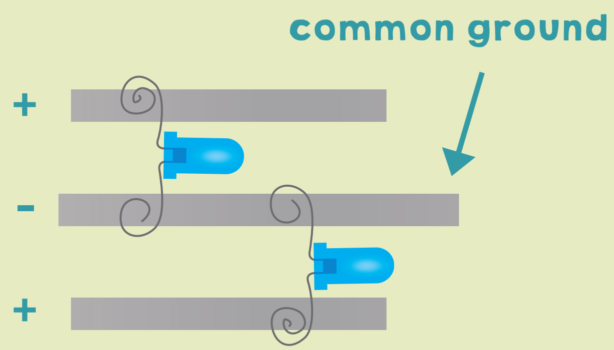
Add two more LEDs so that all six light.



ABOUT COMMON GROUND

A battery (or other power source) can provide voltage to a circuit because there is a charge difference between the two terminals. When there is a conductive path, or circuit, connecting the terminals, current flows. If a battery is labeled 3V, that indicates the potential of the positive terminal of the battery to provide 3V relative to the 0 volts at the negative terminal or "ground."

The term "ground" goes back to early telegraph days when the actual ground was used as part of the circuit. Telegraph stations were connected by a single wire while the earth was used instead of a return wire. At each station one wire would connect to the system and the other was buried in the ground. These systems could use the earth as half of the circuit and save copper wire. The term "ground" is still often used to mean the negative terminal and the traces attached to it. A "common ground" is the return to negative for more than one part of the circuit.

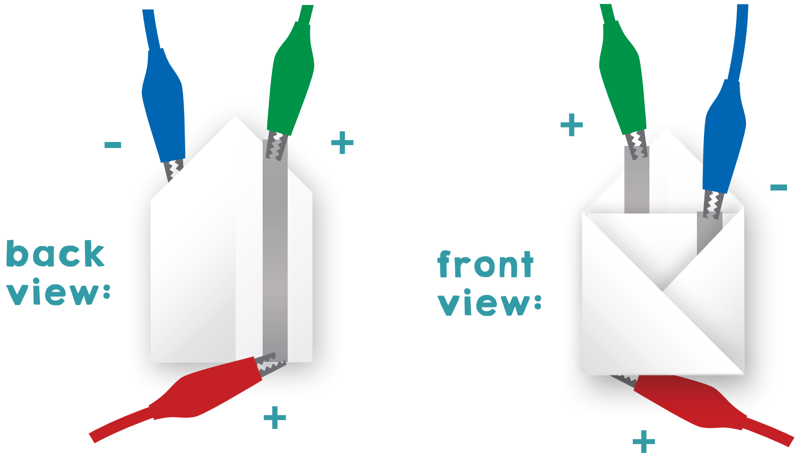


EXPLORING COMMON GROUND IN CIRCUITS

We can use the paper battery holder to power circuits with more than one positive path and a common ground.

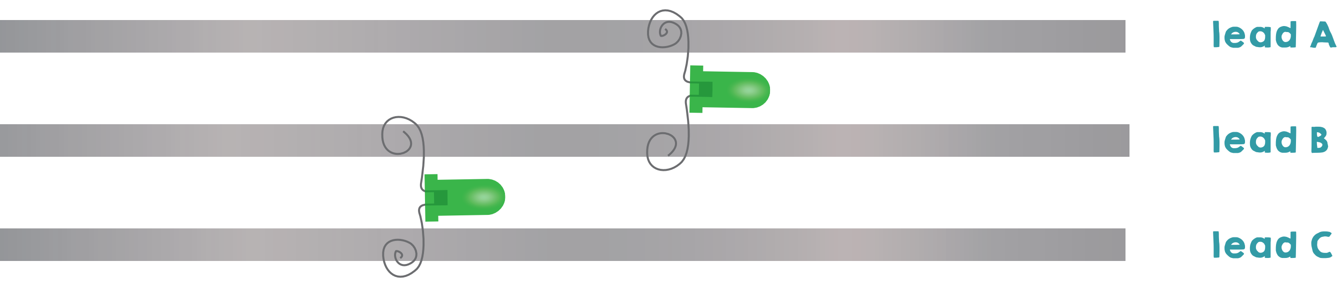
Place the battery into the battery holder. Be sure the negative lead is connected to the negative side of the battery.

Add a third alligator clip to the battery holder for the next few puzzles. Clip to the tape on the back of the holder to attach it to the positive lead. Two clips now connect to the positive side of the battery and one clip connects to the negative side.

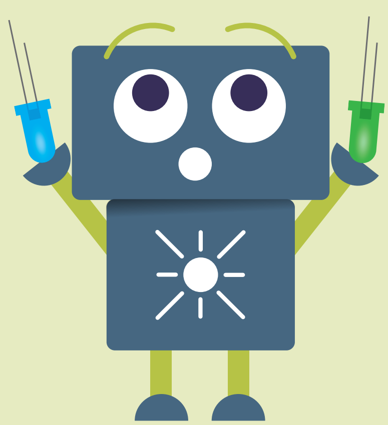


COMMON GROUND PUZZLE #1

Create the circuit in the blue dotted box below. Two positive paths share a common ground. Label the negative and positive leads. Add two more LEDs so they all light.



Disconnect one alligator clip from the circuit at a time. What happens when you disconnect only lead A? What happens when you disconnect only lead B? What happens when you disconnect only lead C?

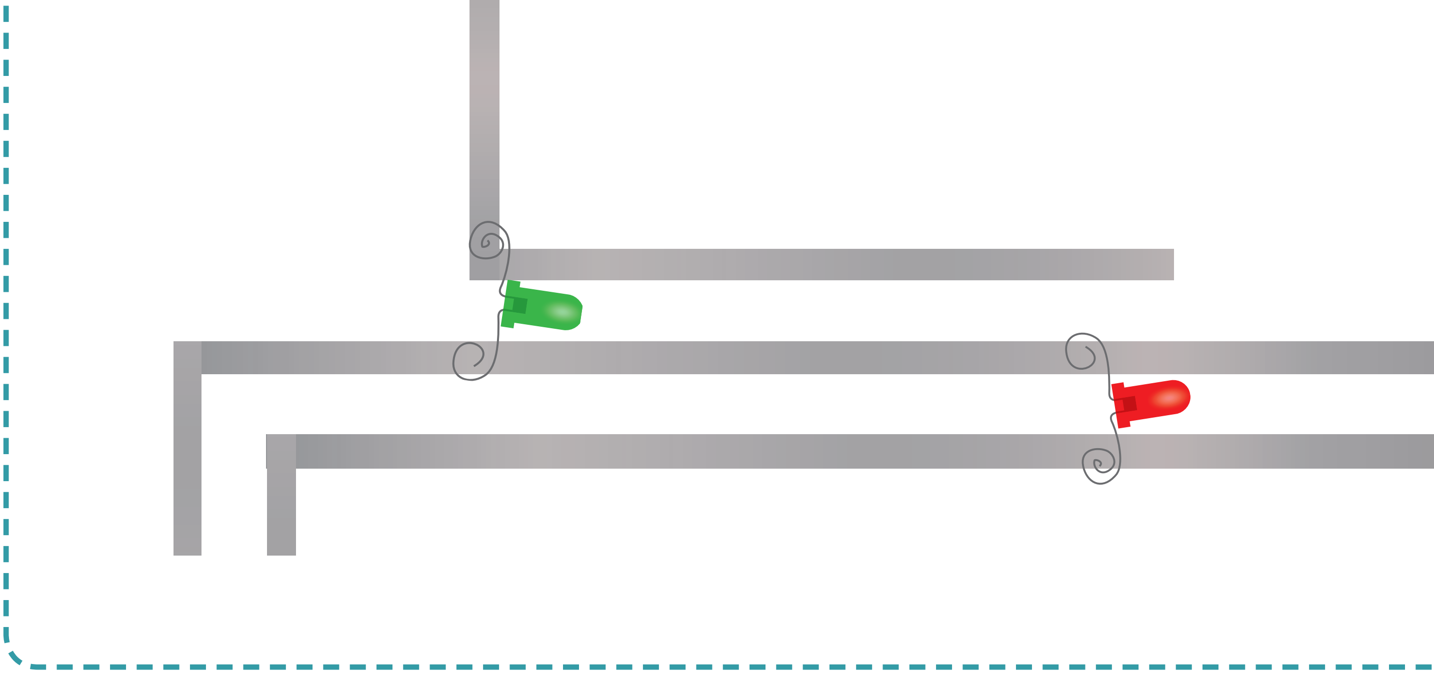


GET CREATIVE!

Common ground is what we call a negative lead that two or more positive leads share. By adding branches off of the battery, we can be more creative with where we place LEDs.

TIP: When adding many LEDs, test LED placement in the circuit puzzle before you tape an LED into position.

*What cool things can **you** make with LEDs?*



COMMON GROUND PUZZLE #2

Create the circuit in the blue dotted box above. Connect alligator clips so two positive paths share a common ground.

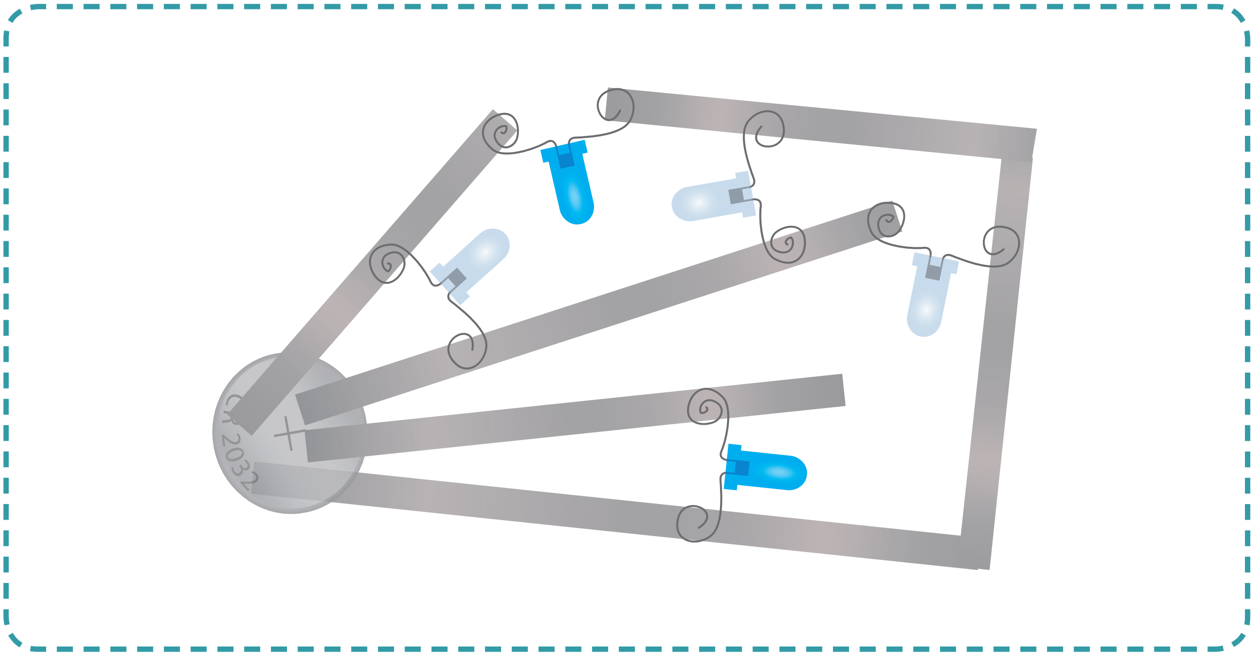
Label the negative and positive leads. Add two more LEDs so that all four LEDs light.

COMMON GROUND PUZZLE #3

Create the circuit in the blue dotted box below. Several positive paths share a common ground.

Label the negative and positive leads.

