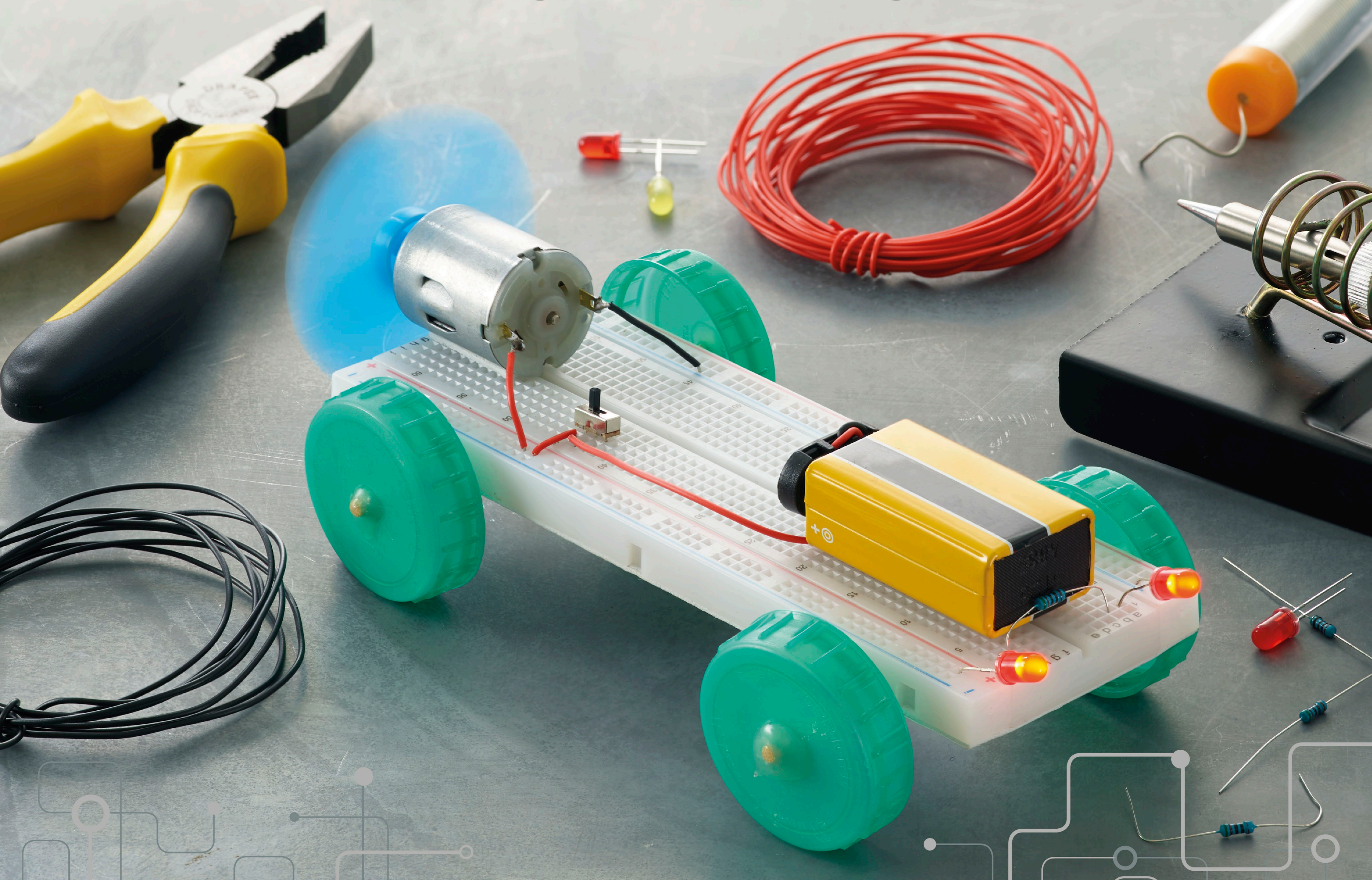
DK SMITHSONIAN

TECH LAB

AWESOME BUILDS FOR SMART MAKERS



JACK CHALLONER

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Senior designer Michelle Staples
Senior editor Steven Carton
Designers Daksheeta Pattni,
Anna Pond, Samantha Richiardi
Editors Kelsie Besaw, Alexandra Di Falco
US editor Karyn Gerhard

Managing editor Lisa Gillespie
Managing art editor Owen Peyton Jones
Producer, pre-production Jacqueline Street-Elkayam
Senior producer Meskerem Berhane
Jacket designers Tanya Mehrotra, Michelle Staples
Jackets design development manager Sophia MTT
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Jackets editorial coordinator Priyanka Sharma
Jacket DTP designer Harish Aggarwal
Picture researcher Rituraj Singh

Publisher Andrew Mcintyre
Associate publishing director Liz Wheeler
Art director Karen Self
Publishing director Jonathan Metcalf

Writer Jack Challoner
Consultants Stephen Casey, Jack Challoner, Lucy Rogers
Photographer Dave King
Illustrators Adam Brackenbury, Daksheeta Pattni

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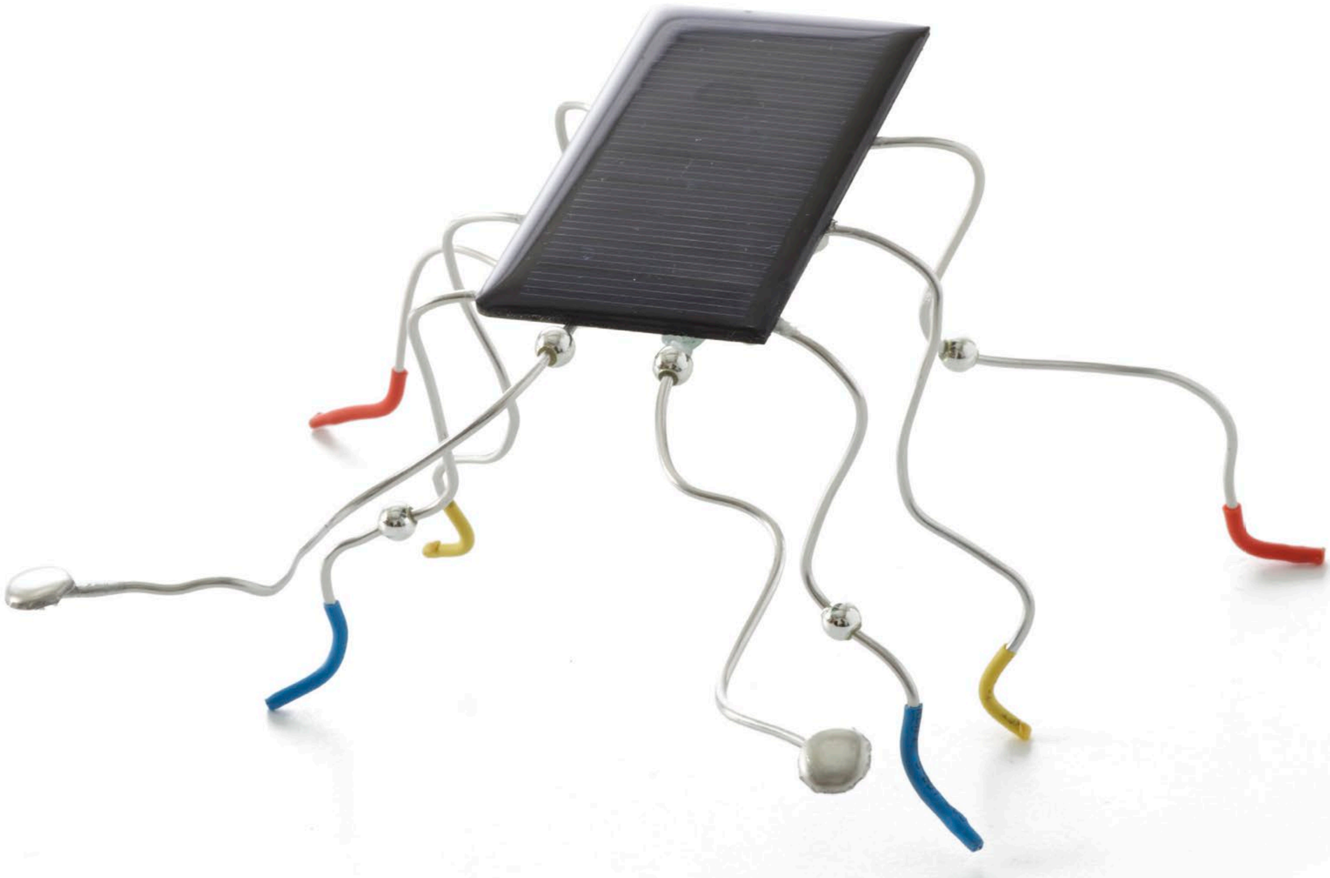
Smithsonian

The Smithsonian
Established in 1846, the Smithsonian is the world's largest museum and research complex, dedicated to public education, national service, and scholarship in the arts, sciences, and history. It includes 19 museums and galleries and the National Zoological Park. The total number of artifacts, works of art, and specimens in the Smithsonian's collection is estimated at 154 million.

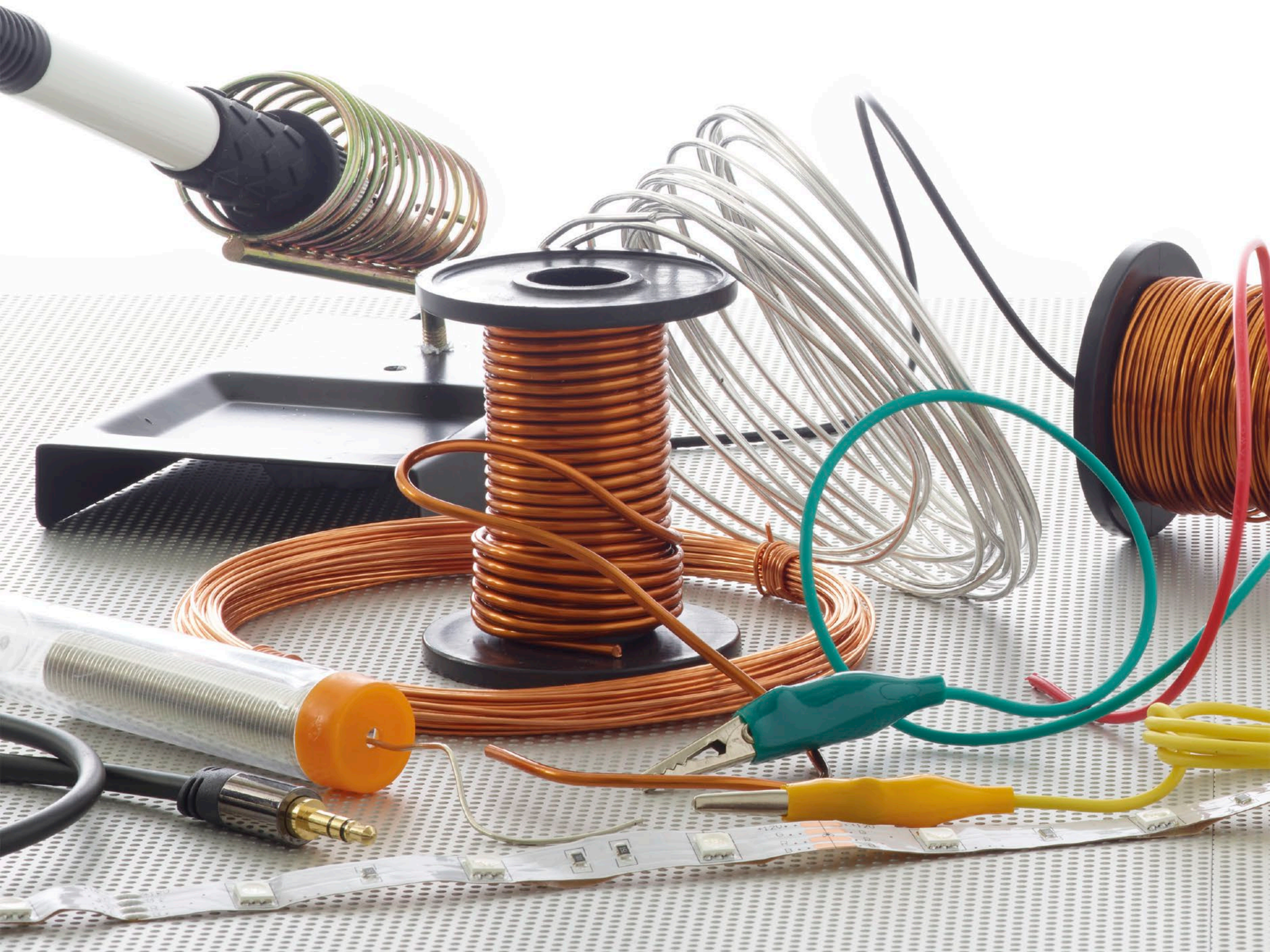
DK SMITHSONIAN

TECH LAB

BRILLIANT BUILDS FOR SUPER MAKERS



Contents



This symbol alerts you to safety issues when making a project. Refer to pp.8–9 for more information on how to do things safely, to avoid harming yourself or those around you.

This symbol alerts you to a particular skill you need for this part of the project, with a page number reference on where to find help with it.

Foreword

Welcome to *Tech Lab*—a book full of projects that involve electronic components such as resistors, capacitors, transistors, LEDs, and integrated circuits (ICs). These components are at the heart of all electronic devices, including computers and smartphones, so you'll gain an insight into how the things we use every day work.