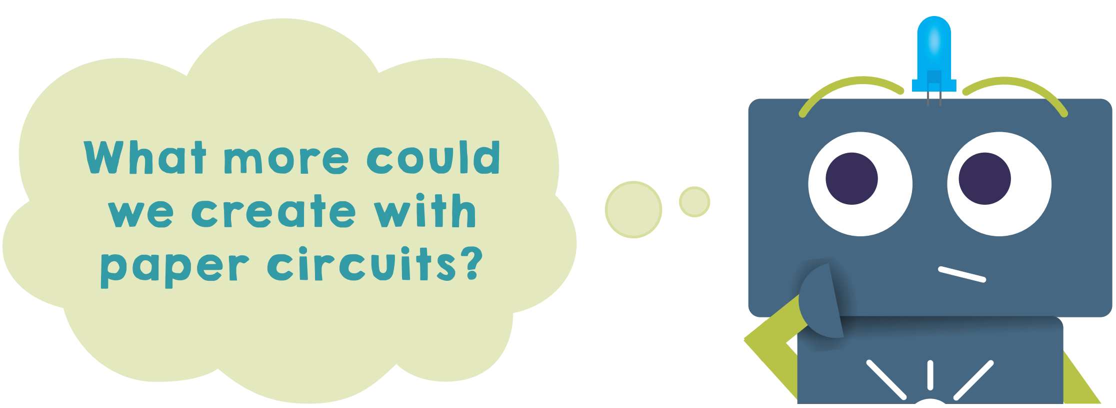
In the diagram one of the LEDs is out of place. Place the LEDs so they all light.



COMMON GROUND PUZZLE #4

Create a circuit with a common ground and four LEDs so that they all light. Use at least two different colors.

Don't be afraid to be creative! What can be done with more than one positive path?



PAPER CIRCUIT PROJECTS

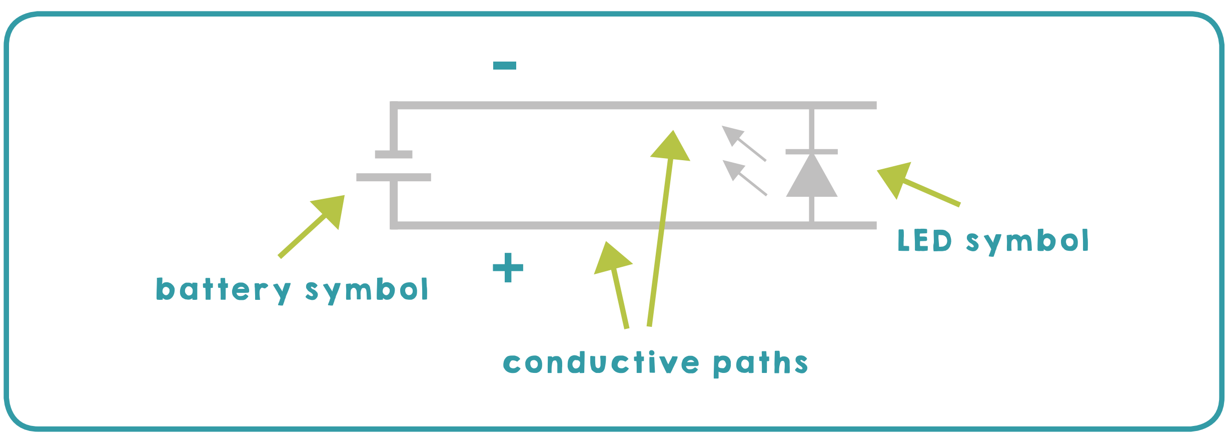
Go beyond! We've learned the basics of circuits and begun exploring circuit layouts, now we can start creating more complicated paper circuit projects by thinking about the different ways we can use paper and circuitry to light up artwork. Don't be confined by the diagrams and pages of this book!

USING CIRCUIT SYMBOLS

The circuit diagrams in the previous sections of this book show wide traces for conductive tape and pictures of the LEDs. Instead of pictures, professionals use a standard set of symbols in their circuit diagrams. In order to simplify circuit diagrams for more complicated projects, we will use the symbols shown in the diagram below.

to get this circuit:

we use this diagram:

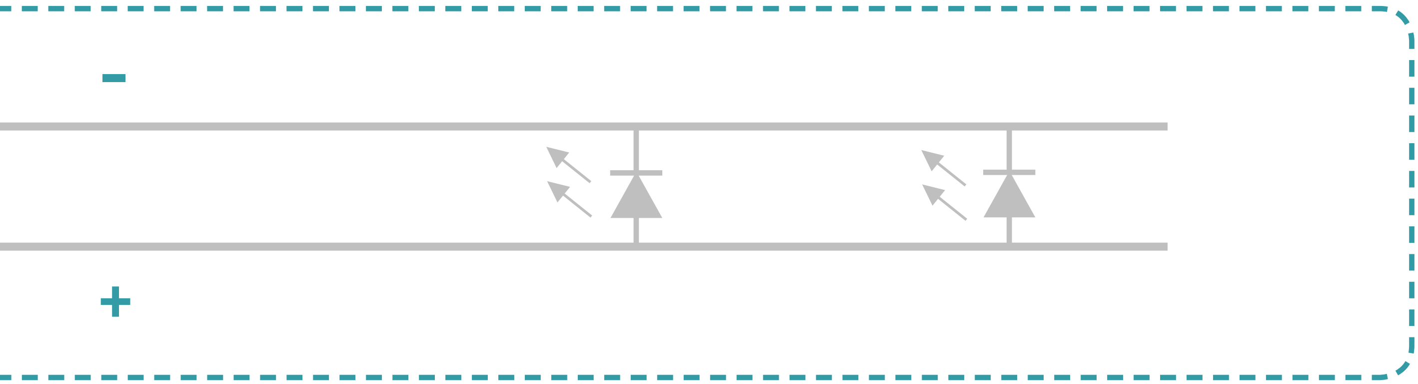


PROJECT #1

Trace the paths of the circuit below with conductive tape, and add LEDs where the LED symbols are shown. Adjust the spacing of your conductive tape for the type of LED you want to use.

Power the circuit by connecting it to the battery holder. Double-check that the positive and negative leads are connected to the correct sides of the battery.

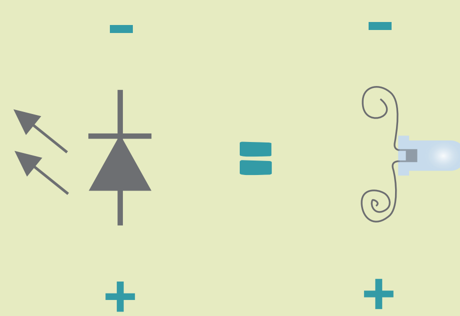
Once the circuit lights, flip over to **page 42** to see the robot's eyes light up!



THE LED SYMBOL

The LED symbol on the left connects the positive and negative leads like the legs of an LED.

TIP: The triangle in the symbol always points towards the cathode!



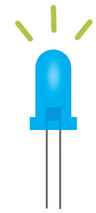
CHALLENGE

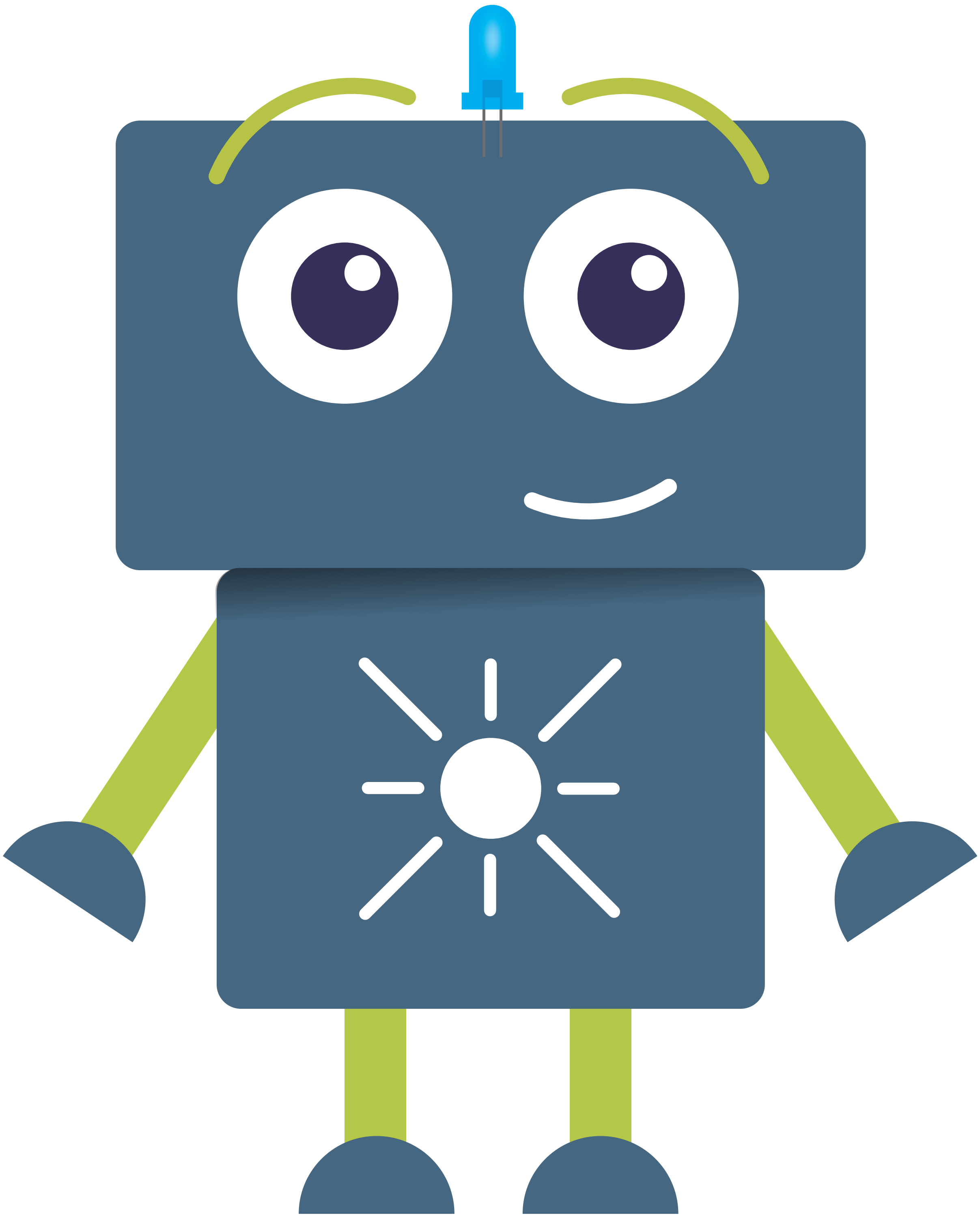
Add to the circuit above so that the robot's blue LED hat on **page 42** lights up.

TIP: To join pieces of nylon conductive tape, overlap the pieces of tape. To join pieces of other tapes, fold the new piece of tape so that the conductive (shiny) sides touch, and use clear tape to connect it to the other piece of tape.

Don't worry!

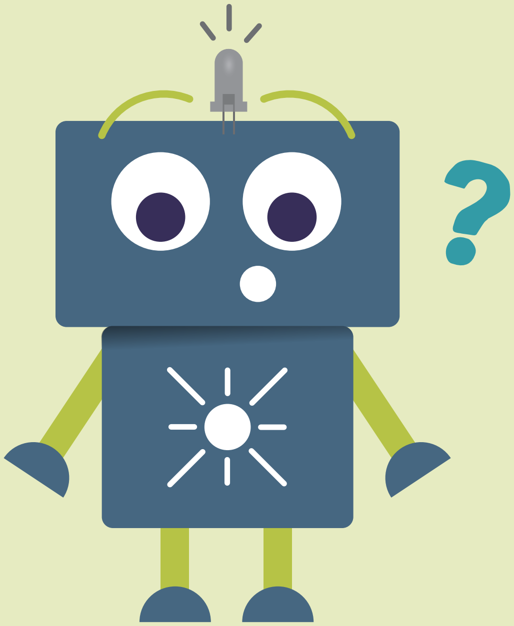
This page is left empty so the lights in your circuit can shine through.