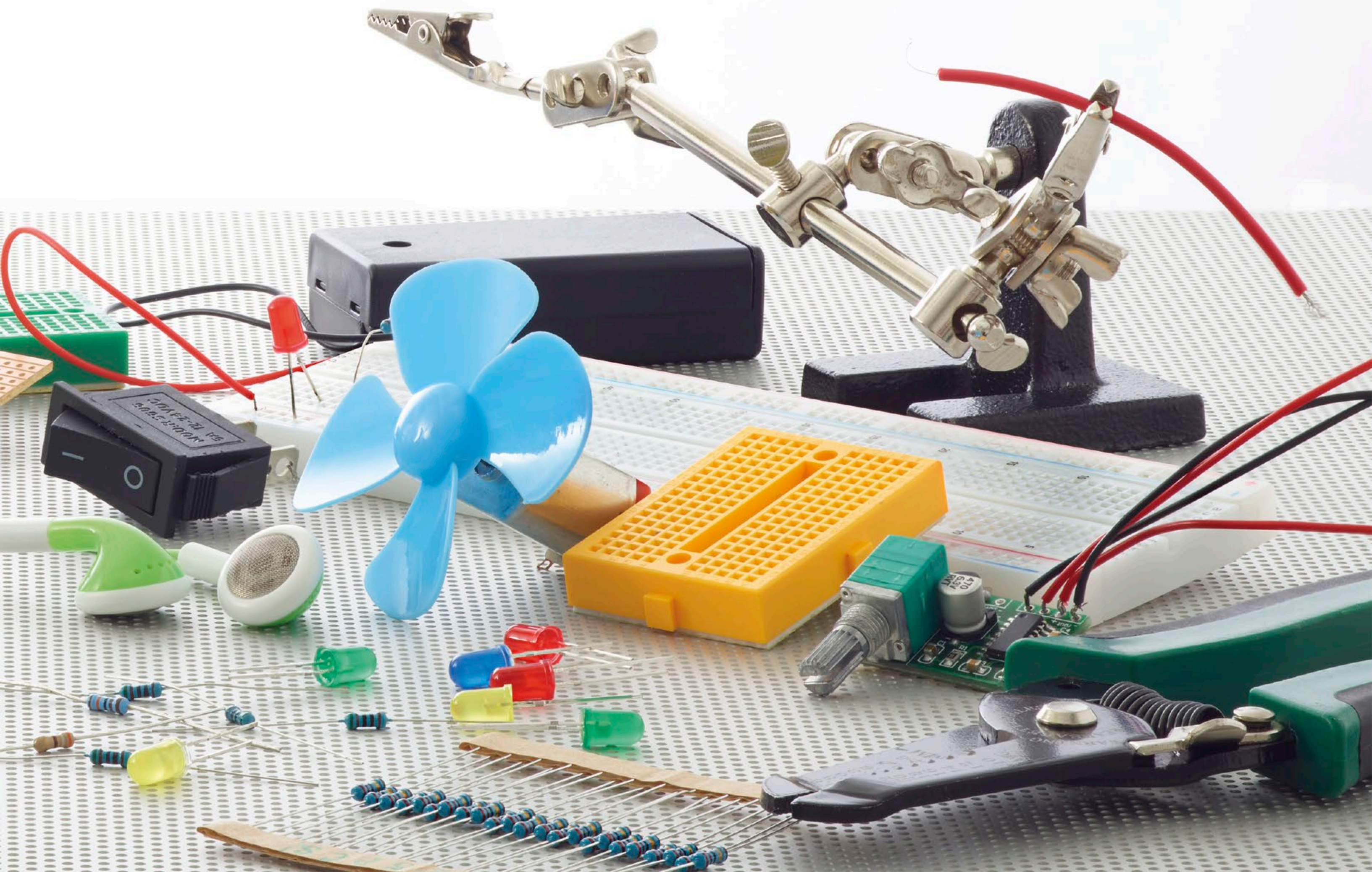
As a child, I took apart old radios that no longer worked, and was fascinated by all the electronic components I could see inside. I was lucky that a friend of the family was an electronics engineer, and she helped me build a few circuits, and took the time to explain how it all worked. She even bought me a soldering iron when I was just eight years old. My father worked for a company that repaired TVs, so we also had lots of old magnets and wires in our garage. I was lucky that I could tinker with these things, as there is no better way to understand how things work than by experimenting, trying things out.

In *Tech Lab*, you'll be building a radio, a metal detector, an electromagnetic crane, a USB-powered fan, and even a remote-controlled snake! You'll also make your own battery, and a night-light that turns on automatically when it gets dark, and many other things. If you can't find the parts you need for these projects in the stores near where you live, there are many online stores that sell electronic components. Take care to order the right things, and follow the instructions carefully when making the projects, and you'll be fine—even if you've never built any electronic circuits before.

I have a clear memory of the first time I used my soldering iron—I got a nasty burn on my hand! I also remember cutting myself a couple of times, when using saws and drills. Make sure you read the safety and skills sections at the beginning of this book, so you don't do the same. As well as the safety section, you will also find information about the components and tools you will be using in this book, many of which may be new to you.

Finally, when you are doing the projects, follow the instructions carefully, but when you feel confident, don't be afraid to experiment, be curious, and be creative—you never know what you might discover!

Jack Challoner

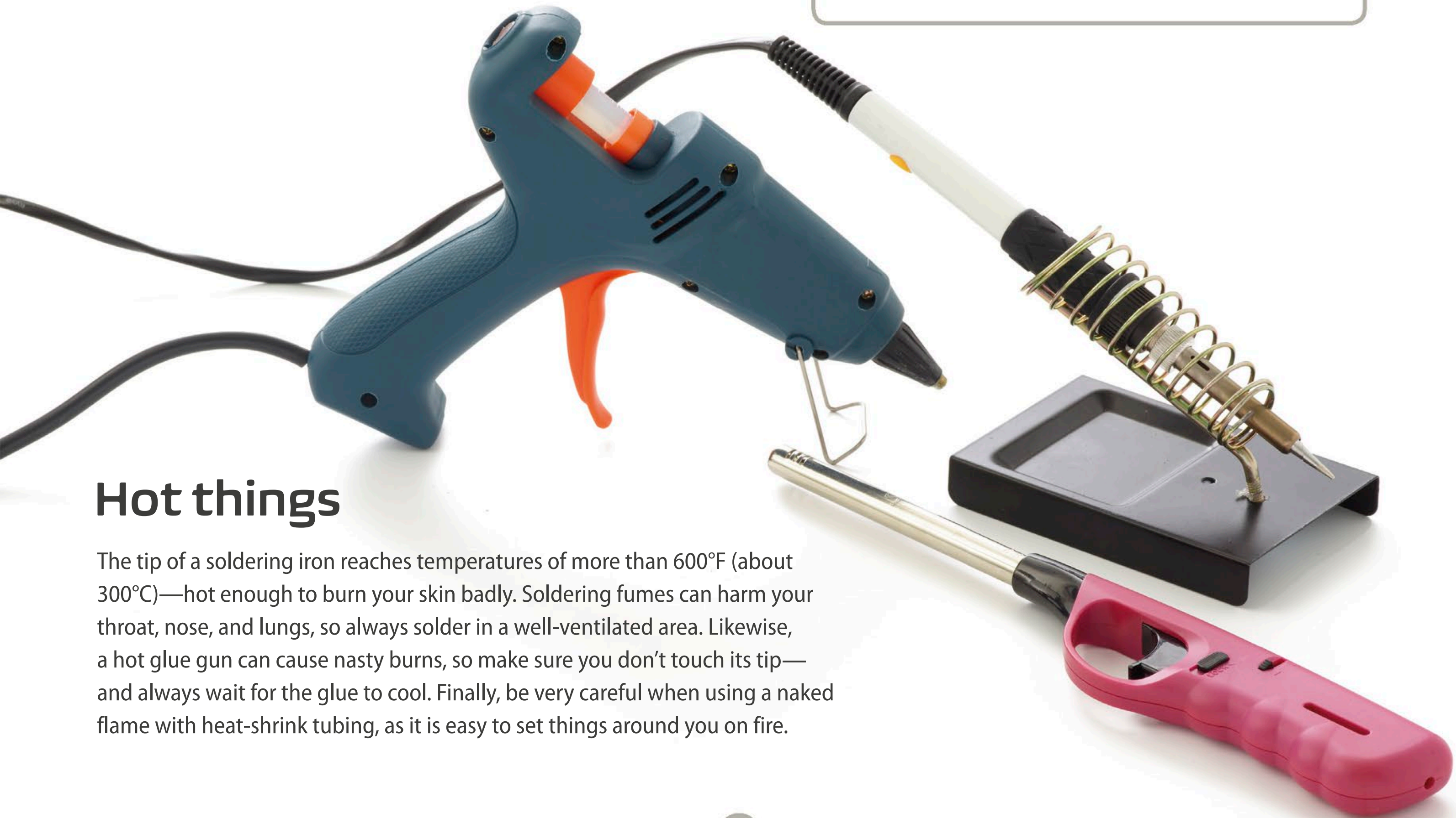


Staying safe

There are lots of exciting projects in this book. We want you to try all of them, and to have fun, but we also want you to stay safe. Read through the general safety tips on these pages before you try any of the projects.

Manufacturer's guidelines

It is always important to read the guidelines that the manufacturers of various tools, components, and safety-wear items include with their products. They aren't all the same, and the things you use might be slightly different from the ones we have used. Ask an adult if you are unsure about anything.

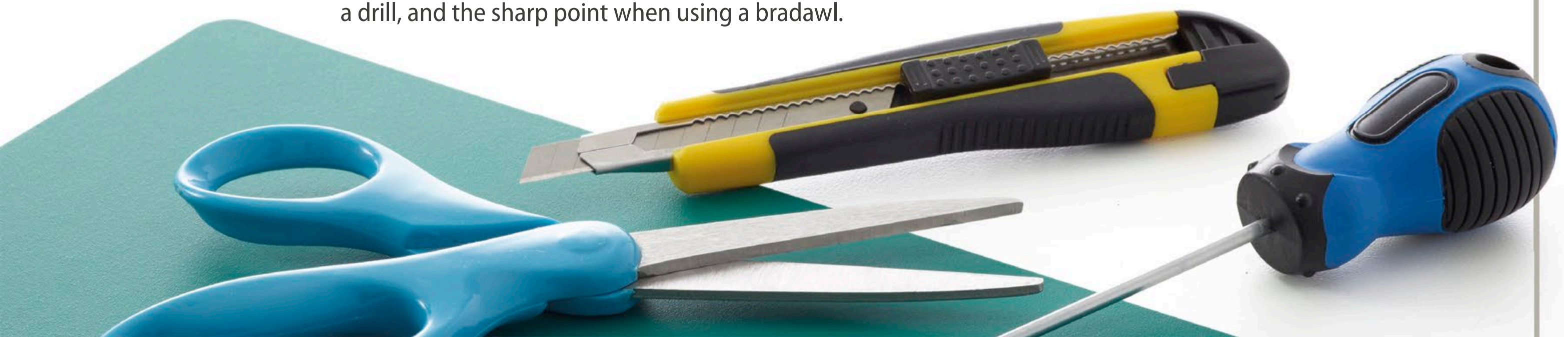


Hot things

The tip of a soldering iron reaches temperatures of more than 600°F (about 300°C)—hot enough to burn your skin badly. Soldering fumes can harm your throat, nose, and lungs, so always solder in a well-ventilated area. Likewise, a hot glue gun can cause nasty burns, so make sure you don't touch its tip—and always wait for the glue to cool. Finally, be very careful when using a naked flame with heat-shrink tubing, as it is easy to set things around you on fire.

Sharp things

The majority of these projects require you to cut and puncture things. Be extra careful with scissors, utility knives, saws, and drills, as their sharp edges can easily slip and cut you. When making holes in materials, keep your fingers and hair clear of the drill bit when using a drill, and the sharp point when using a bradawl.

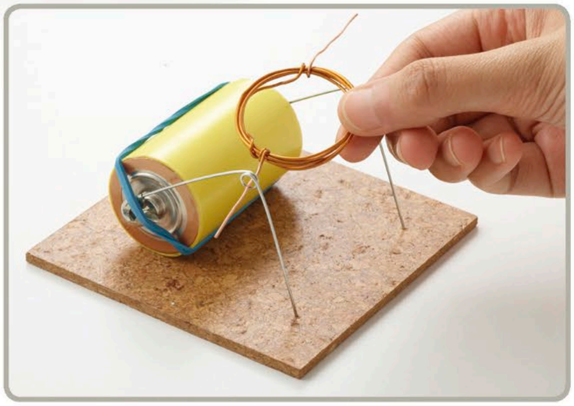


Safety wear

You should wear safety goggles and a dust mask when soldering, cutting wires, and drilling, to protect your eyes and throat from small bits of solder, wire, or other debris that can fly into the air. It's recommended that you wear cut-resistant gloves for cutting, but also for handling sharp things.

Electrical hazards

The majority of projects in this book involve electricity supplied by batteries. Never put batteries near or in your mouth. Some projects require mains electricity—it is extremely important to check the project instructions carefully and to make sure your wiring is perfect as powerline electricity can cause painful shocks and burns, and can even kill you. For both battery and powerline projects, disconnect anything that is becoming hot or smoking, before checking your wiring.



Disposing of things

It is very important to dispose of things properly when they are no longer needed. Most of the electronic components you use can be disconnected and reused. Plastic, card, and paper can be recycled, as can dead batteries. Metal blades can also be recycled—most companies offer safe and environmentally friendly ways of doing this, so check before you buy. It is important that none of these things end up in the regular garbage.

Working environment

Keep your working area clear and clean. Never have food or drink near where you are making projects. If there are younger children or pets in your home, never leave them unattended near hot, sharp, or electrical objects. When finished, clean up after your tools, components, and projects to minimize the chance of injury.

Toolbox

There are some things that are used again and again in these projects, so much so that we call them our "toolbox." They are mentioned briefly in the "you will need" section of each project, but here they are, with a description of each one. It's a good idea to get an actual toolbox in order to store and organize them properly.

Spring clamp

In this book, we use spring clamps to secure things that need to be drilled or sawed, so they don't move around.

Squeezing the trigger forces hot liquid glue out of the nozzle at the front of the gun.

Hot glue gun

Hot glue guns dispense hot glue, which helps to stick parts of a project together. They use glue sticks, which are inserted in the back.

Adhesive putty

Adhesive putty is mainly used in this book to protect work surfaces when you are making a hole in something. You can also use it to hold things in place as you work on them.

Scrap wood

Bits of scrap wood are useful when drilling or sawing to prevent damaging your work surface.