ILLINOIS

TROUBLESHOOTING YOUR CIRCUIT



LEDS BLINK OR DON'T STAY LIT

There's a connection issue! Some ways to fix it are:

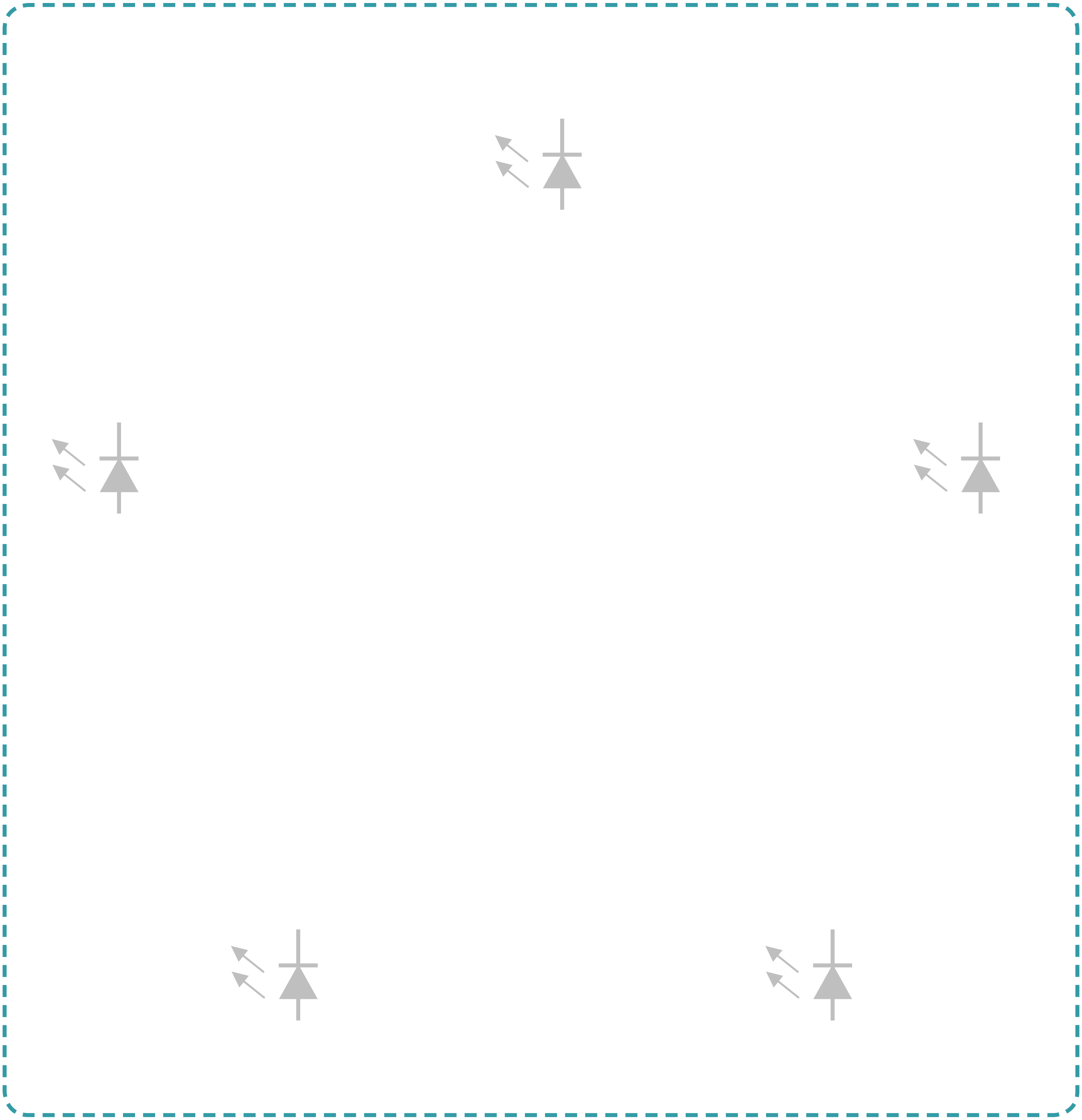
- Firmly press down any corners where two pieces of tape meet.
- Double-check that your battery is secured.
- Add some clear tape to the legs of the LED to help keep it secure.
- Be sure the teeth of the alligator clips touch the conductive tape on both the circuit and battery holder.

LEDS WON'T LIGHT

The most likely cause is that the polarity is incorrect somewhere. Check that the LEDs in the circuit are placed in the right direction. Ensure that you've connected the positive conductive tape lead to the positive lead on the battery holder. If this still doesn't work, check your connection as described above.

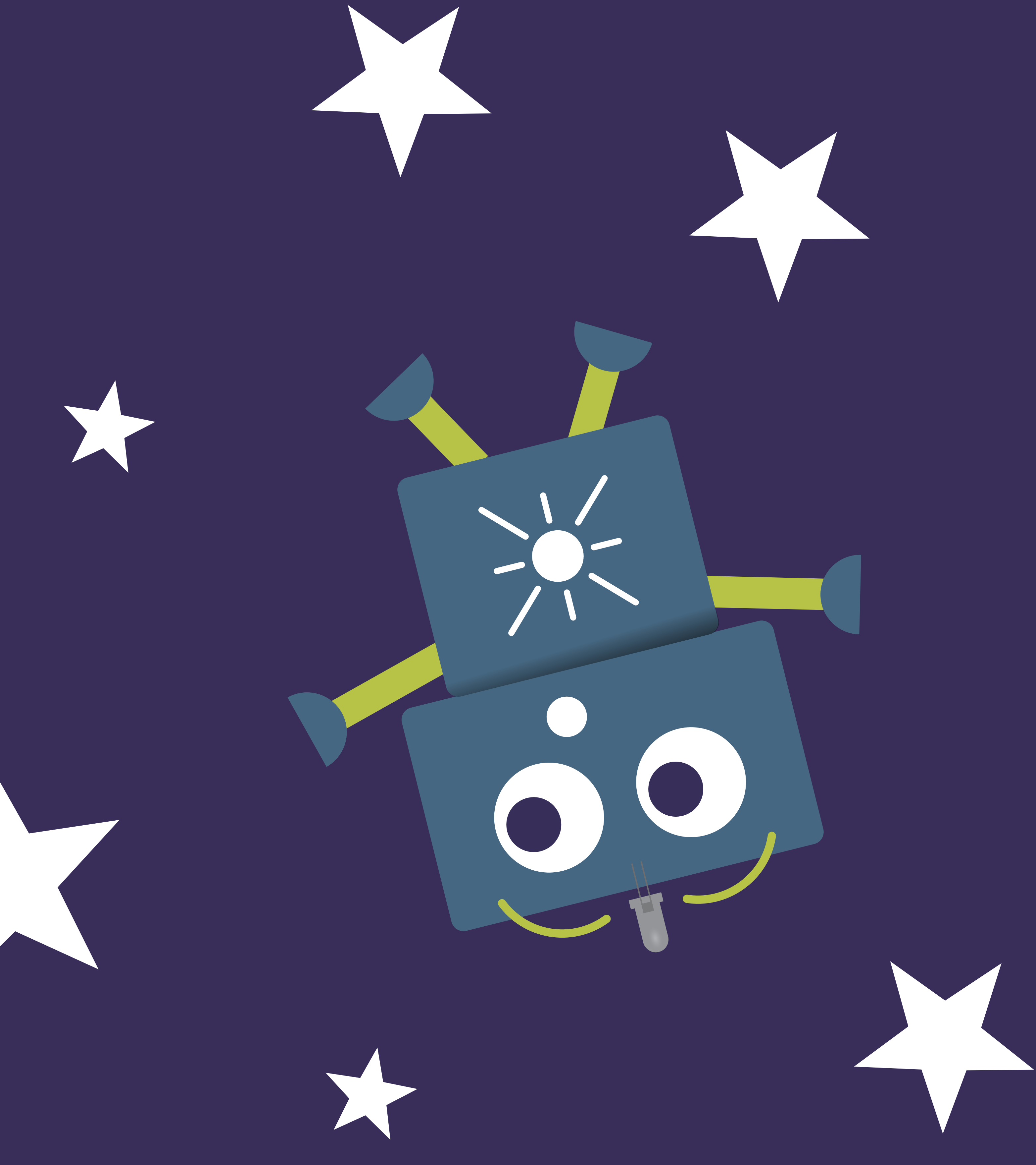
PROJECT #2

Each LED symbol has been placed behind a point of the star on **page 46**. Design a circuit that will light all five points of the star.



Don't worry!

This page is left empty so the lights in your circuit can shine through.



Don't worry!

This page is left empty so the lights in your circuit can shine through.

 ILLINOIS

PROJECT #3

The robot's light is out on **page 47**! Use the space below to create a circuit that lights the gray LED on the robot's head. Can you use the same circuit to light the stars on **page 47**?

PROJECT #4: TRY IT YOURSELF

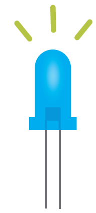
Create your own light-up artwork on **page 52.** Decide where you want the lights to be, and then build a circuit in the space below to make those points light. Be creative and use the whole space!

Try not to erase and redo the artwork when you run into a problem. What techniques can be used to light up all the different parts of your artwork?

 ILLINOIS

Don't worry!

This page is left empty so the lights in your circuit can shine through.



SHOW US YOUR STUFF

Use the space below to document photos or notes of the circuits you've made in this chapter! Did you try any of the challenges? Show us how they went!

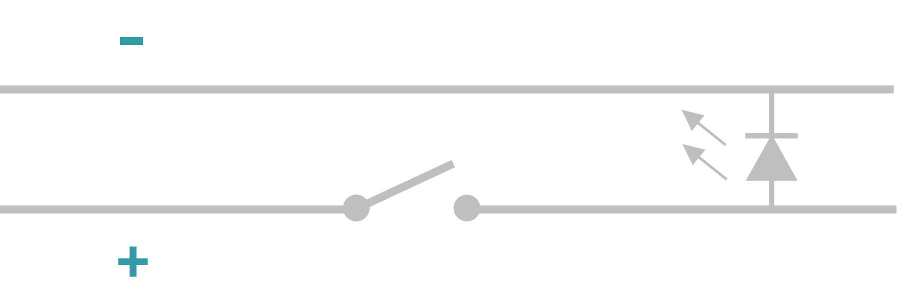
USING SWITCHES

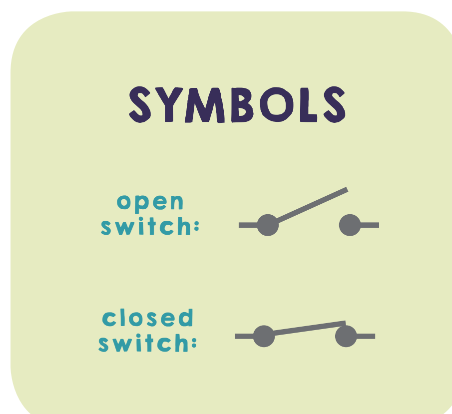
Switch on! Switch off! Sometimes, we don't want the LEDs to be on, or maybe we just want them to come on at specific times. Switches give us control in our circuit, just like light switches in a home or the on/off button on personal devices.

WHAT IS A SWITCH?

Switches allow us to control when parts of the circuit turn on or off. Switches are either open or closed. When they are open, they create a gap in the circuit which stops the flow of electricity. When they are closed, they close the gap, allowing the electricity to flow throughout the circuit.

Use the space below to create a circuit with a switch using the instructions on **page 55.**



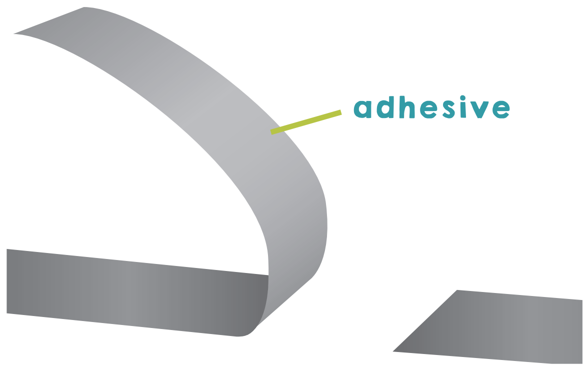


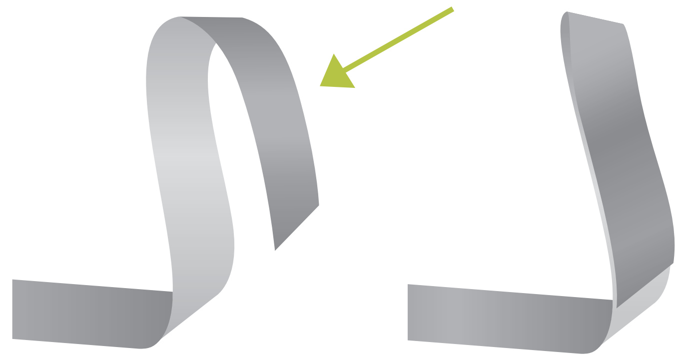
This is an example of a **single pole, single throw (SPST)** switch. It is the simplest kind of switch. It is part of only one circuit and can be connected in only one way.