Tape

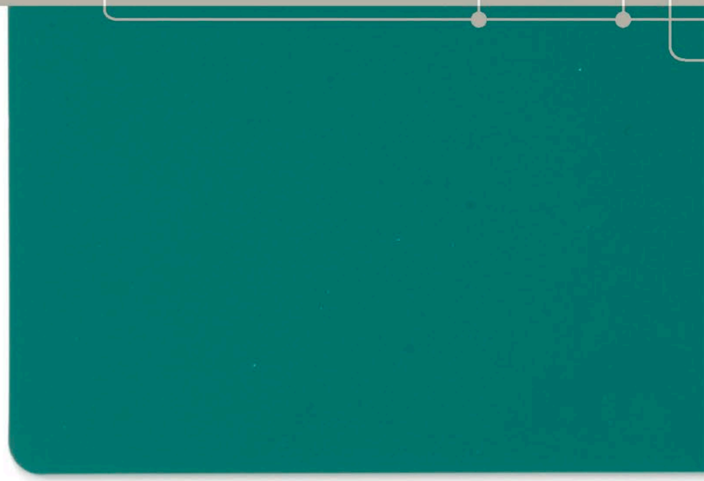
Sometimes, it's easier to use tape instead of glue to stick things together. In the projects in this book, we use electrical tape, double-sided tape, and double-sided foam tape.

Electrical tape is especially useful for insulating electrical wires.

Utility knife

Use a utility knife to cut through thin plastic or cardboard. The blade of a utility knife is very sharp, so be careful, and always cut against a straight metal edge, such as a metal ruler.

The blade is in sections that snap off when the front one gets blunt. Ask an adult to help you break off sections.



Cutting mat

When cutting through thin plastic or cardboard with a utility knife, always make sure you use a cutting mat underneath to protect your work surface.

Make sure you use scissors that are clean and sharp.

Scissors

Scissors can be used to cut through paper as well as to cut out shapes that don't have straight lines.

It's best to use a bradawl with a soft-grip handle.

Bradawl

The sharp point of a bradawl can make holes in plastic or thin wood. It can also be used to make a small pilot hole to guide you as you begin drilling.

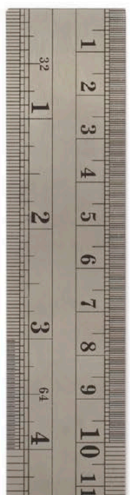
Sandpaper comes in a variety of grain sizes.

Sandpaper

We have used sandpaper to smooth down rough edges, and also to scrape the coating off enameled copper wires.

Markers or pencils

Most projects involve making marks as a guide for cutting or drilling, so it is a good idea to keep a marker and pencil in your toolbox.



Ruler

Many things in this book need to be measured properly, so you'll need a ruler. We recommend getting a sturdy metal ruler, which has markings for both imperial and metric measurements.

Make sure the teeth on the blade are facing forward.

Junior hacksaw

Use a junior hacksaw to cut through small pieces of wood and plastic pipe. Different types of blades are used for different materials, so make sure you choose the correct type.

Wire strippers

Some wires are coated in a layer of plastic insulation to prevent electricity from flowing where it shouldn't. Wire strippers are used to expose the metal part of the wire so that it can be connected to a circuit.

Drill

A drill uses drill bits to make holes. Drill bits come in many different sizes, and different kinds are used for making holes in specific materials. Ask an adult to help you choose the right drill bit and to help you drill safely.

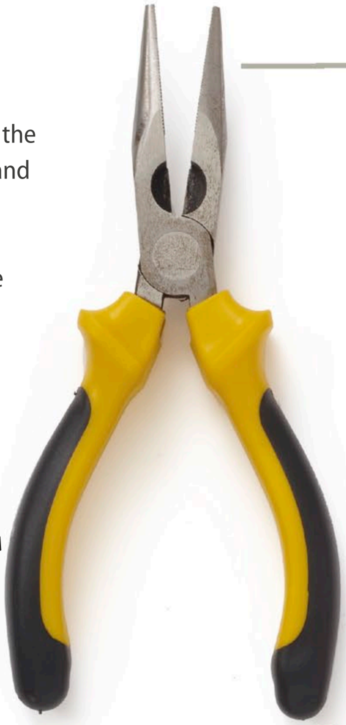
These drill bits are designed to make holes in wood. They can also make holes in soft plastic.

Wire cutters

In order to prepare wires that need to be connected to a circuit, you will need to use wire cutters to cut the wires to the correct length. Wire cutters can also be used to cut thin pieces of wood.

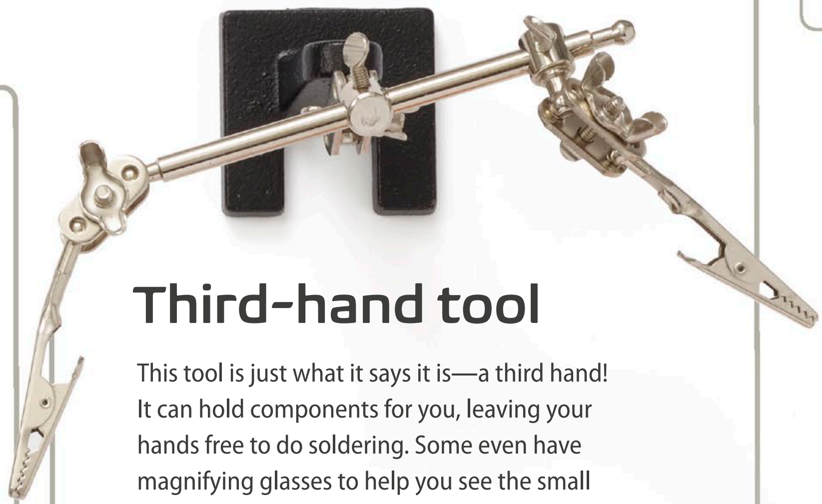
Pliers

You can use pliers to bend the ends of connecting wires and legs of components, or to shape thick wire. The most useful type of pliers for the projects in this book are "needle-nose" pliers.



Always grip the handle firmly when using pliers.

Third-hand tool



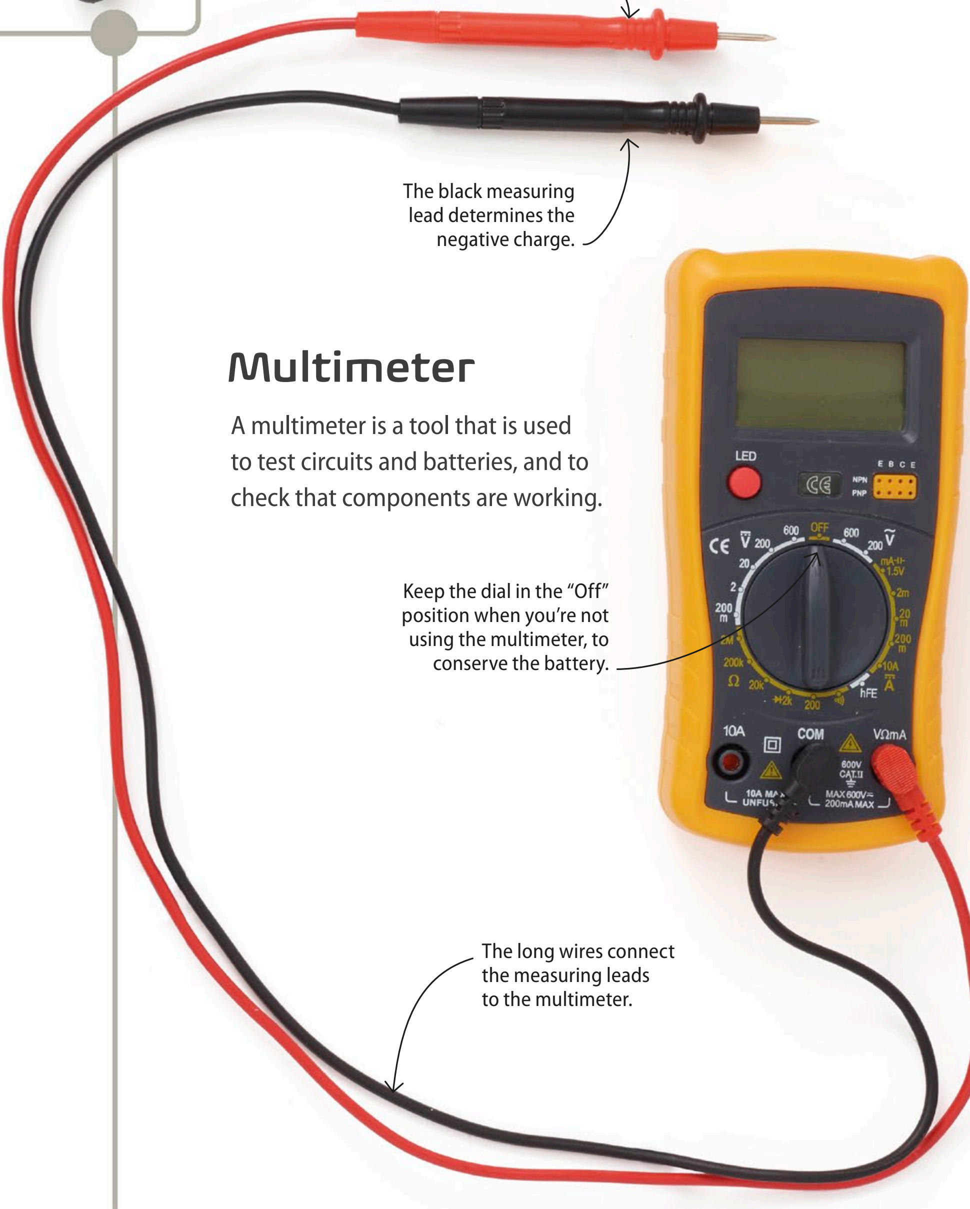
This tool is just what it says it is—a third hand! It can hold components for you, leaving your hands free to do soldering. Some even have magnifying glasses to help you see the small solder joints more clearly.

Soldering iron (and solder)

Try to buy solder that doesn't have lead in it.

A soldering iron is used to heat up and melt solder. Solder is an alloy (a mixture of metals) that can be used to join wires and electronic components to make circuits.

Multimeter



A multimeter is a tool that is used to test circuits and batteries, and to check that components are working.

The red measuring lead determines the positive charge.

The black measuring lead determines the negative charge.

Keep the dial in the "Off" position when you're not using the multimeter, to conserve the battery.

The long wires connect the measuring leads to the multimeter.

Components

Every electric circuit is made up of components that control the flow of electric current around the circuit. In this book, you will use many different types of components, and it is useful to understand what they are, how they work, and the things to look out for when you are buying them.

Power sources

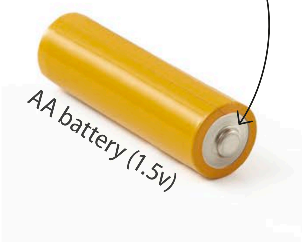
The most common way to power a circuit is with a battery. Inside a battery, chemical reactions produce electrons and generate electromotive force, which pushes the electrons around the circuit (see “Circuits” on pp.30–31). We also use solar panels in one project to provide electromotive force. The unit of measure of electromotive force is the volt (V).

Solar panels come in an array of sizes and shapes, and should be selected with the job they are expected to do in the circuit in mind.

Solar panels work best with direct sunlight or the beam of a halogen light.

Micro mini solar panels

This is the positive (+) end of the battery.



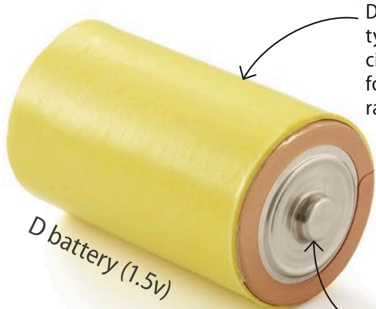
AA battery (1.5v)

This is the positive (+) terminal of the battery.

PP3 battery (9v)

Nine-volt batteries are rectangular, and their terminals are on the top of the battery.

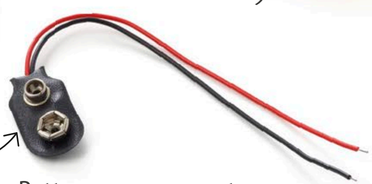
D batteries are typically used to power circuits you want to run for a long time, such as radios and motors.



D battery (1.5v)

This is the positive (+) end of the battery.

A snap connector can fit directly onto a 9v battery, or onto certain battery packs.

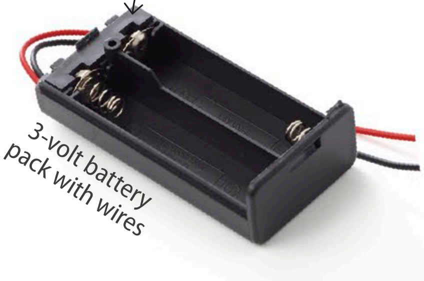


Battery snap connector

Some battery packs have terminals similar to the ones on 9v batteries.

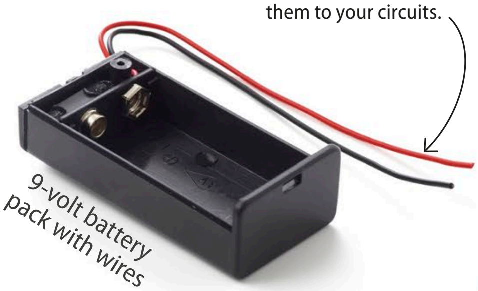
3-volt battery pack

Three-volt battery packs are suitable for two AA batteries.



3-volt battery pack with wires

You will need to strip the wires on battery packs with wire strippers before you can connect them to your circuits.



9-volt battery pack with wires

Capacitors

Capacitors are used to store electric charge. When current starts to flow in a circuit, a capacitor begins to charge up— once fully charged, no more current can flow. The unit of capacitance is the farad (F). Most capacitors have a tiny amount of capacitance—normally microfarads (millionths of a farad, μF), nanofarads (billionths, nF), or picofarads (trillionths, pF).

The capacitance of this variable capacitor can be changed by turning the knob in the middle.

Variable tuning capacitor

Electrolytic capacitors have a (+) or (–) marked on them and need to be connected in a circuit with this in mind.

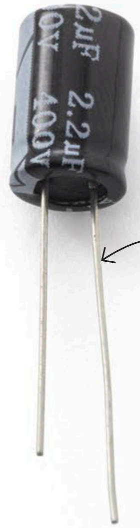
Most capacitors are ceramic capacitors. They are usually colored orange.

Electrolytic capacitors often have one leg (the positive leg) longer than the other.

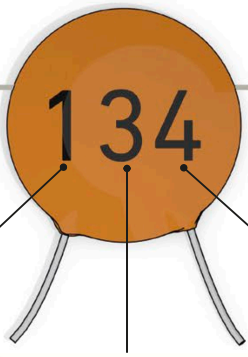
0.1 μF (100 nF) capacitor

0.01 μF (10 nF) capacitor

10 μF capacitor



2.2 μF capacitor



1	3	0000
The “1” indicates the first number of the capacitance.	The “3” indicates the second number of the capacitance.	The “4” shows the amount of zeros to add, making this capacitor 130,000 pF.

Reading a capacitor

On some capacitors, the actual value may be written out: for example, 34 nanofarad would be written “34 nF”. On most capacitors, however, there are only numbers. The numbers form a code for the capacitance in picofarads (pF). The first two are digits, and the third one is the number of zeros to add. To convert to nanofarads, divide by 1,000.

Resistors

Resistors are used to control the amount of electric current and voltage supplied to different parts of a circuit. They can ensure that a particular leg of a transistor is supplied with the correct voltage, for example, or control how fast a capacitor charges. The value of a resistor is measured in ohms (Ω). One thousand ohms is one kiloohm (kΩ), while one million ohms is one megaohm (MΩ).

390 Ω resistor

The colored bands give the resistor's value, in ohms.

100 Ω resistor

1 kΩ resistor

A photoresistor is a type of resistor that controls a circuit based on how much light is hitting it.

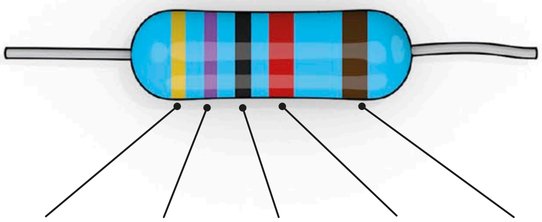
Photoresistor

Some resistors have five bands, while others have four.

10 kΩ resistor

Reading a resistor

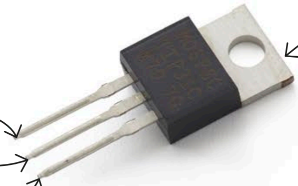
The diagram to the right shows you how to read the four (or five) grouped colored bands of a resistor to determine its resistance value. The first three bands are numbers, with the fourth being the multiplier. The separated colored band on the far right of the resistor tells you how dependable the given value is. In this case, the resistor's bands are yellow, purple (or violet), and black—which gives the number 470. The fourth band is red, which means it's 470 multiplied by 100 Ω, which equals 47,000 Ω (usually written as 47 kΩ). The final band is the tolerance, which is brown, meaning the resistor's true value is within 1% of the 47 kΩ reading.



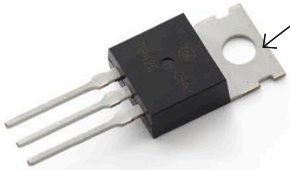
1st number	2nd number	3rd number	Multiplier	Tolerance
0	0	0	1 Ω	
1	1	1	10 Ω	± 1%
2	2	2	100 Ω	± 2%
3	3	3	1 kΩ	
4	4	4	10 kΩ	
5	5	5	100 kΩ	± 0.5%
6	6	6	1 MΩ	± 0.25%
7	7	7		± 0.1%
8	8	8		
9	9	9		
			0.1 Ω	± 5%
			0.01 Ω	± 10%

Transistors

Most transistors have three terminals—emitter, base, and collector. When a small amount of current flows into the base, it allows electrons to flow from the emitter to the collector (or from the collector to the emitter). A transistor can also act as an amplifier, because the large current flowing between the emitter and collector is a copy of the changes in the much smaller current flowing through the base.



TIP31 NPN transistor

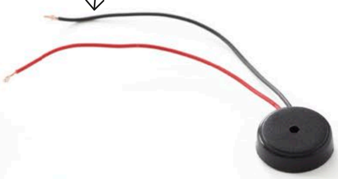


TIP42 PNP transistor

Speaker and earphones

Speakers, when supplied with varying electric currents, produce vibrations that travel through the air as sound waves. Earphones contain tiny speakers. Piezo sounders can only produce simple sounds, like buzzes or single tones.

Speaker 4 Ω 3 W



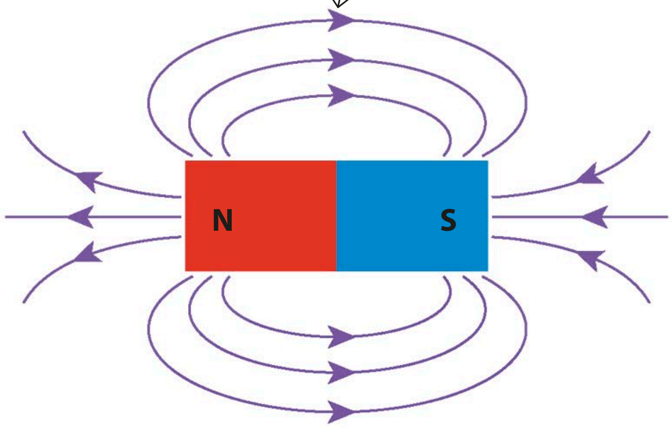
Piezo sounder

Speaker 8 Ω 1 W

Earphones

Magnet

You are probably familiar with permanent magnets. These always have a magnetic field and a "north" and "south" pole. Electromagnets are coils of wire, normally wound around an object containing iron. They only have a magnetic field when current flows through the coil.



Ferrite magnet

Wires

The connections between components are normally made with wires. The wire itself is metal, a good conductor. That means electricity can flow easily (with almost no resistance) through it. Wires are normally covered in plastic or enamel (lacquer), which do not conduct electricity, to prevent short circuits (see p.38).

Thick unlacquered copper wire

Wire comes in different thicknesses, or gauges.

36-gauge enameled copper wire

28-gauge enameled copper wire

You can use solid-core or stranded insulated wire in your circuits.

Red and black insulated wire

These wires carry audio information.

Auxiliary jack cable

The clips can be attached temporarily to a circuit.

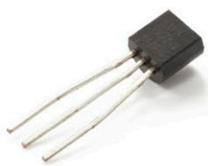
Crocodile clip wires

Most USB cables have an A and a B side.

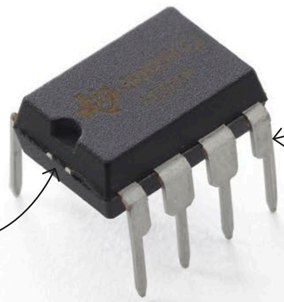
USB cable

Integrated circuits

Inside complicated electronic devices such as smartphones are several integrated circuits (ICs). These small packages contain ready-made circuits, with transistors, resistors, diodes, and capacitors, all built into a single piece of material. In this book, we use the 555 timer IC, which has eight legs—each with its own function. We also use the TA7642 chip, which is able to pick up AM radio signals.



TA7642 chip



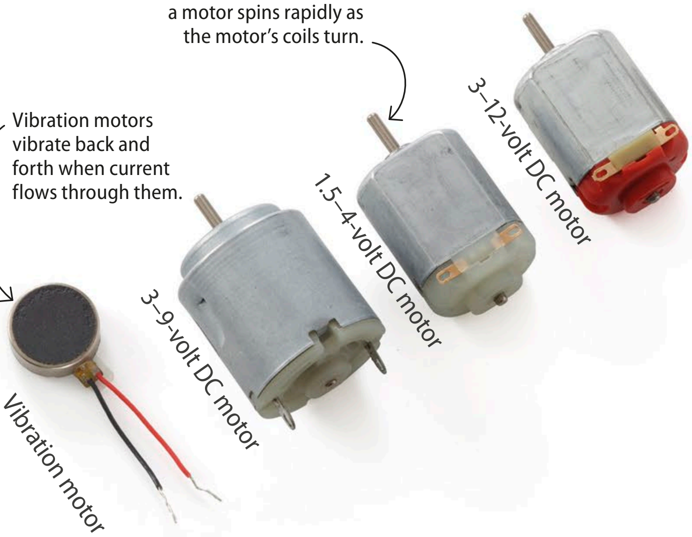
Each leg has a specific function in a circuit.

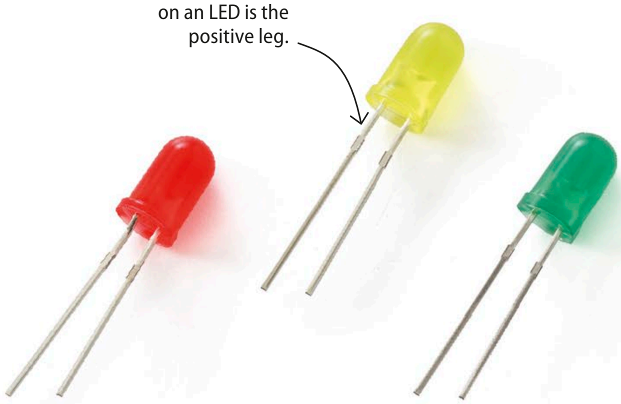
Always take note of which way the notch in the IC should face in a circuit.

555 timer IC

Motors

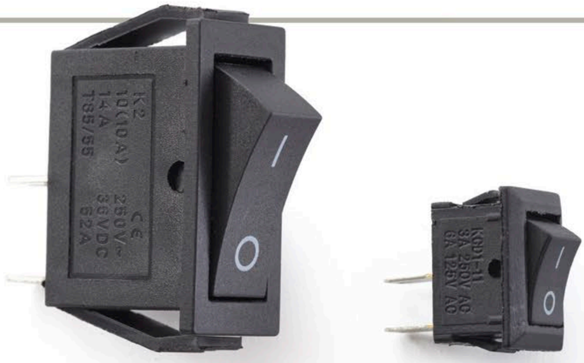
All motors convert electrical energy into movement energy. Coils inside the motor's body are pushed around by magnetic forces. Different motors require different voltages, so make sure you use the right one for the project you are working on.





LEDs

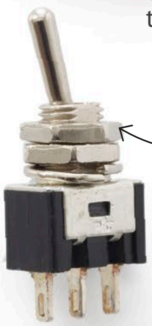
LED stands for "light-emitting diode." A diode is a component that allows electric current to flow in one direction only. It must be connected the right way around in a circuit, so all diodes are marked with a (+) or a (–) sign, or they have one leg shorter than the other. An LED is a diode that produces light when current flows through it.



Switches

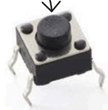
A switch is a mechanical device that creates a break in a circuit. When you activate the switch, it opens or closes the circuit, depending on the type of switch it is. "Single-pole, single-throw" switches are the simplest and most common type of switch. They either allow or prevent current to flow.

Single-pole, single-throw (SPST) switch



Single-pole, double-throw (SPDT) switch

Double-pole, double-throw (DPDT) switch



Tactile button switch

Skills

You are going to be making a lot of very exciting things as you work through this book. It's a good idea to brush up on the basic skills you will need in order to make these projects properly, and also to stay safe. You may need to ask an adult for permission to use tools, and if you run into any problems when performing these skills.

Cutting things

Scissors are great for cutting paper or thin cardboard, but to make a straight cut through thicker cardboard, you need to use a utility knife. And for cutting wood, plastic, or metal, you will need saws. Whatever you are cutting, mark it out carefully first, using a pencil and ruler. Cutting tools have sharp blades, so you need to measure carefully, keep your work space clear, and concentrate as you cut.

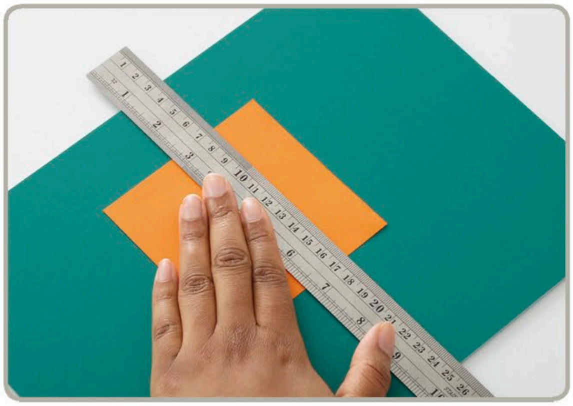
Utility knife

In order to cut thick cardboard or foam board, you will need to use a utility knife (also known as a craft knife). These knives have extremely sharp blades, so be extra careful, and ask an adult if you are not sure how to them. You may want to ask an adult to help you change the blade when it becomes dull.

Be aware
Wear safety goggles and gloves when cutting, even with a utility knife, as the blade could snap. See "Sharp things" on p.8 and "Safety wear" on p.9 for more tips.

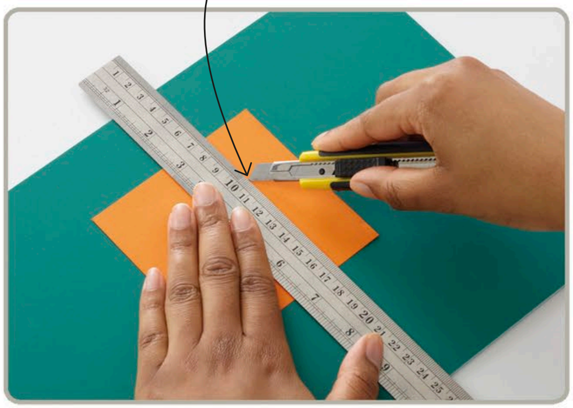
This is the cutting side.

1 Study the blade to see which is the cutting side. Using the wrong side could cause the knife to slip. If the blade is extendable, don't extend it too far, as it may wobble or snap.



2 Place the material to be cut on a cutting mat. Line up a straight metal edge, such as a metal ruler, where you want to make your cut. Hold the metal edge securely in place.

You may find that lightly scoring the material a few times will help when you come to make your cut.



3 Press down firmly on the handle of the blade and pull the knife slowly across the material, at an angle away from your body. Be careful not to go too fast or let the knife slip over the metal edge.

Hacksaw

A hacksaw has a cutting blade stretched across its frame. It can cut through wood, metal, and plastic, depending on the blade you use. When you use a hacksaw, you cut with a backward and forward motion, with pressure applied on the forward stroke. As with any cutting tool, a hacksaw can be dangerous if used incorrectly.