ILLINOIS

CREATING SWITCHES WITH CONDUCTIVE TAPE

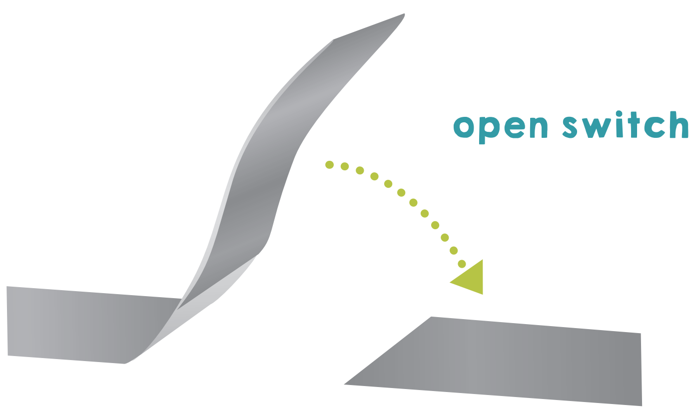
Create a switch at an open part of a circuit. When the switch is closed the conductive parts of tape on each side of the opening need to overlap to make a connection.

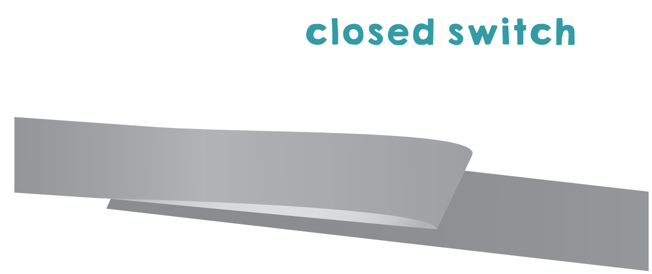




1. When one piece of conductive tape reaches across the opening, extend the first piece so that it overlaps with the second piece, but don't tape it down.

2. Take this extended piece of tape and fold it under so that the conductive side shows on both sides. Make sure this piece can still reach the second piece of tape.





3. We're done! Press down firmly on the folded over piece of tape so that the conductive sides on both are touching to close the gap. This turns the circuit **on**. Lift the folded piece of tape to open the gap.

Power the circuit you created on page 54. What does the switch do?

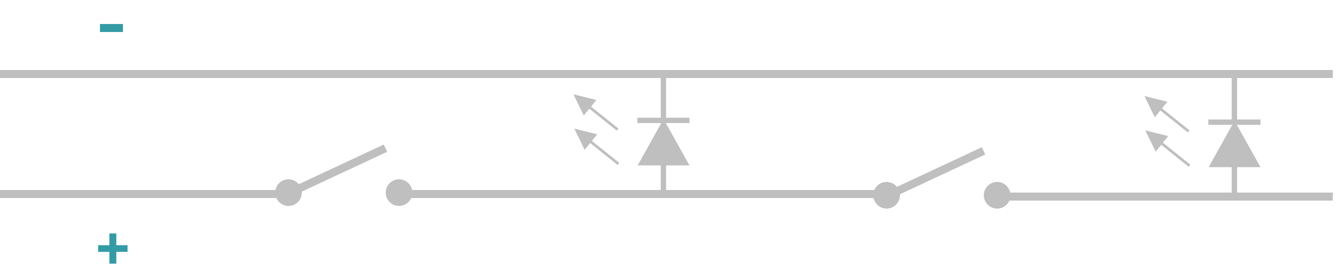
EXPLORING SWITCHES IN CIRCUITS

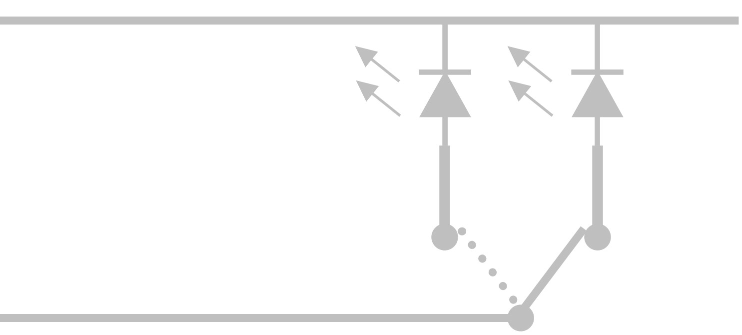
SWITCH PUZZLE #1

Use the space below to create this circuit with two SPST switches and two LEDs. Power the circuit with one battery.

Close both switches. Open both switches. Close only the left switch. Close only the right switch.

What does each switch do?





SWITCH PUZZLE #2

Use the space in the blue dotted box to create this circuit with one **single pole, double throw (SPDT)** switch and two LEDs. This switch is part of only one circuit but can be connected in two ways.

Power the circuit with one battery and label the positive and negative leads.

What does this switch do?

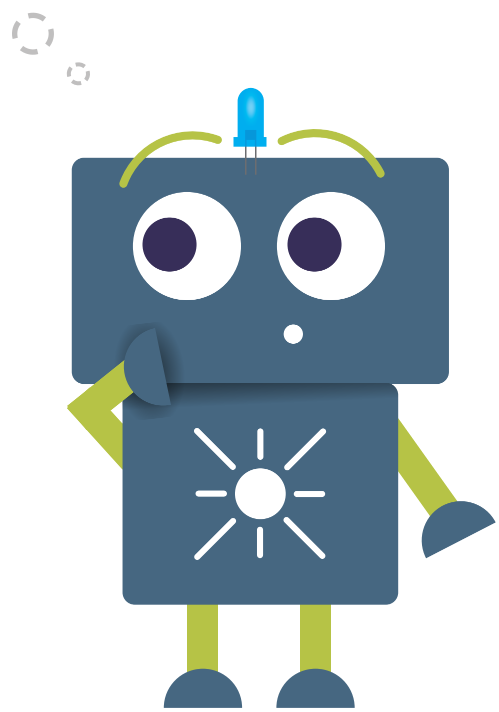
How might a single pole, double throw (SPDT) switch be useful in everyday life?

SWITCH PUZZLE #3

Use the space below to create this circuit. Power the circuit with one battery. Label the positive and negative leads.

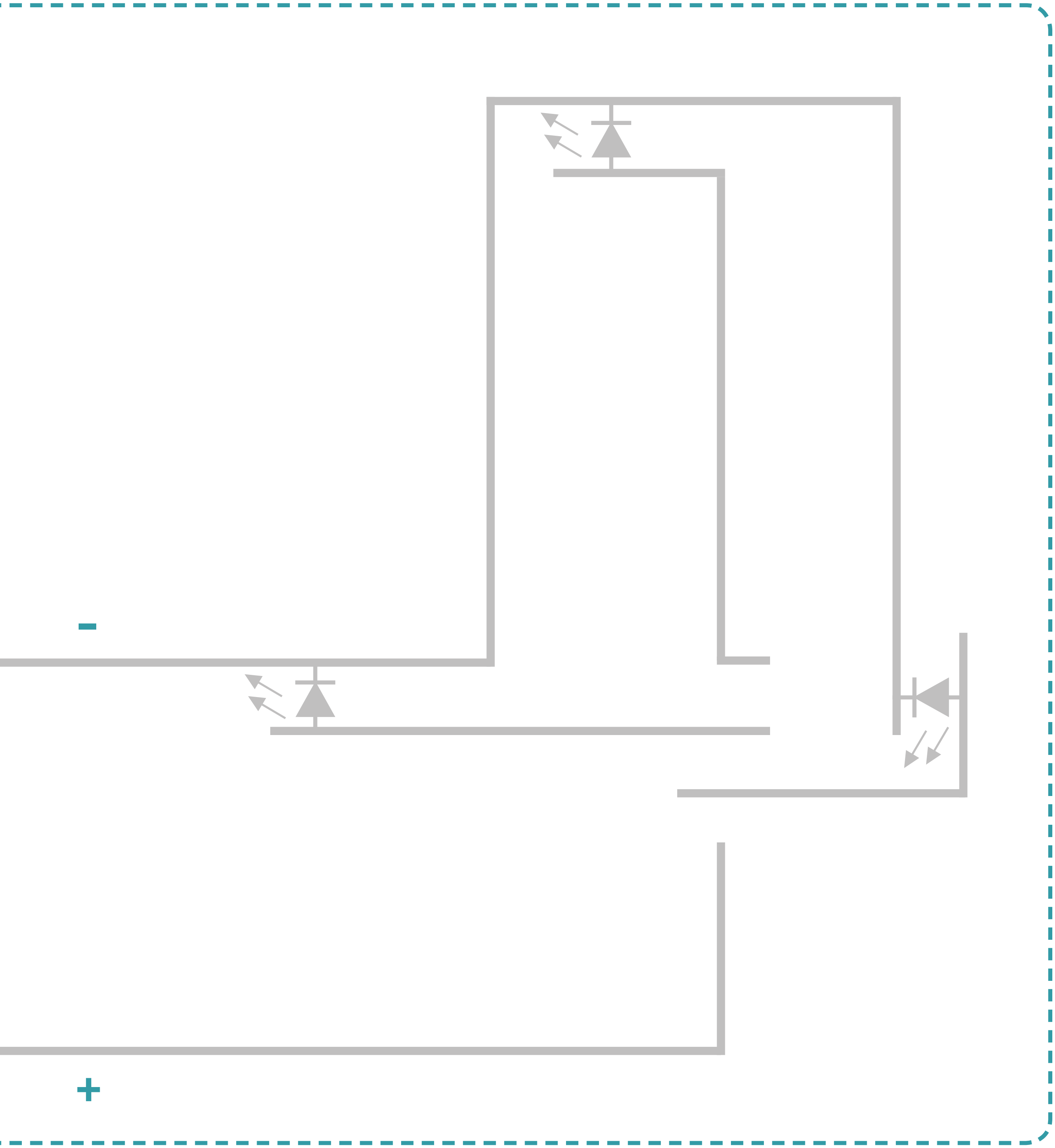
What does this switch do?

What do all of the switches have in common? How do each of the switches determine when the LEDs are on?



PROJECT #5: TURN ON THE LIGHTS!

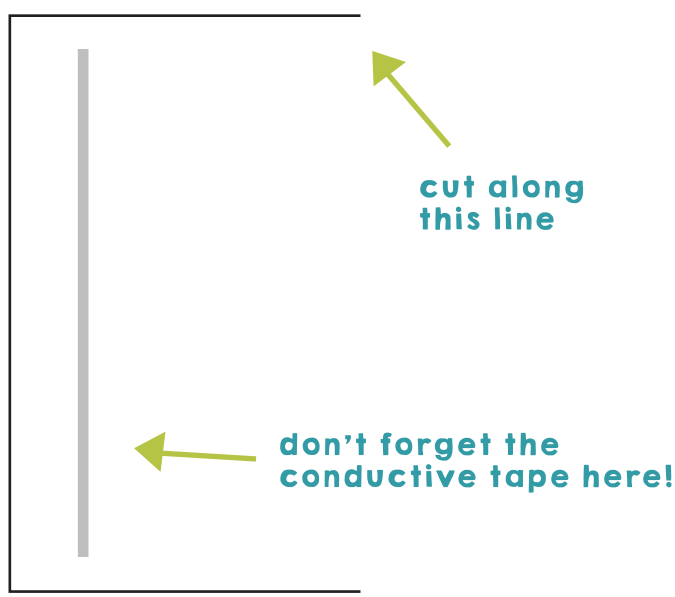
Trace the gray lines with conductive tape to create the path of the circuit and add LEDs to light up the windows of the house on **page 60**.



ILLINOIS

Use scissors to cut along the black line in the blue box below to create a paper flap. Turn to **page 60** and notice that the paper flap creates a door to a house. The tape on the back of the door is a switch.

When does the house light up? How does the door act as a switch?