Scrap wood protects your working surface, and also provides a little bit of a ledge to allow you to cut properly.

1 Use clamps or a vise to hold what you are cutting firmly in place. Secure the item you are cutting over the edge of your worktable, or to some scrap wood.

Keep the hacksaw as straight as you can when cutting.

2 Press the blade firmly down and away from you. If you don't have a vise, find a safe way to lean on one end of the item while the other end hangs over the edge of the table.

3 If you are cutting pipe (which you need to do in one of the projects), wrap a piece of paper around the pipe and tape it in place. This will give you a flat edge as a guide.

4 Hold the handle of the hacksaw firmly and angle the saw downward. Press the blade away and down, keeping the saw in one line. You may need to start slowly in order to create a groove in the pipe.

Since the pipe is round, you can't use clamps and may not have a vise that can steady it. Instead, hold the pipe firmly with your free hand.

Using a glue gun

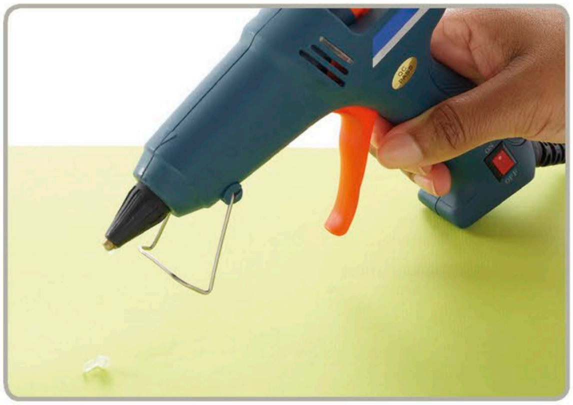
Many of the projects in this book use strong glue dispensed by a hot glue gun. The glue comes from glue sticks, which are inserted in the back of the gun. When plugged into an electrical outlet, a heating element inside the gun melts the glue stick. The glue becomes very hot inside the gun, so never pull out a glue stick, and never leave a glue gun plugged in and unattended. You will need to plan where to work when using a glue gun, since most do not have long power cords.

Be aware

The nozzle and the glue are hot, so don't touch them. If you do, run the burn under icy-cold water for a few minutes. See "Hot things" on p.8 for more tips.

Manufacturer's instructions

Don't forget to check the manufacturer's instructions on how to use their tools (particularly for electrical tools). Each manufacturer makes tools a little differently, and so might include features that make a tool easier to use, or things you need to take into consideration when using that tool.

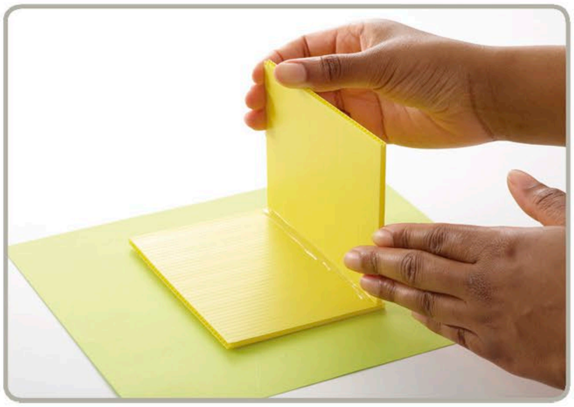


1 Place paper or a work mat on your work surface to catch any hot glue that might drop by accident. Plug in the glue gun, place it safely on its stand, and wait for a few minutes for the glue to heat up.

2 Make sure enough glue is loaded into the glue gun. If the stick in the gun is short, simply push another stick in through the hole in the back of the gun. Before starting, make sure the items you are going to glue are clean and dry.

Keeping the trigger pressed will keep the hot glue coming from the nozzle.

3 To use the gun, gently squeeze the trigger of the glue gun. Melted glue will ooze out of the nozzle.



4 Release the trigger once you have applied enough glue. The glue takes about 30 seconds to cool and harden. Do not touch the glue until it has dried, as it can burn you.

Drilling

A drill is a powerful machine that makes holes in things. The part of the drill that makes the holes is the drill bit. There are drill bits specifically designed for making holes in wood, plastic, metal, and concrete, so ask an adult to help you select the right kind. Drill bits also come in a wide range of sizes (relating to the width of the drill bit), so that you can be sure to make the hole the right size.

Be aware
Make sure you tie back your hair if it is long and secure any loose clothing before drilling.
See "Sharp things" on p.8 and "Safety wear" on p.9 for more tips.

This is the chuck.

1 Once you have selected the correct drill bit, insert it into the front part of the drill, called the chuck. Turning the ring at the front of the drill opens and closes the jaws of the chuck.

Make sure the drill bit is straight before drilling with it.

2 Twist the ring clockwise to close the jaws around the drill bit. Turn it as far as you can to make sure the drill bit is securely held in the chuck. You can remove the drill bit by turning the ring counterclockwise.

3 With the drill bit secured, you are ready to begin drilling. Make sure your drill bit spins clockwise when viewed from behind the drill. Flip the switch on the side if it's spinning counterclockwise.

Use scrap wood underneath your item so you don't drill into your work surface.

4 Use clamps or a vise to secure the item you are drilling. This will stop it from spinning around and will free your hands to concentrate on the drilling.

5 Place the drill bit where you want to drill. Squeeze the trigger, and press the drill bit firmly down. Make sure you keep the drill straight so you don't drill a crooked hole.

Using a bradawl

A bradawl can be used to make a guide, or pilot, hole in something you want to drill. It can also be used when you need to make a hole in a flexible material, like a plastic bottle or box.

Be aware
The tip of the bradawl is very sharp, and can easily puncture and tear skin. Keep it away from your eyes at all times.
See “Sharp things” on p.8 for more tips.

1 Place some adhesive putty underneath the material in which you want to make your hole. Push the bradawl through the material, twisting back and forth, until it reaches the adhesive putty.

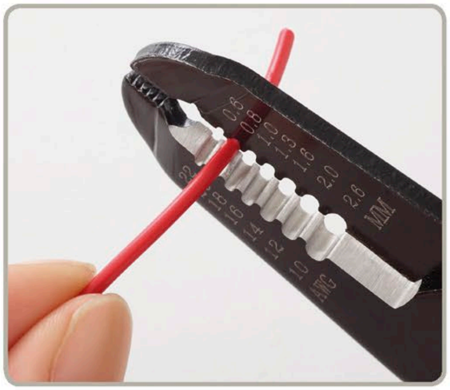
2 If you can’t use adhesive putty, carefully hold the material, with your fingers away from where you are making the hole. Push the bradawl, twisting it back and forth, until it comes through the other side.

Preparing wires

Wires have a layer of plastic insulation. To make a connection to a circuit, the end of the insulation needs to be stripped off to reveal the metal wire inside. Normally, you just need to strip about 3⁄8 in (1 cm) off the end.

Be aware
Stranded wires can be very sharp, and can puncture the skin. Be careful when using sharp things to cut wires.
See “Sharp things” on p.8 for more tips.

1 First, cut the wire if necessary with wire cutters. Some wire-stripping tools have a cutting blade, but you can also use a pair of wire cutters, scissors, or pliers.



2 Put the end of the wire through the open jaws of the wire-stripping tool. The tool has lots of different-sized holes. Find the one that matches the wire by gently squeezing the handles together.

3 Squeeze the handles together more firmly and pull the wire away from the wire-stripping tool. The insulation should come away cleanly.

Before cutting or stripping a wire, make sure the wire is not connected in a live circuit.
See “Electrical hazards” on p.9 for more tips.

Soldering

A soldering iron is one of the most essential tools when making electric circuits. It is used to melt solder, which is a metal alloy (a mixture of metals). When the solder cools, it hardens to create a strong bond between wires and components. Because it is made of metals, solder conducts electricity. Make sure the solder you use is designed for electrics and not plumbing.

1 When you are doing any soldering work, make sure you sit at a bench or put down paper, as droplets of solder can fall off and damage the table.

Always be aware of the position of the cord, so you don't accidentally pull the soldering iron off the table.

The fumes produced during soldering can irritate asthma, so don't get too close—and make sure the room is well ventilated. See "Hot things" on p.8 for more tips.

When you're not using it, place the soldering iron safely back in its stand.

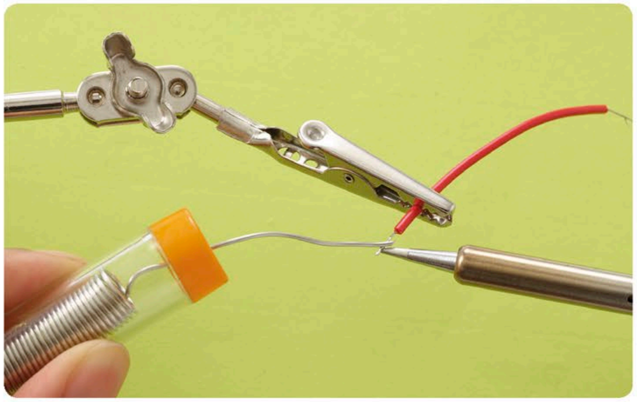
Be careful not to let your skin come into contact with the hot soldering iron.

Set your soldering iron to the lowest temperature setting.

2 Place the soldering iron in its holder and turn it on. It will get very hot within a few minutes, so be careful! Make sure you wear safety goggles because hot solder can spatter.

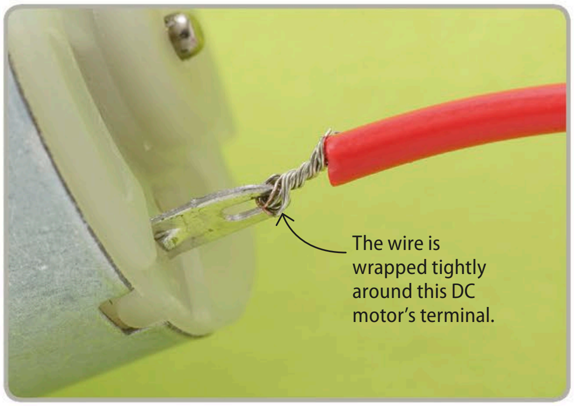
3 Before you start soldering, clean the tip of the soldering iron with a wet sponge—some soldering iron stands have a sponge built in. Alternatively, you can buy a bronze sponge specifically designed to clean soldering iron tips.

4 It's a good idea to use a third-hand tool to hold the wires or components to be soldered. This allows you to safely hold the soldering iron and solder in each hand while you make your connections.

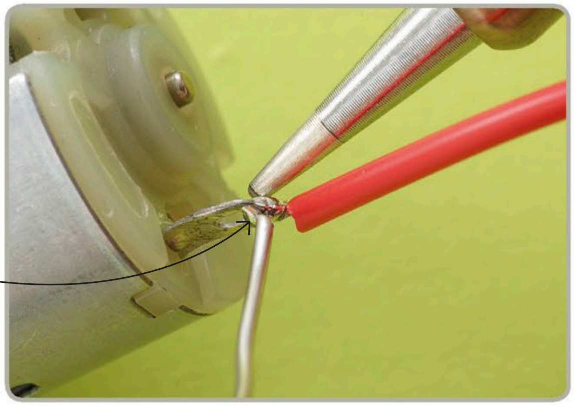


Tinning

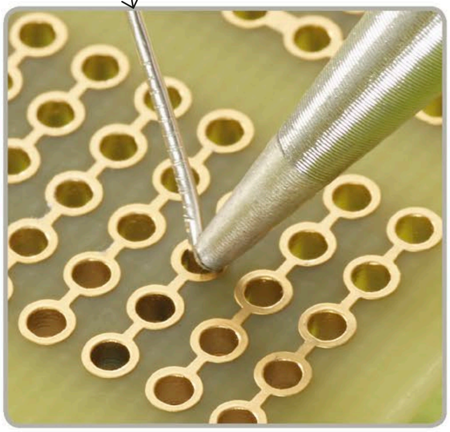
It is generally a good idea to cover the parts to be joined with a thin coat of solder, as it helps to ensure the wires will make a good electrical connection. This is called tinning. To do this, place the soldering iron onto the end of a stripped wire or onto the terminal of a component. After about two or three seconds, touch the solder onto the heated wire or terminal, and the solder should flow onto it. It is also a good idea to tin the tip of the soldering iron just before you start soldering to protect it from rusting.



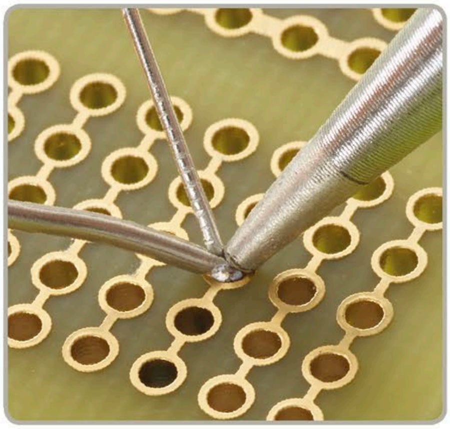
5 Make a good physical connection before you solder. If you're attaching a wire to something, twist it firmly around whatever you're connecting it to.



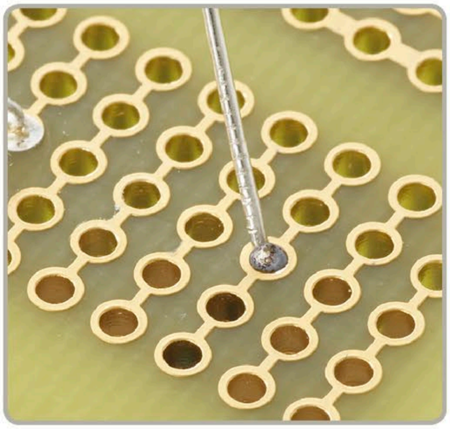
6 Hold the soldering iron against the joint, not the solder. The solder will melt onto the hot joint within a second or two. When it has done so, remove the soldering iron, but keep the joined parts still for a few seconds to let the solder harden.