ILLINOIS

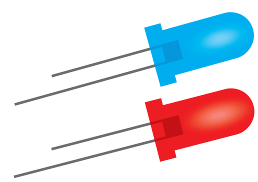
#2

Power Sources

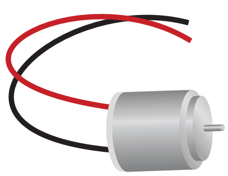
MATERIALS NEEDED

Scissors

Hand Crank Generator

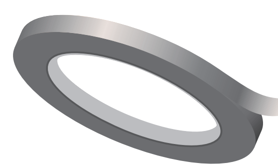


Multiple LEDs

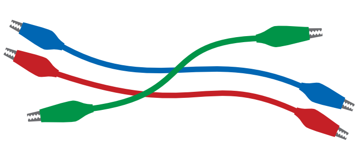


Small Hobby Motor

Small Screwdriver

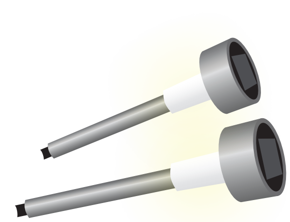


Conductive Tape



3 Alligator Clips

Coin Cell Batteries



2 Solar Path Lights

SOLAR POWER

Sun light! Photovoltaic (PV) cells, or solar cells, produce electricity directly from light. A solar panel is made up of many cells. A very small panel can power a calculator or small light, and large arrays can power several buildings. Solar panels power the International Space Station and have become especially useful for providing electricity in places that are not near existing power lines. Where do you see solar power?

WHAT ARE SOLAR PATH LIGHTS?

Solar path lights, similar to those to the right, can easily be found at dollar stores or hardware stores. They use small solar panels, rechargeable batteries, and circuitry and smart switches to produce light at night.

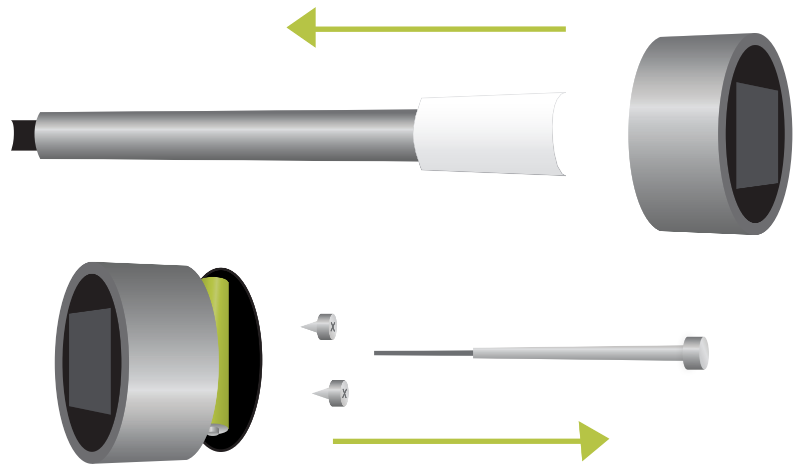
Observe how the light operates. When does the light come on? Remove the tab that protects the battery. If there is a switch, turn it to on.

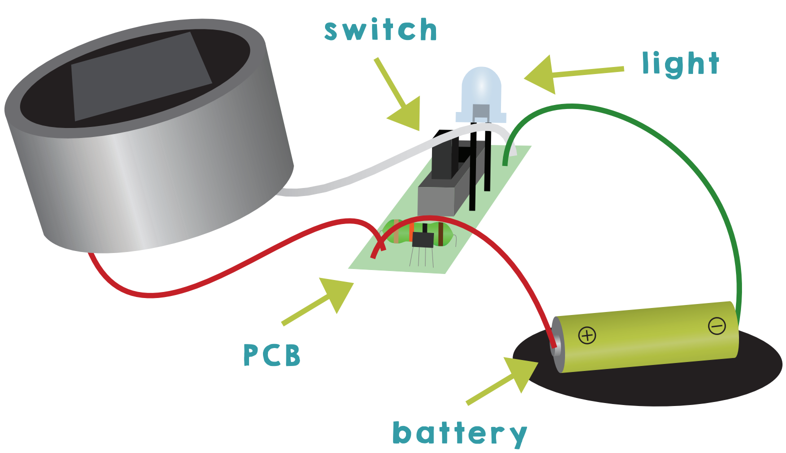
What happens when the sun shines on the solar panel? What happens when the solar panel is in the dark? Why is the path light designed to work this way?

TAKE A LOOK INSIDE

Remove the stake and plastic lens. We won't use them for this activity.

Use a small screwdriver to unscrew the black plastic bottom. Carefully pry the black plastic bottom away.



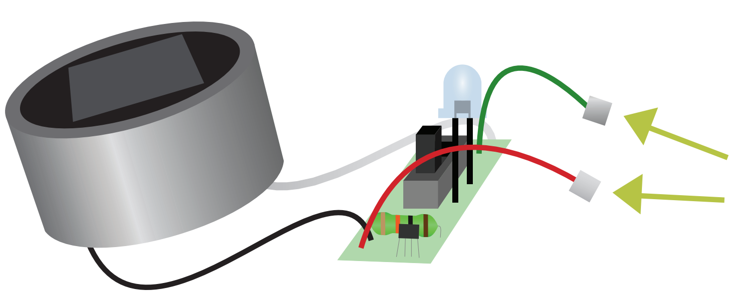


There will be a battery connected to the black plastic bottom and a small circuit board with wires. Two of the wires go through the solar panel holder and attach to the solar panel and two of the wires attach to the battery.

Unscrew the printed circuit board (PCB) from the black battery holder.

There may be a switch on the PCB. When the switch is off, the light is off. Turn the switch to on.

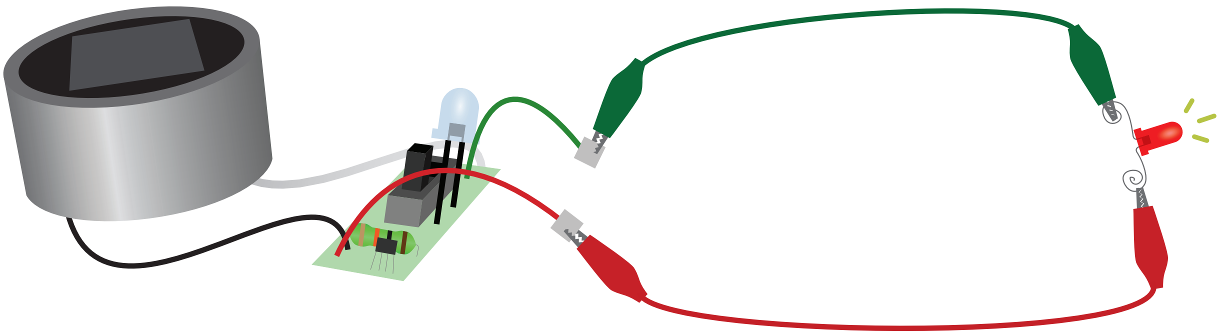
Is the light on when the solar panel is in the dark or when it is light?



Remove the battery. Gently slide each of the two small metal plates (one of the plates has a small spring) out of the black battery holder. The plates are attached to wires from the PCB. Be careful not to detach them.

Can you make the LED on the PCB turn on? How or why not?

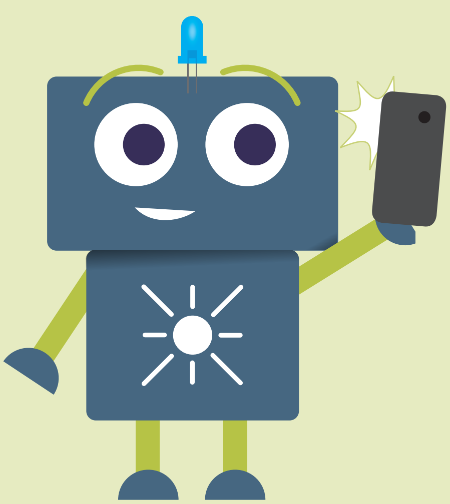
Connect alligator clips to the metal plates to replace the battery with a red LED as shown.



When is the red LED on? Is the white light on the circuit board also on?

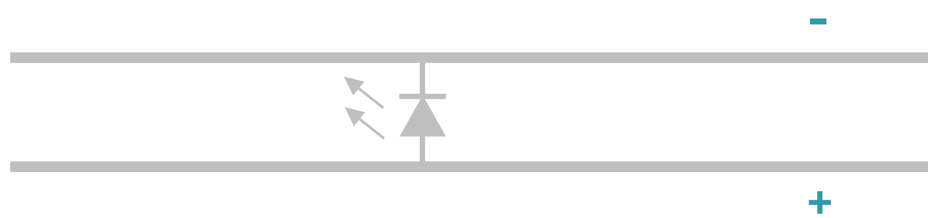
The solar path light is designed to produce light at night. When light shines on the solar panel the power it produces charges the rechargeable battery. When the solar panel is not producing power (when it is dark), the battery powers the white LED on the PCB.

When we remove the battery and connect an LED to the battery connectors, the solar panel powers the LED. Without the battery in the holder, the white LED on the PCB cannot light.



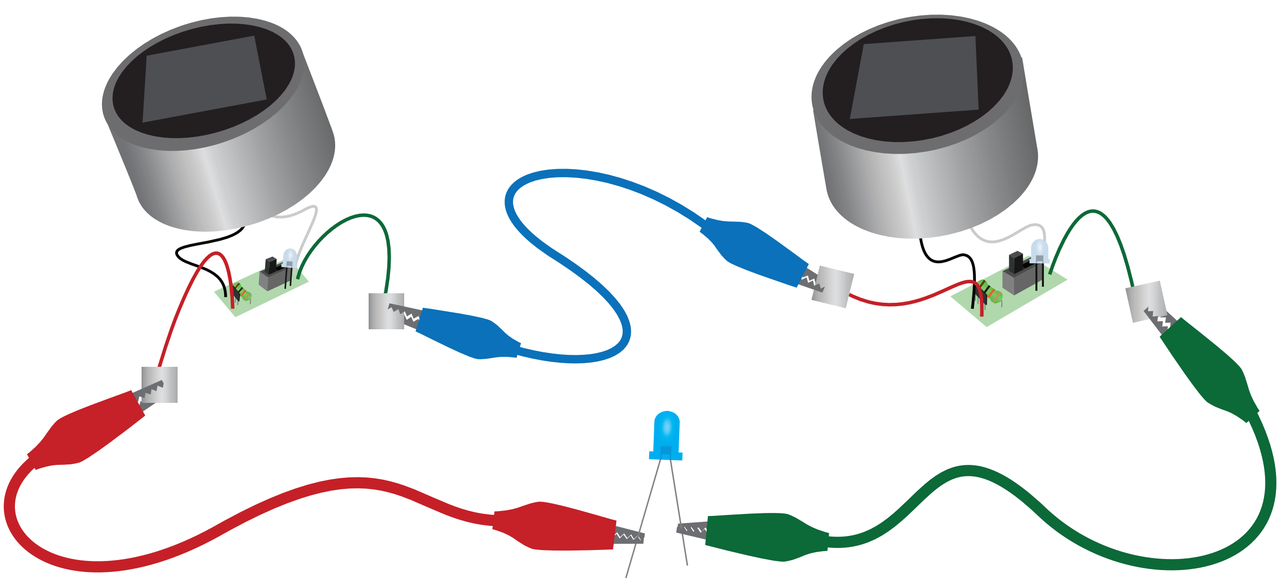
When light shines on the solar panel, it produces electricity. The solar panel works best in sunlight, but you can also try a lamp or the flashlight on your phone. Fluorescent light works less well.

Create a conductive tape circuit and power it with solar power.



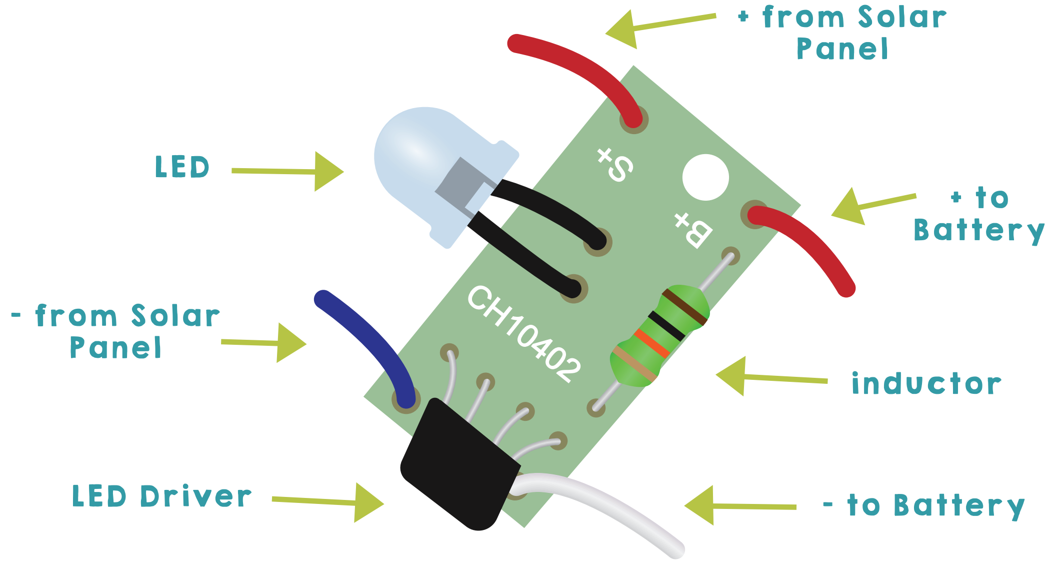
Which colors of LEDs will light? How many?

Connecting two solar panels in series increases the voltage output. Create the circuit below. Then use this configuration with the conductive tape circuit in the blue dotted box above.



Which colors of LEDs will light now? How many?

A CLOSER LOOK

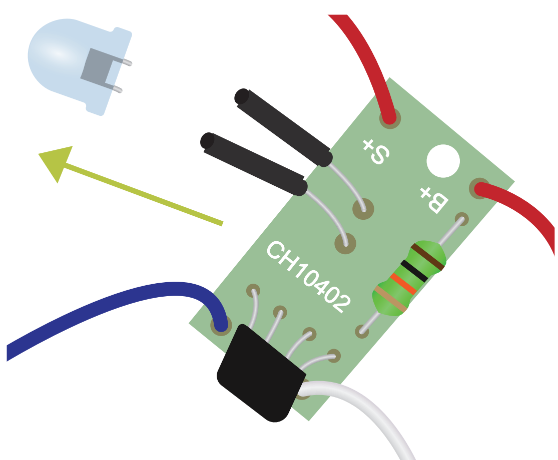


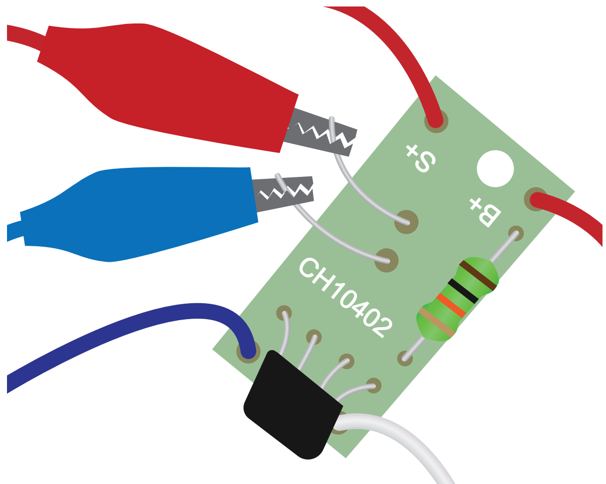
Inside the inductor cover is a coil of wire wrapped around an iron core. An inductor is a type of electromagnet. Current passing through an electromagnet produces a magnetic field. The circuit on this PCB uses the magnetic field to boost the power to the white LED.

The PCB circuitry and components control how the path light functions. The LED driver acts like a switch. If the LED driver detects current from the solar panel, the solar panel charges the battery. If the solar panel is not producing, the battery powers the LED.

Either the battery or the solar panel can power the LED directly, but the PCB circuitry makes the solar panel charge the battery when there's light and uses the battery to power the LED when it's dark.

REPURPOSE THE PCB

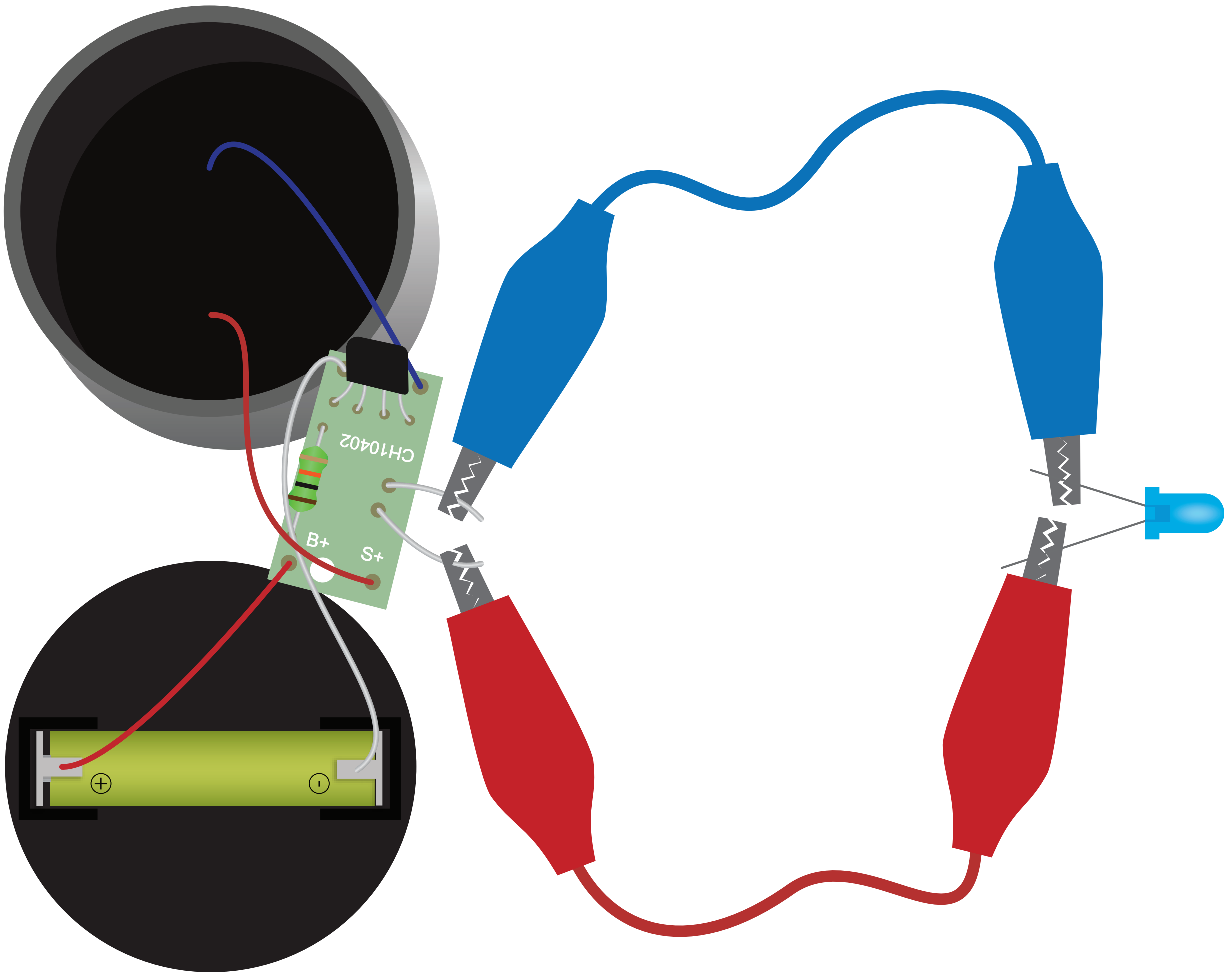




1. Use scissors to cut the black wires between the white LED and the PCB. Cut as close to the white LED as possible. The remaining black insulation should slip off easily, revealing two metal wires.

2. The bare wires were previously the legs of the white LED. Use alligator clips to connect these to a new LED.

ILLINOIS

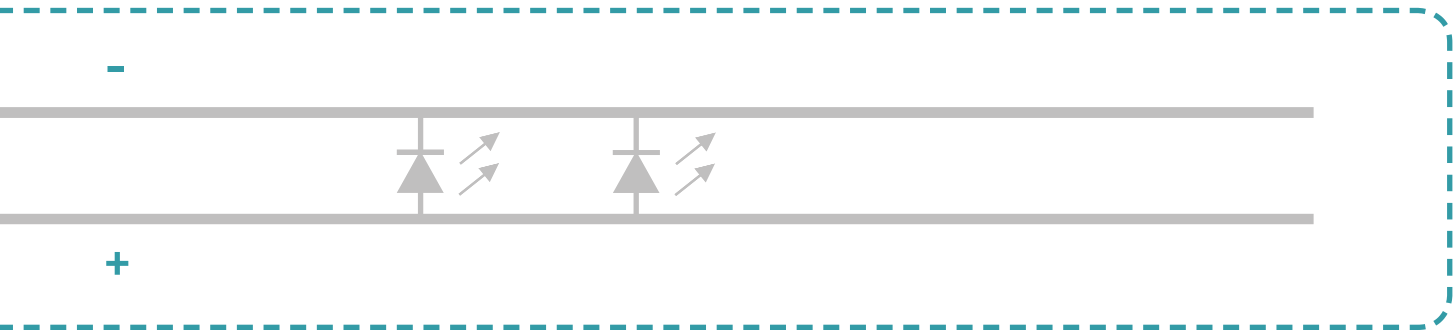


3. Carefully slide the metal battery connector plates back into the black battery holder and replace the battery. Connect the other ends of the alligator clips to legs of a blue LED.

When does this LED light? What supplies the power?

Try other LEDs. What colors of LED light? How many?

4. Use the solar path light configuration in step 3 to power the conductive tape circuit in the blue dotted box. Begin with two LEDs and add more one by one. Try different colors of LEDs.

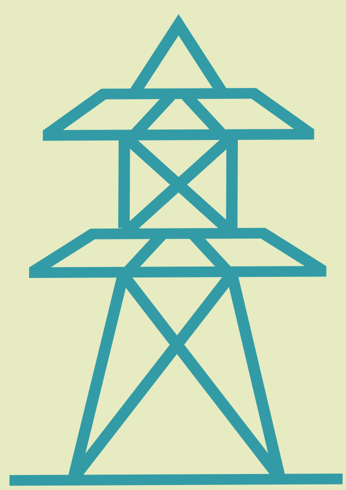


How many LEDs can be lit? What colors?

DID YOU KNOW?

A resilient circuit is able to recover quickly. The U.S. Power Grid is a collection of resilient circuits designed to keep power flowing to all of our homes, schools, and businesses throughout the year, rain or shine, no matter the conditions. One way to do this is to use lots of sensors and controllers that are very similar to the ones you have been using.

When one part of an electrical system experiences a problem, the issue can be detected by sensors, and smart switches and controllers act to redirect power from other parts of the system in order to maintain power in the affected areas.



GENERATORS

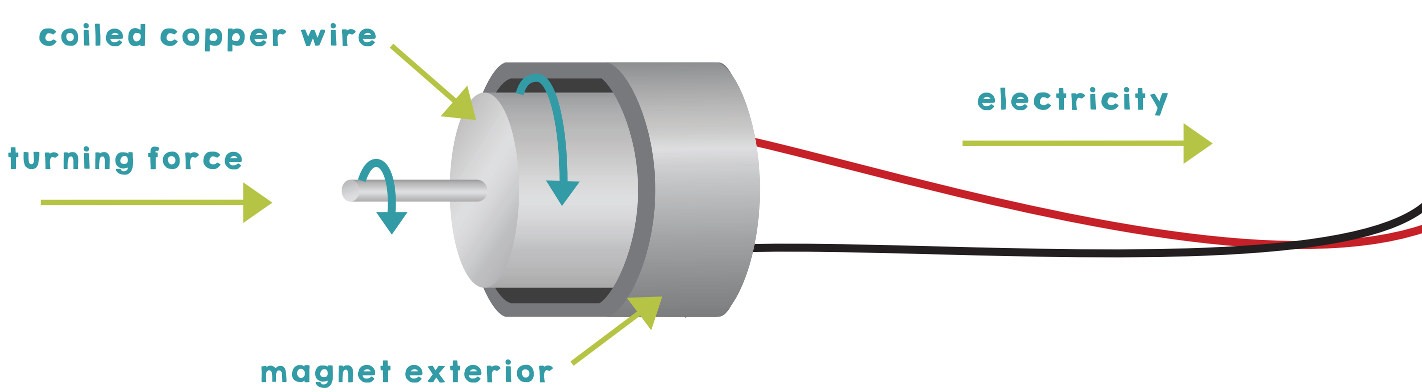
Beyond batteries! Batteries supply electricity to many of the small appliances that we use, especially portable items, but most battery power is limited. Solar panels produce only a small percentage of the total electricity in the U.S. Instead, most of the electricity that powers our homes, schools, and businesses is delivered through the system of power lines and is primarily supplied by generators.

WHAT ARE GENERATORS?