7 When soldering a component to a perforated breadboard, touch the soldering iron to the hole for a few seconds.



8 Once the hole and the component are hot, touch the solder to the hole.

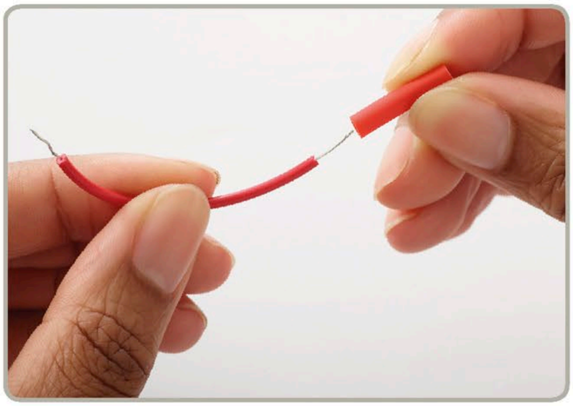


9 The solder will flow around the soldering iron and fill the hole, securing the component leg to the board.

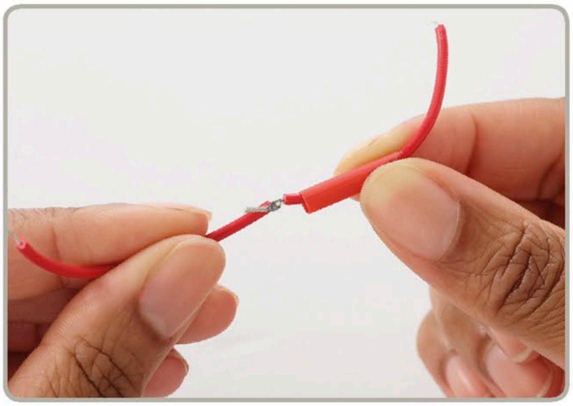
Using heat-shrink tubing

In some of the projects, you will be using heat-shrink tubing. This is a flexible plastic tube that shrinks when you apply heat to it. It is used to cover soldered joints to make sure no other parts of a circuit can touch them. It will also make the joint stronger.

Don't apply the flame for more than a few seconds, and don't hold it too close to the tubing. See "Hot things" on p.8 for more tips.

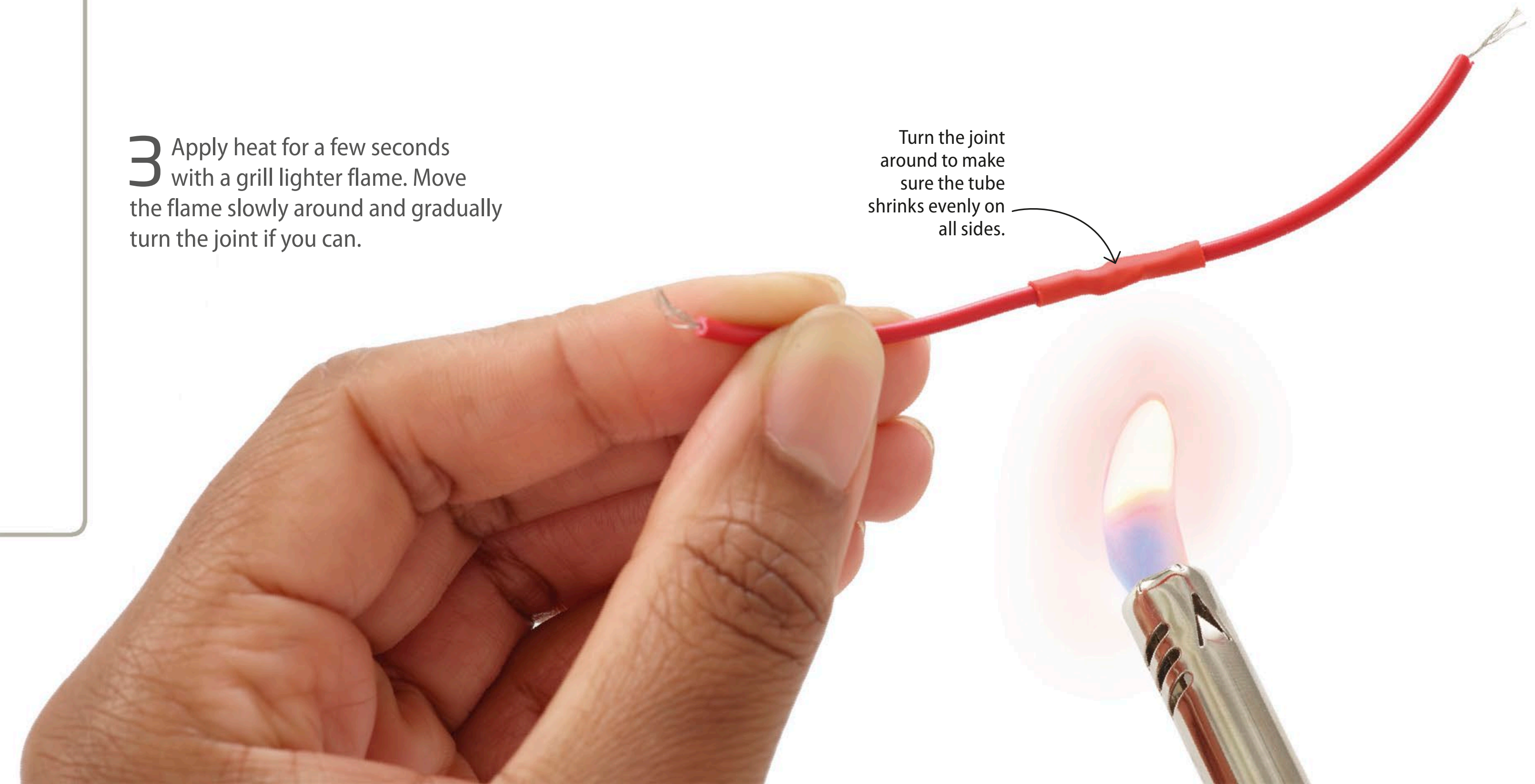


1 Before you begin soldering two wires together, cut the tubing so that it will safely cover the join in the wires. Slip the tubing over one of the wires.



2 When your two wires are soldered, slip the tubing over the solder joint so that it covers it completely.

3 Apply heat for a few seconds with a grill lighter flame. Move the flame slowly around and gradually turn the joint if you can.



Using a multimeter

A multimeter is a device that can measure voltage, current, and resistance. In the projects in this book, you will only be using it to check that there is a continuous path for electricity to flow through your circuits, or through the components you use. You do this by testing to see if electricity can flow between the two metal prongs. This is very useful for checking for a broken connection in your circuit.

This section is used to measure electric current, in amps (A).

The prongs connect to these sockets.

This section is used to measure voltage (V), measured in volts.

This section is used to measure resistance, in ohms (Ω).

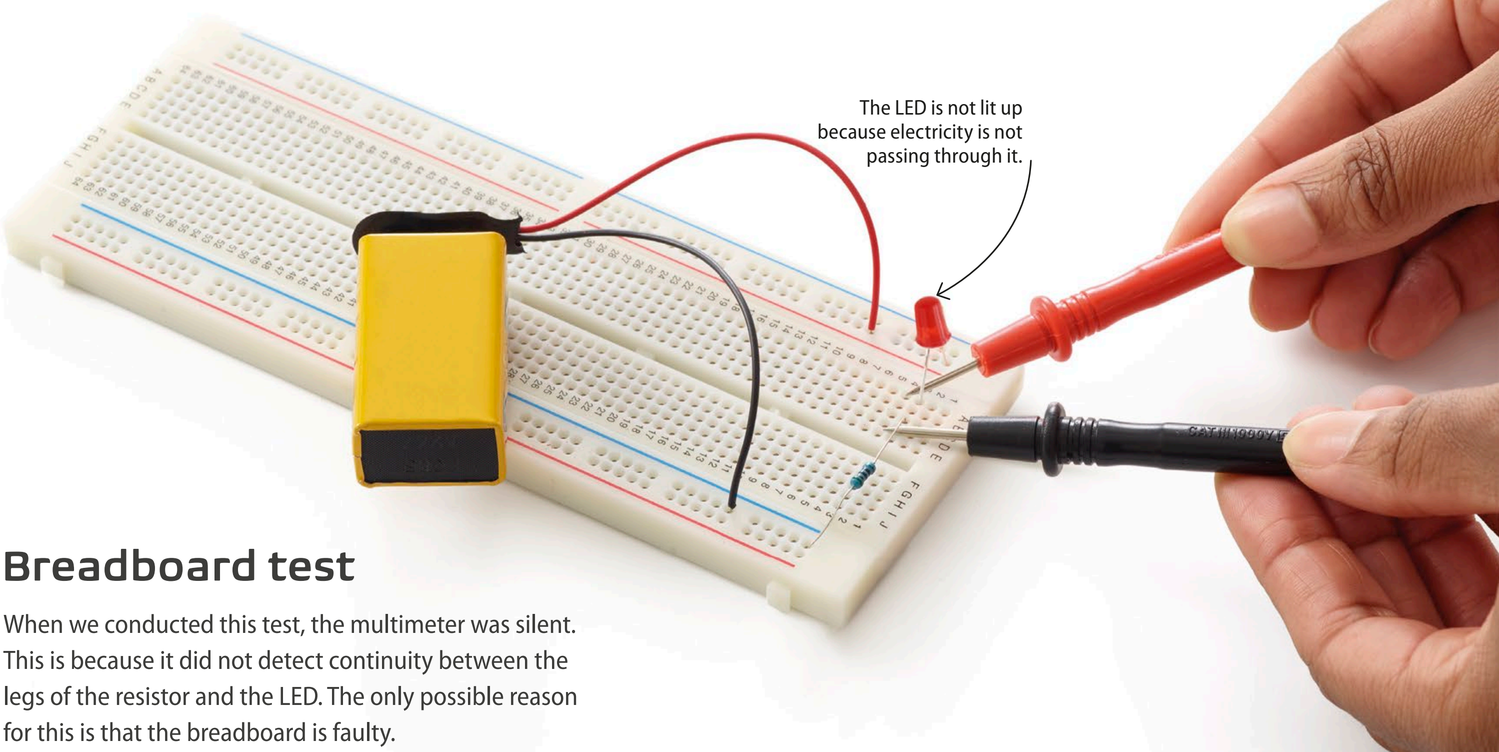
Every multimeter is different, so you may need to read the manual if your model is different to this one.

This setting is useful for testing for short circuits, broken wires, or loose connections.

1 Plug the multimeter's red and black measuring prongs into the red and black sockets. If your multimeter's sockets aren't color coded, plug the black lead into "COM" and the red lead into "VΩmA." If your model doesn't have these markings, you may need to search online for its particular layout.

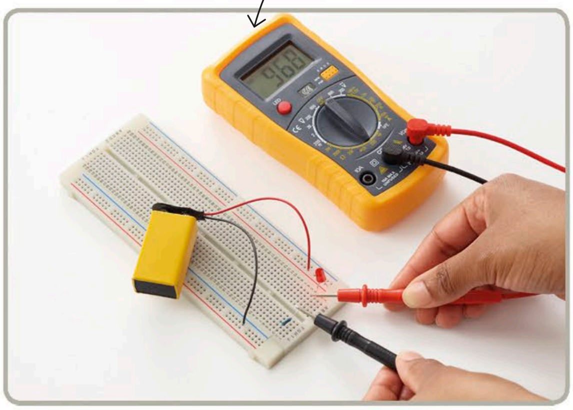
2 If your multimeter has a continuity test setting (the icon looks like a sound wave), turn the dial to it. Touch the measuring prongs together. You should hear a high-pitched noise when they come into contact, which shows that the prongs are working. Next, you will test your circuit.

3 To see if there's a break in a circuit, or if there's a short circuit—in which case, there would be continuity between two parts of a circuit where there shouldn't be—use the continuity setting. In the circuit below, there was no current flowing through the LED, so we did a continuity test to see if the breadboard was faulty, since the components were plugged in correctly.

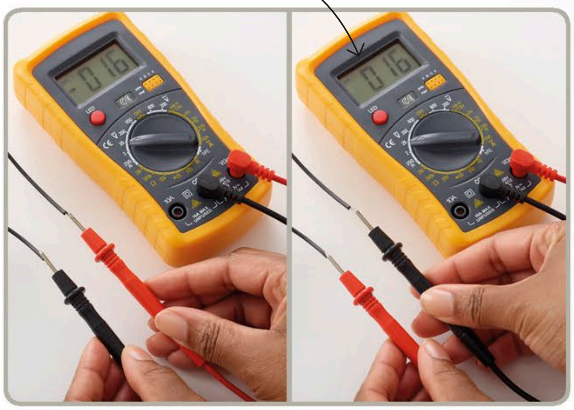


Breadboard test

When we conducted this test, the multimeter was silent. This is because it did not detect continuity between the legs of the resistor and the LED. The only possible reason for this is that the breadboard is faulty.