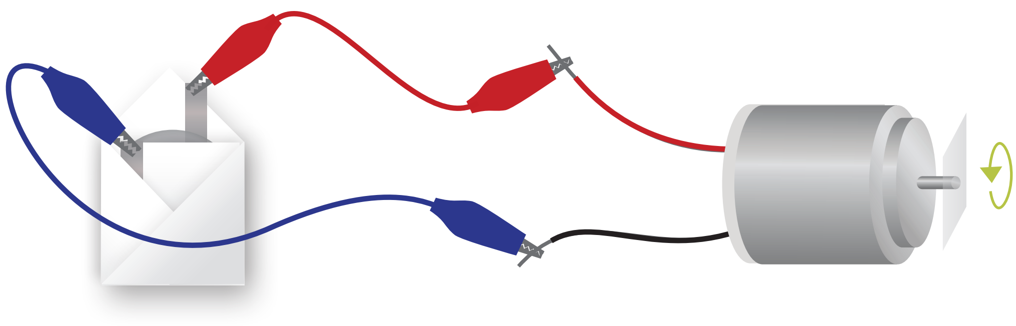
Generators that supply electricity to the power grid rely on work done by Michael Faraday in the 1830's. Faraday found that when a magnet is moved inside a coil of wire or a coil of wire is moved inside a ring of magnets, electric current is produced in the wire. It is also true that when current is moving through coiled wire near a magnet, motion is produced.

Generators in power plants use turbines powered by steam or moving water to rotate the generator shaft. A turbine can be turned by moving water (a waterfall or water moving through a dam) or by the wind, but most often fuel is burned to create steam that forces the turning. Whatever the source of the force, turning magnets inside a coil of wire creates current in the wire.

A small hobby motor can act as a generator. When a turning force spins the shaft, it is a generator. It produces electricity that flows through the red and black leads. When a power source like a battery is connected to the leads, it is a motor and the shaft spins.

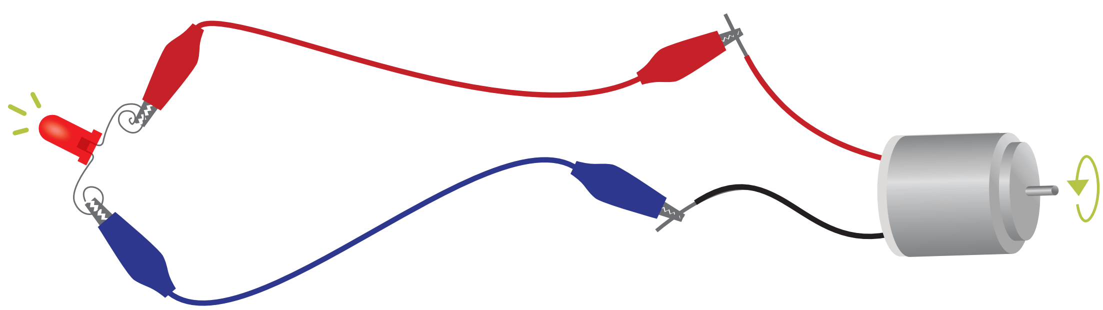


EXPLORING GENERATORS



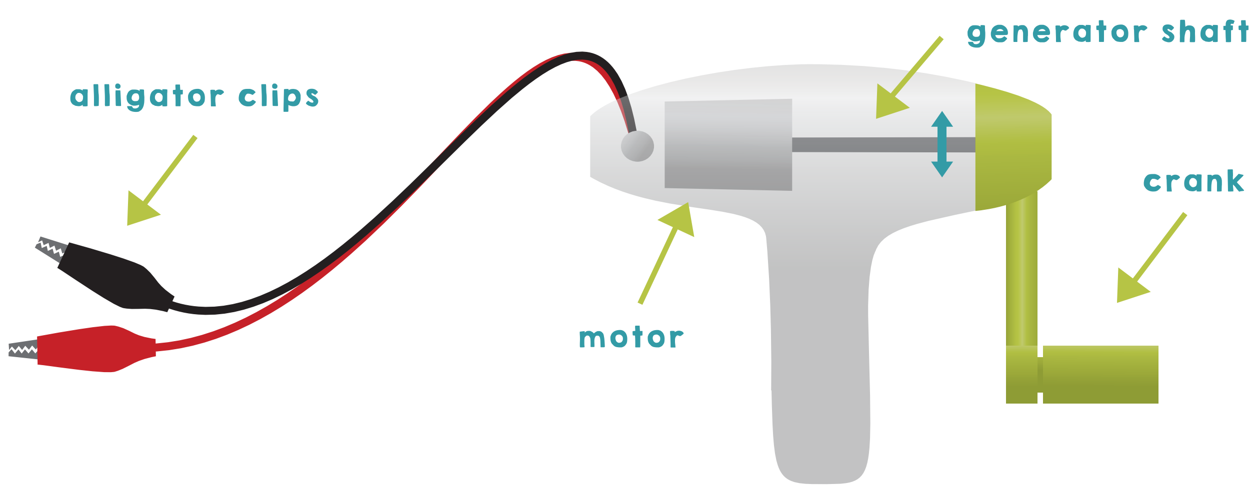
Attach the motor leads to a battery to see the motor shaft spin. Put a small piece of tape on the motor shaft to make it easier to see. Reverse the leads on the battery. Unlike LEDs, a motor will spin, but what changes?

Attach a red LED to the leads of the generator and flick the shaft between your finger and thumb to give it a quick turn and see the LED flash on. (You may need to turn the shaft in the opposite direction or reverse the leads because of the LED polarity.) You can't turn the shaft at a consistently high enough speed to keep the LED on with your fingers.



What other way can you make the shaft turn?

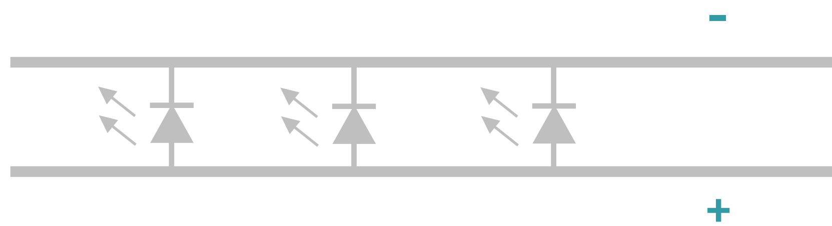
A small DC hand crank generator like the one below uses a handle to make turning the shaft easier and has gears to turn it faster. Think about how you could design wind turbine blades or a hand crank to turn the generator shaft on your hobby motor.

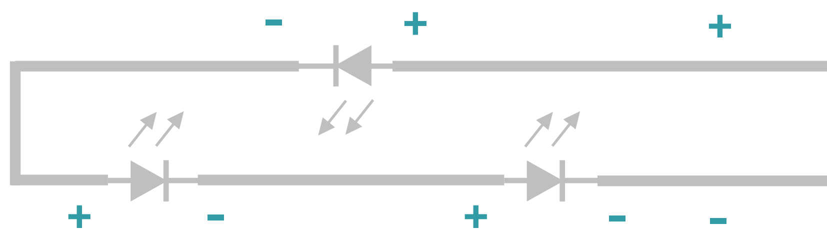


 ILLINOIS

Create the circuits in the first two blue dotted boxes and use the third box to create your own circuit. Use a hand crank generator to power each circuit by slowly turning the crank clockwise. Be careful when turning the crank. You could turn too fast and burn out the LEDs!

For which circuit is it easier or harder to turn the crank?

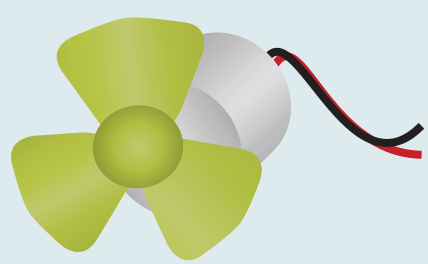




Generators

CHALLENGE

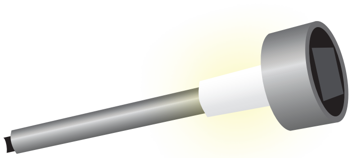
Design a wind powered generator to power your circuits.



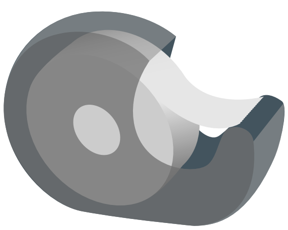
#3

Power Park Lane

MATERIALS NEEDED



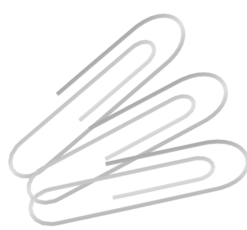
Solar Path Light



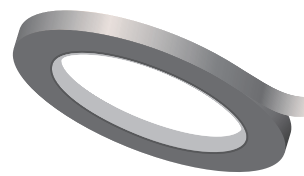
Clear Tape

Scissors

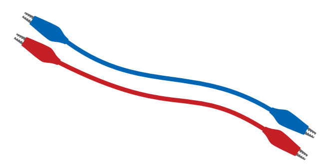
Coin Cell Batteries



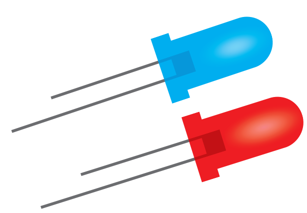
8+ Paper Clips



Conductive Tape



Alligator Clips



Multiple LEDs

POWER UP THE BLOCK

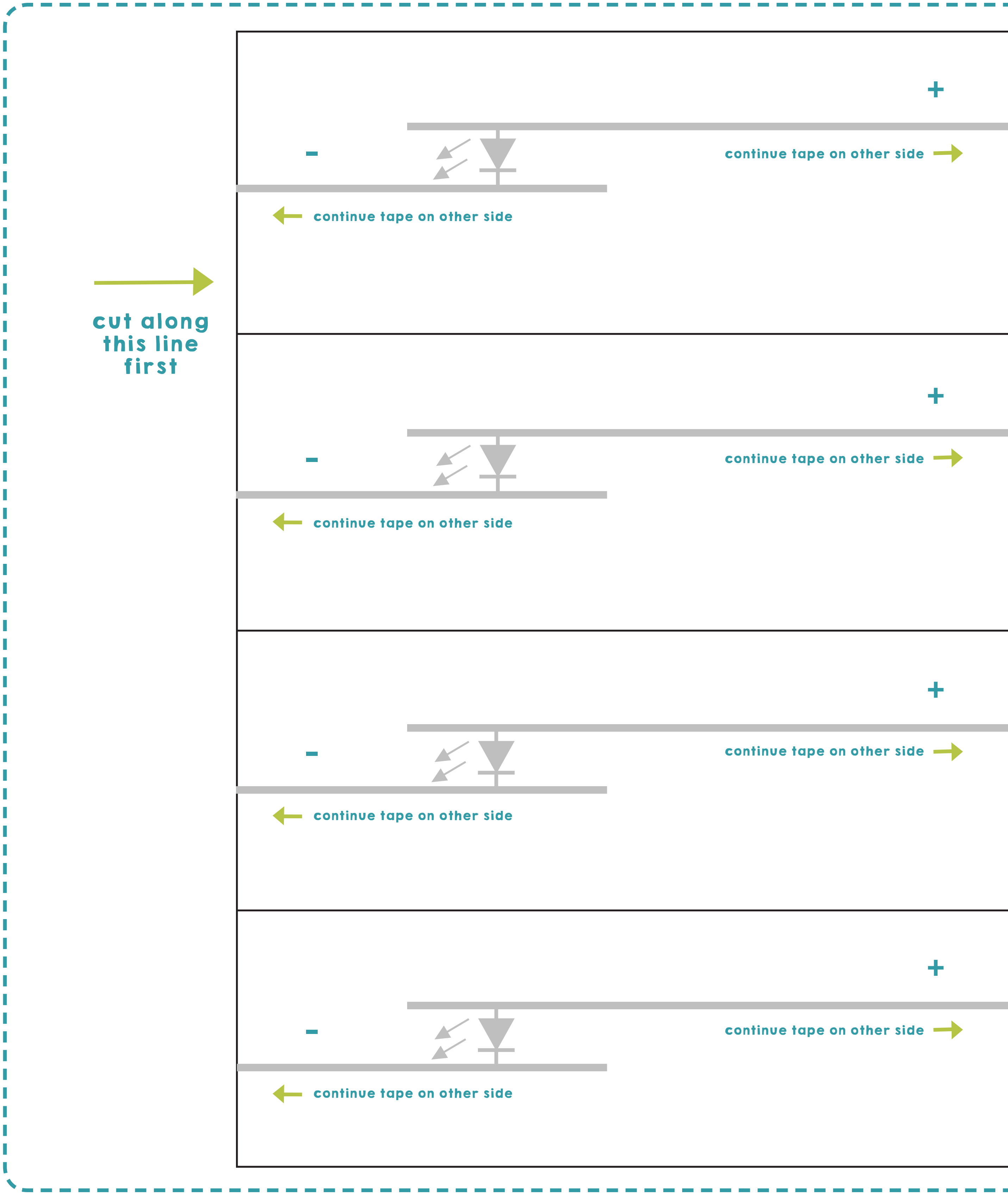
Apply your skills! Build and power this paper craft neighborhood. Use your creativity to add extra features!