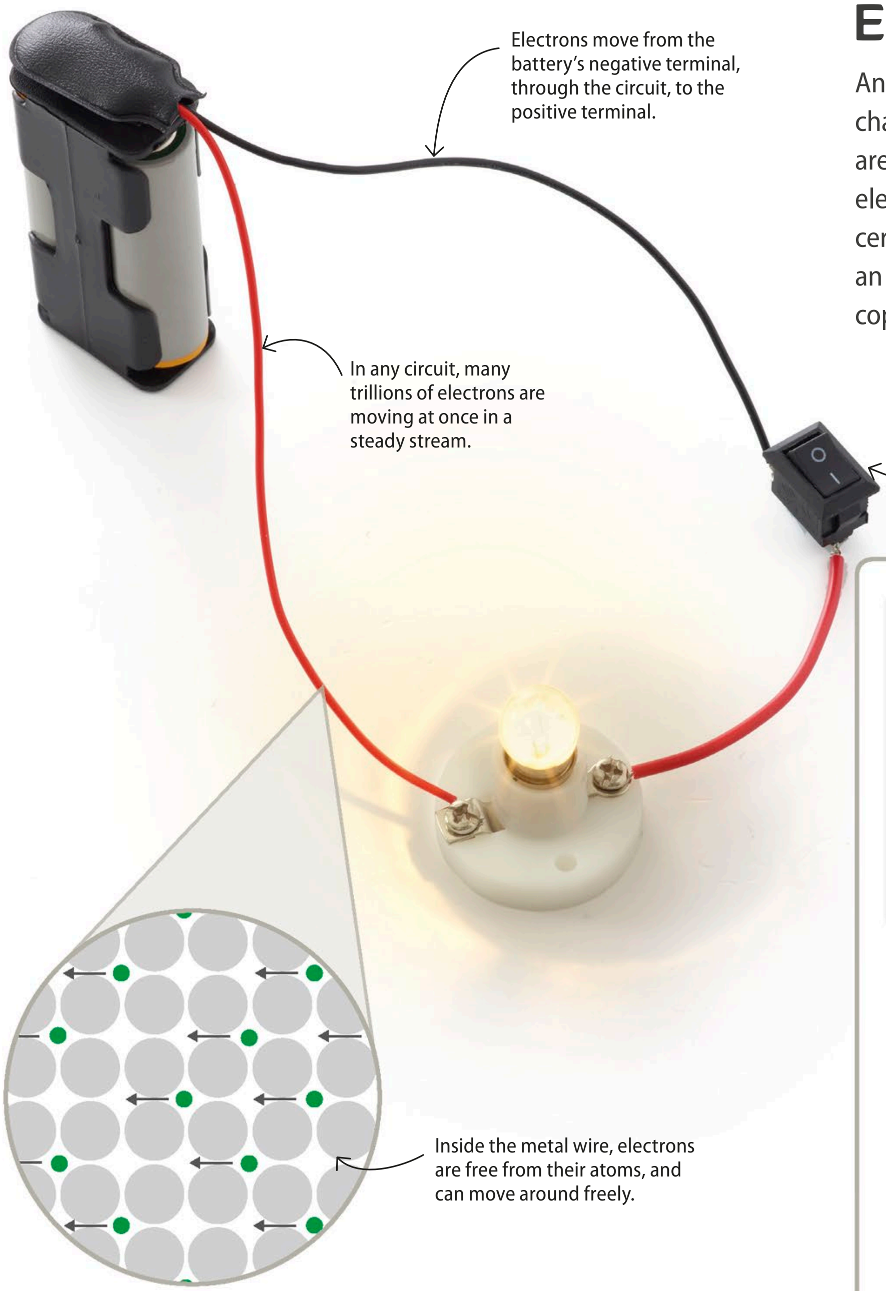
4 If your multimeter does not have a continuity test setting, set the dial to the most sensitive resistance setting. This may be indicated by the word "Resistance" or by the symbol for ohms (Ω). In a functioning circuit, your multimeter should read close to zero.



5 You can use your multimeter to test for polarity in wires—which is positive and which is negative. Click the dial to a voltage setting (V) just above the voltage of the circuit. Touch the prongs to the wires. If there is a minus symbol in front of the number reading, swap the leads.

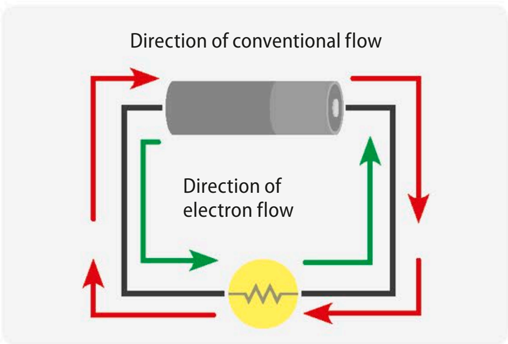
Electric circuits

All of the projects in this book involve building electric circuits. In each case, electric current flows around a circuit, providing energy to make something happen—such as lighting a lamp or making sound in a loudspeaker. Current can only flow if there is a complete circuit—a path along which the electrons can move.



Electric current

An electric current is any movement of electric charge. In electric circuits, the things that move are particles called electrons, which carry negative electric charge. Electrons can move easily through certain materials, called conductors. The wires of an electric circuit are made of metal (normally copper)—and metals are good conductors.



Which direction?

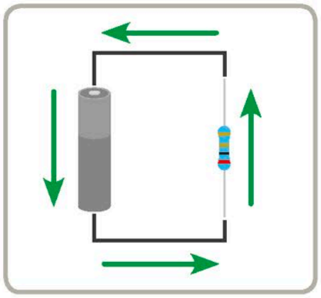
Scientists began investigating electricity long before they knew about electrons. They thought current flowed from the positive end of a battery to the negative end, but in reality, it is the other way around. The old way, called "conventional current," is still used in most diagrams, but when we show electric current in this book, we will show the direction of electron flow.

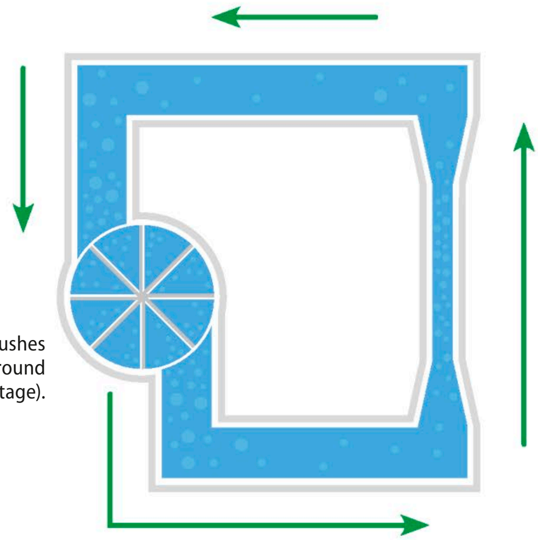
Voltage, current, and resistance

In order to understand electric circuits, you will need to know about voltage, current, and resistance. To help you understand what these mean, it helps to imagine an electric circuit as a loop of pipes with water pushed through them by a pump. In this analogy, the pump is a battery, the pipes are the wires, and the water represents the electrons.

Voltage

To produce a current in an electric circuit, there has to be a force on the electrons. That force, called an electromotive force (emf), can be supplied in many ways—for example, by a battery. The greater the emf, the more energy the electrons have, and voltage, in units called volts (V), is a measure of the energy of each electron. In the water analogy, voltage is the pressure the pump produces.



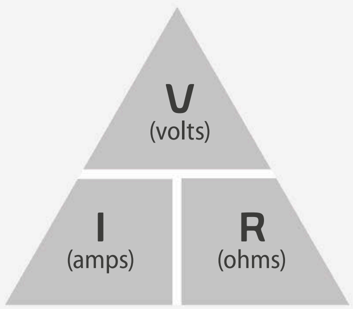


Current

The current flowing in a circuit is a measure of the number of electrons passing any point in the circuit each second. The greater the voltage and the lower the resistance, the greater the current. Electric current is measured in units called amperes (A), or amps for short. In the water analogy, current is the amount of water flowing per second.

Resistance

Electrons move easily through metal wires—as the wires put up very little resistance to their movement. But most electrical components have some resistance, and the total resistance of a circuit determines the flow of electrons (the current). Resistance is measured in units called ohms (Ω). Resistors are components that have particular resistances—they control current in a circuit. In the water analogy, resistance is the width of the pipes.



$$V = I \times R$$

$$I = \frac{V}{R}$$

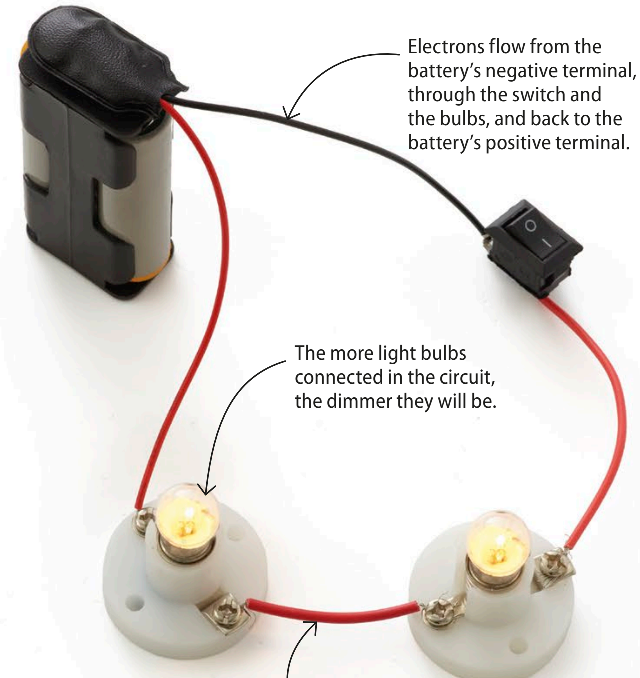
$$R = \frac{V}{I}$$

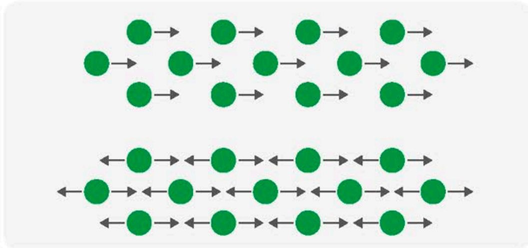
Ohm's Law

A rule called Ohm's Law, shown as a mathematical equation, summarizes the relationship between the voltage, resistance, and current in a circuit. The equation states that voltage is current multiplied by resistance; current is voltage divided by resistance; and resistance is voltage divided by current. If you know two of the values, you can work out the third using Ohm's Law. Ohm's Law is useful when designing circuits, as you can use it to quickly find out what components you need to build a working circuit safely.

Series and parallel circuits

In some circuits, the wires and components are connected one after another, "in series." In other circuits, there are branches in the circuit, in which case the wires and components are "in parallel." Most circuits have at least some components connected in parallel.





AC and DC

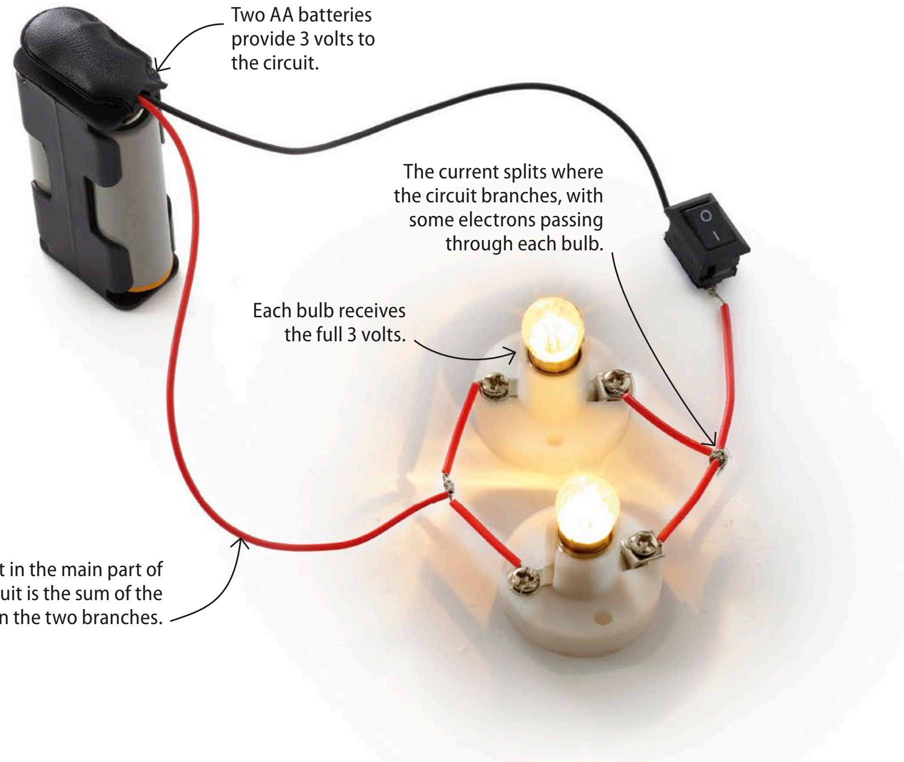
In some circuits, the electrons move in one direction only—this is called direct current (DC, top illustration above). In others, they move backward and forward. In that case it is called alternating current (AC, bottom illustration above).

Series circuits

In a series circuit, there is only one path through which the current can flow. All the electrons pass along the same route. The current in a series circuit is the same throughout the circuit—it is determined by the total resistance of all the components. The energy of the electrons is shared between all the components.