CREATE POWER PARK LANE

1. Cut along the black solid lines on **page 77**. The 4 strips of paper are the houses on the block. Add conductive tape to the circuit traces, continuing the tape around both sides. Then, add an LED to each house where marked and secure each with clear tape.
2. Turn each strip so the house image is facing up and mountain fold on the gray dotted lines so that each house stands up like a tent. Tape the edges together with clear tape without covering the conductive tape traces. Add two paper clips to the bottom flaps of the houses so that each paper clip touches a different piece of conductive tape.
3. Trace the white lines on **page 79** with conductive tape to create the street. Connect the positive and negative "street" leads to alligator clips and a power source. Place each of the houses onto the street so that the paper clips on each house connect to the correct lead.
4. Use the battery in the paper battery holder to light up the block. How many coin cell batteries do you need to light up every house?
5. Next use the components of the solar path light to light up the block. Do you want the lights on when the solar panel is in the dark or in light?

How did you use your problem-solving skills to power the block? Which was the best power source for lighting up Power Park Lane and why?

ILLINOIS


cut along this line first
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continue tape on other side
continue tape on other side
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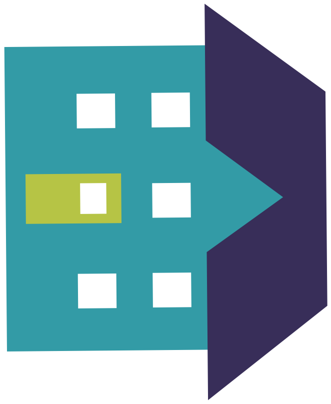

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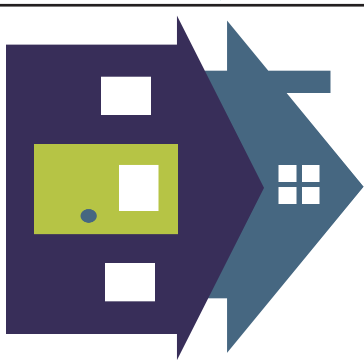

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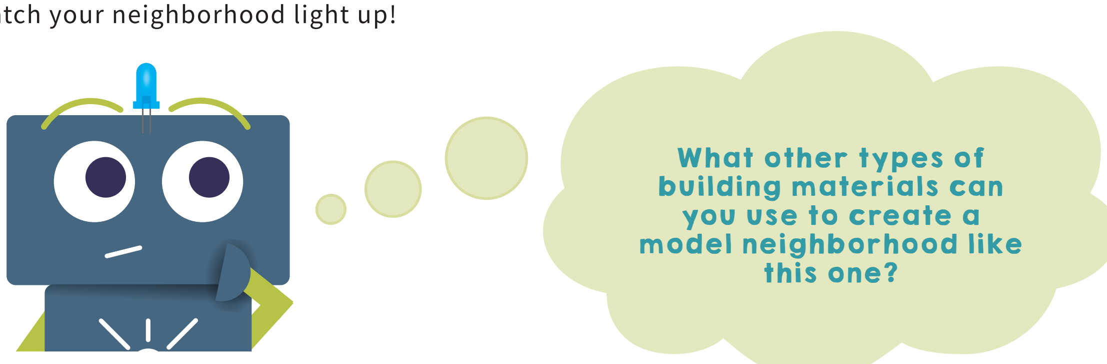
Power Park Lane

DESIGN YOUR OWN BLOCK

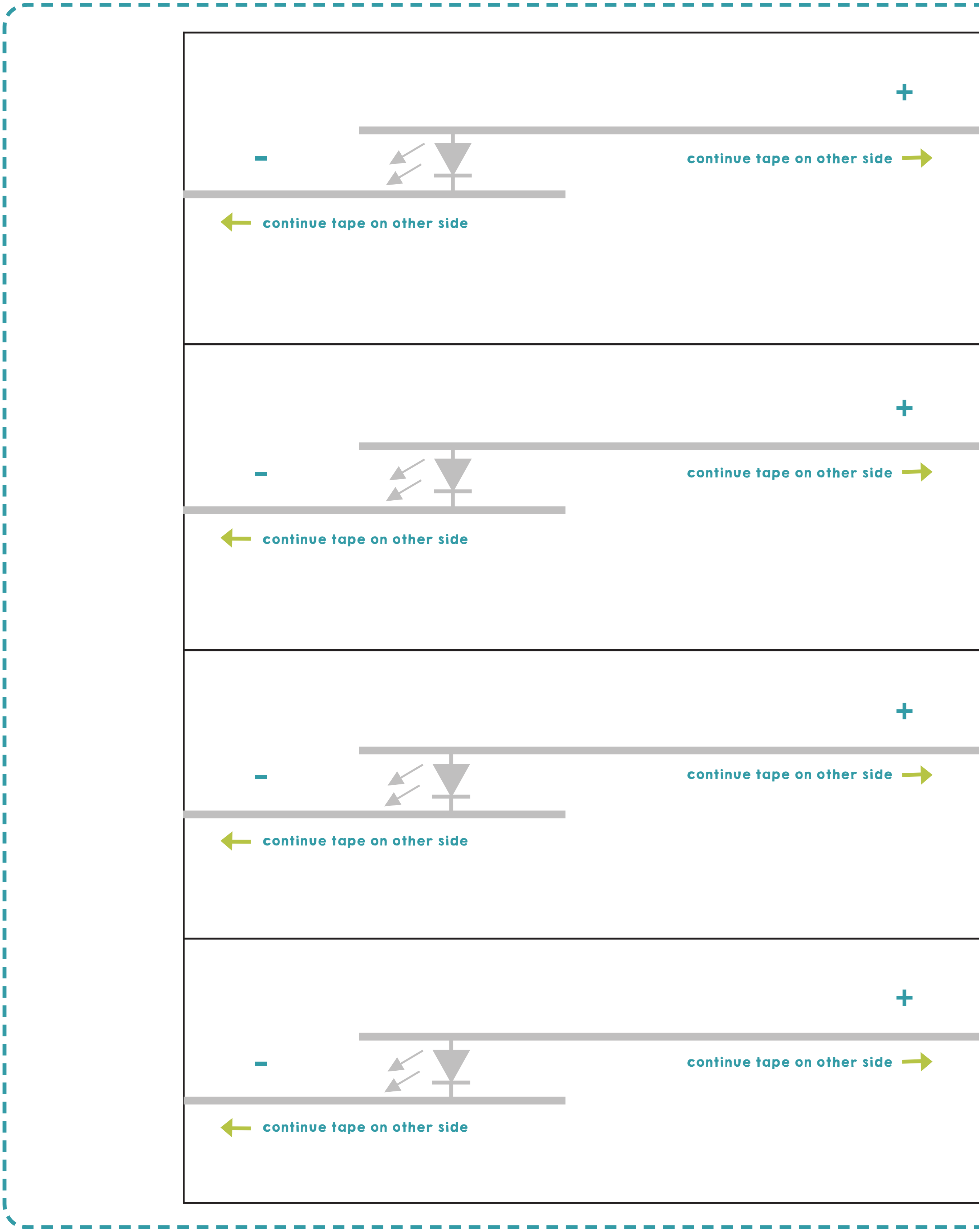
There's an empty lot next to Power Park Lane! Create your own paper craft neighborhood components and experiment with designing circuits.

CREATE YOUR OWN BUILDINGS AND STREETS

1. Cut out each house strip on **page 81** and flip each strip so that the LED symbols are facing down. Use the blank spaces to draw your own buildings on **page 82**. What other types of structures or buildings besides houses need to be powered?
2. Add conductive tape to the traces on each strip, continuing the tape around both sides. Add an LED to each building where marked and secure each LED with clear tape.
3. Turn each strip so the house image is facing up and mountain fold so that each house stands up like a tent. Tape the edges together with clear tape without covering the conductive tape traces. Add two paper clips to the bottom flaps of the houses so that each paper clip touches a different piece of conductive tape.
4. Use the space on **page 83** to create your streets. Remember that each building needs to connect to a positive **and** a negative lead. Can you create multiple streets? How might you want to use a switch or multiple power sources?
5. Use alligator clips to connect the positive and negative traces to the power sources. Place the buildings on your streets so that the paper clips on each building connect to the correct lead. Watch your neighborhood light up!



ILLINOIS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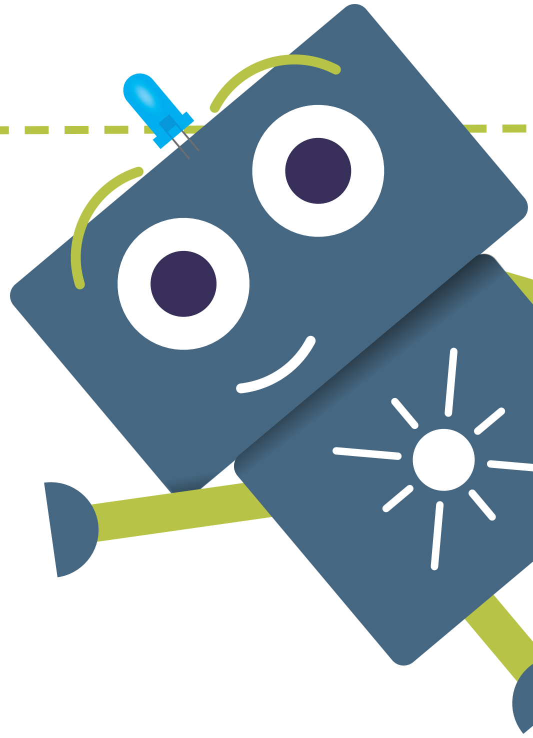
LEARN MORE



CIRCUITS AND ELECTRONICS

Electronics Tutorial Videos

http://afrotechmods.com/tutorials/

BATTERIES AND CIRCUITS

Search for the Super Battery – NOVA

https://www.pbs.org/wgbh/nova/video/search-for-the-super-battery/

How do batteries work? – Qualitative Reasoning Group at Northwestern University

http://www.qrg.northwestern.edu/projects/vss/docs/power/2-how-do-batteries-work.html

Generate Electricity with a Lemon Battery – Scientific American

https://www.scientificamerican.com/article/generate-electricity-with-a-lemon-battery/

How to Measure the Power Output From a Battery - Sciencing

https://sciencing.com/measure-power-output-battery-12312498.html

What is a Circuit? - Sparkfun Tutorial

https://learn.sparkfun.com/tutorials/what-is-a-circuit/all

How Inductors Work – How Stuff Works

https://electronics.howstuffworks.com/inductor1.htm

LEDS

50 Years of LED History – Wired Magazine

https://www.wired.com/2012/10/the-history-of-led/

L is for LED – Adafruit Circuit Playground video series

https://youtu.be/E2WcaJySVuw

Why a Blue LED is Worth a Nobel Prize – Popular Science

https://www.popsci.com/article/technology/why-blue-led-worth-nobel-prize/

Light Emitting Diodes (LEDs) – Sparkfun Tutorial

https://learn.sparkfun.com/tutorials/light-emitting-diodes-leds

All About LEDs – Adafruit Explore and Learn

https://learn.adafruit.com/all-about-leds/

SOLAR POWER AND GENERATORS

How Are Magnets Used to Generate Electricity? - Sciencing

https://sciencing.com/magnets-used-generate-electricity-6665499.html

Electricity Generators – Explain That Stuff

https://www.explainthatstuff.com/generators.html

Solar Energy Basics – National Renewable Energy Lab

https://www.nrel.gov/research/re-solar.html

How Does Solar Power Work, Anyway? – The Climate Reality Project

https://www.climaterealityproject.org/blog/how-does-solar-power-work-anyway