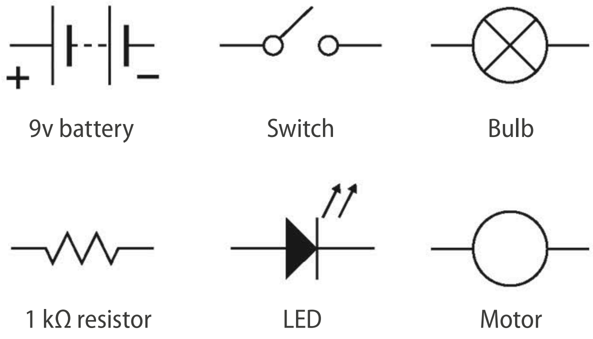
Parallel circuits

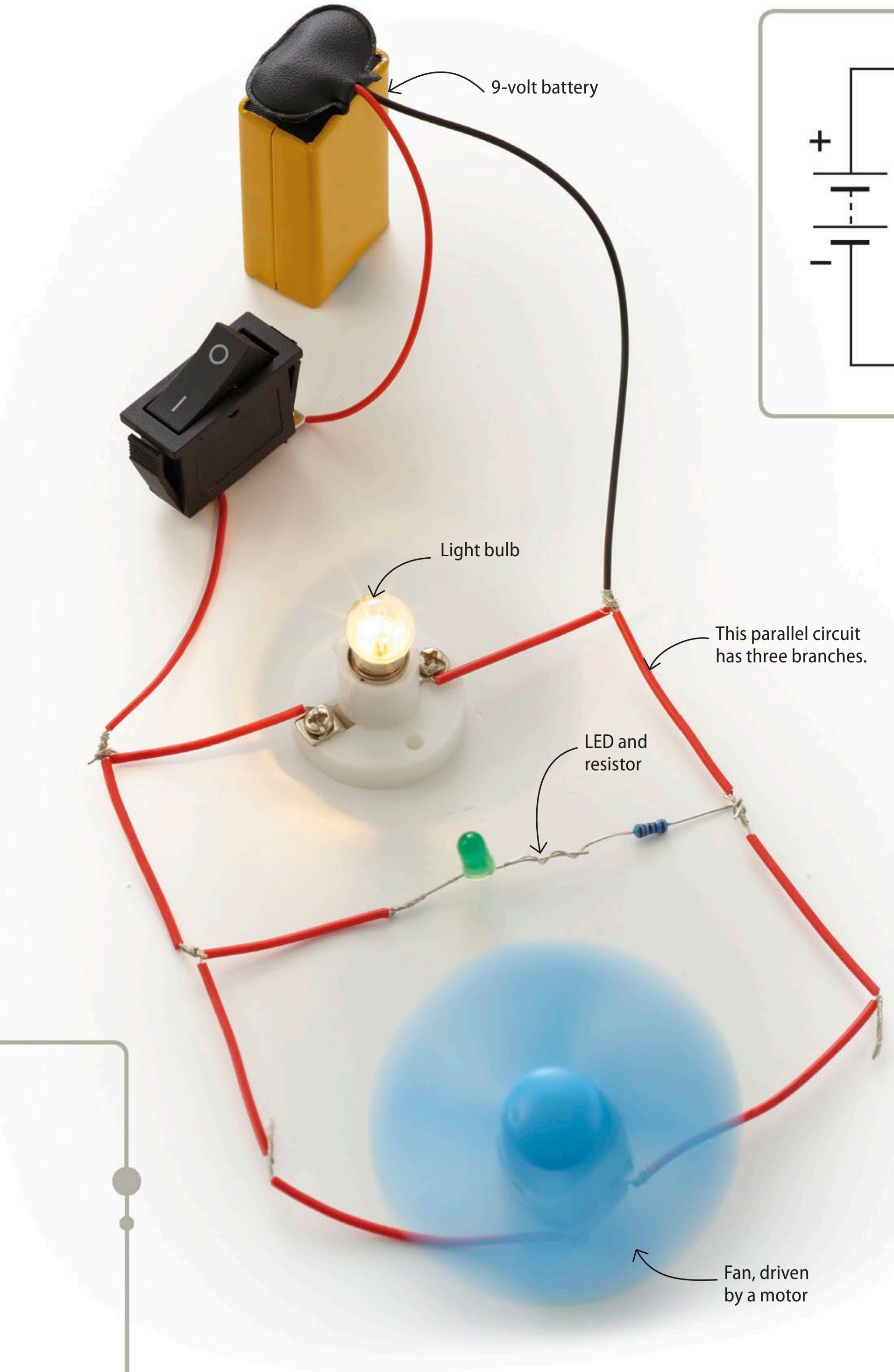
In a parallel circuit, electric current can flow through different paths because the circuit branches. Some electrons will go one way, and others, another. The current in each branch depends on the total resistance of the components in that branch—and each branch receives all the energy of the electrons that come that way.

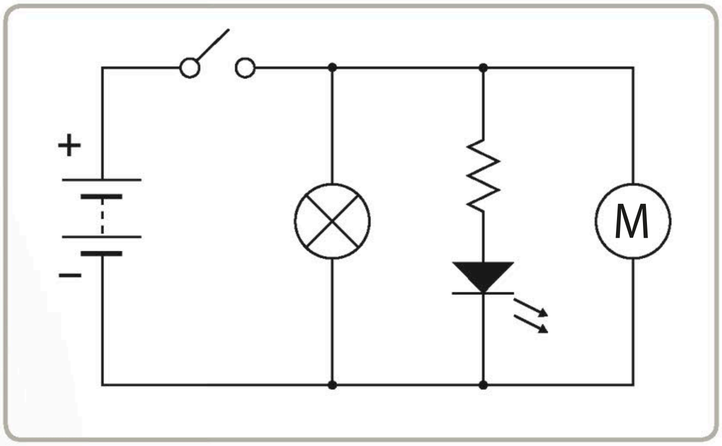


Circuit diagrams

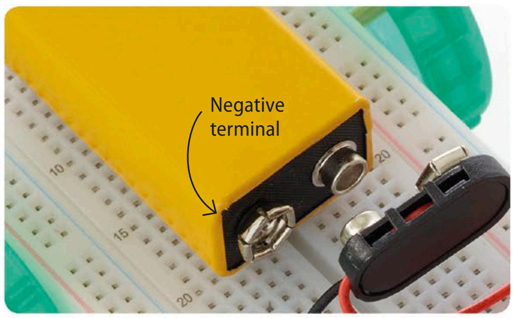
When electronics engineers are building circuits, they don't draw the battery, wires, and components as they are in real life. Instead, they use diagrams that show clearly how the various parts of the circuit are connected. So that there is no confusion, there are standard symbols for each kind of component, and wires are shown as straight, even if in the actual circuit the wires bend. We have included circuit diagrams for every project on pp.152–155.







Circuit diagram for the circuit to the left



What is "ground?"

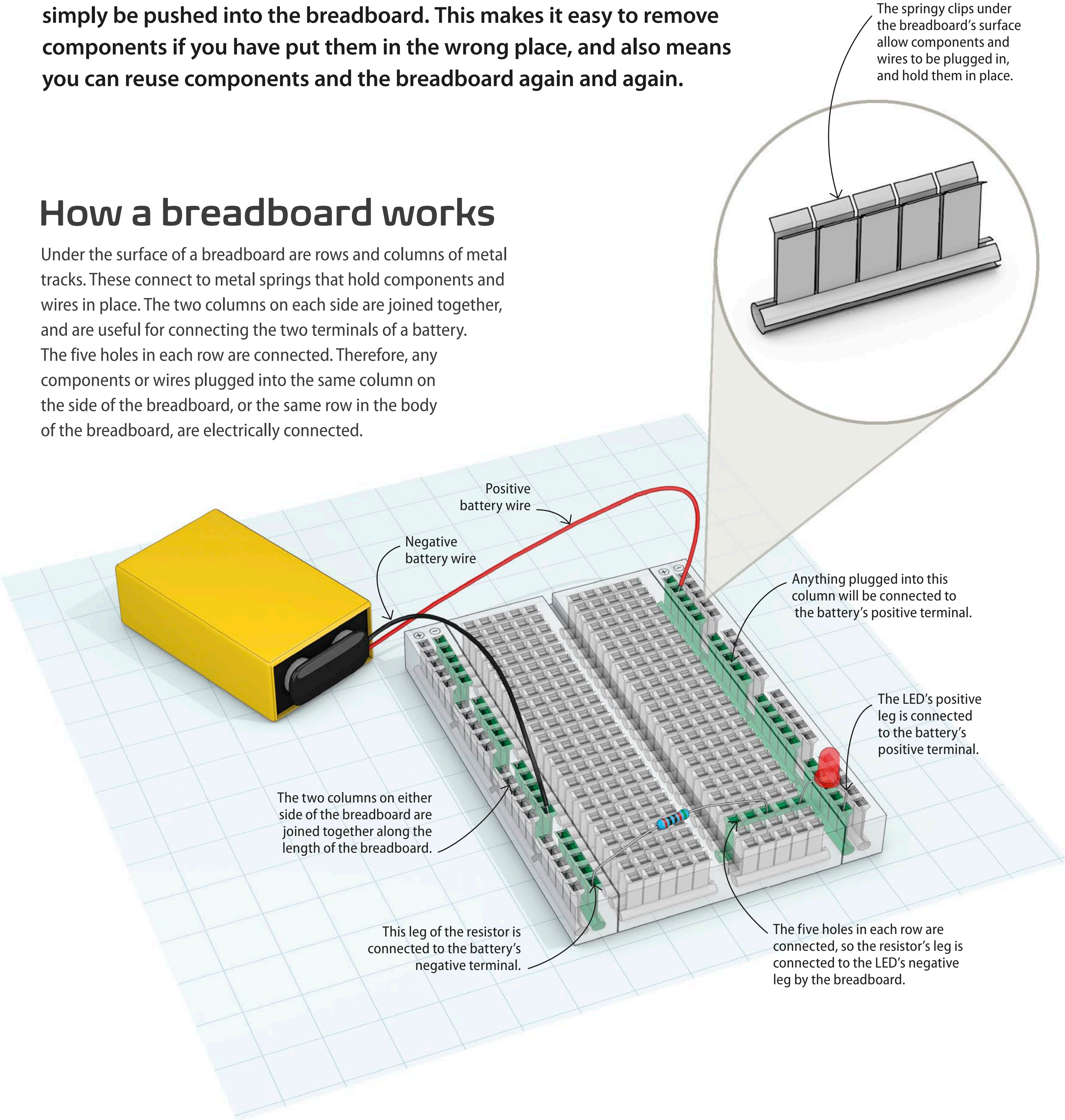
Ground, or "earth," is the point of a circuit with the lowest voltage, and is often, but not always, zero volts (0v). In the circuits in a home, it is a metal spike in the ground, but in battery circuits, it is normally the negative terminal of the battery.

Breadboards

A breadboard is a plastic board with springy metal tracks inside that make it easy to connect the wires and components in a circuit. Instead of needing to solder components and wires together, they can simply be pushed into the breadboard. This makes it easy to remove components if you have put them in the wrong place, and also means you can reuse components and the breadboard again and again.

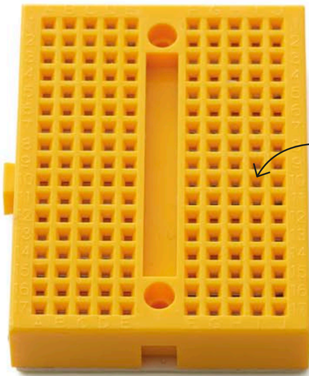
How a breadboard works

Under the surface of a breadboard are rows and columns of metal tracks. These connect to metal springs that hold components and wires in place. The two columns on each side are joined together, and are useful for connecting the two terminals of a battery. The five holes in each row are connected. Therefore, any components or wires plugged into the same column on the side of the breadboard, or the same row in the body of the breadboard, are electrically connected.



Different breadboards

There are several different kinds of breadboards. The most common are full-size breadboards, which have 64 rows. These are big enough for complex circuits, but mini breadboards are useful for smaller projects. Perforated boards are similiar to breadboards, but they require soldering, so they are used for more permanent circuits.



Sets of five holes are connected together in the same way as in a full-size breadboard.

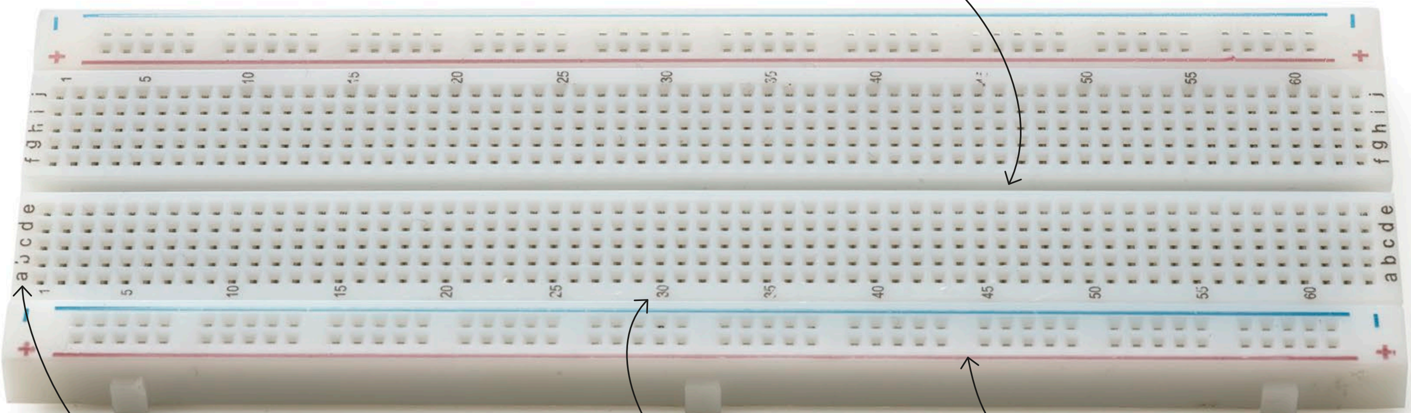
Mini breadboards

These smaller versions do not have columns to carry power from the battery, but otherwise they work in the same way as full-size boards. Most have clips along the sides, so they can be attached to each other. Some have holes for screws or adhesive backs, which enable you to mount the mini breadboard onto things.

Full-size breadboards

On a full-size breadboard, numbers and letters make it easy to follow circuit-building instructions—there is only one "C7" hole, for example. On full-size and mini breadboards, the gap along the middle is designed so that integrated circuits (ICs) can be plugged in. (For more on ICs, see p.17).

Legs of ICs plug into the hole on either side of the gap.

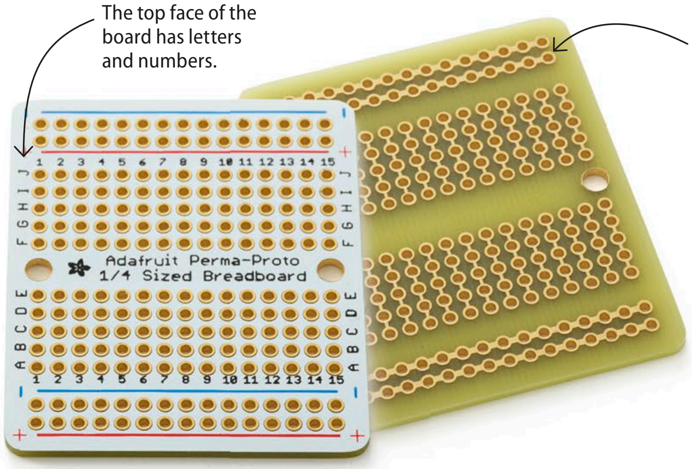


Each column in the middle of the breadboard is lettered.

Each row is numbered.

Positive and negative power columns are normally indicated with red and blue lines.

The top face of the board has letters and numbers.



The underside has metal tracks that show how the rows and columns are connected.

Perforated boards

The holes, or perforations, in a perforated board are joined together in rows and columns, just like in a breadboard. But wires and components cannot simply be plugged in—they have to be soldered into place.

Troubleshooting

Every project in this book includes an electric circuit. If you follow the instructions closely, and are careful with each of the connections you make, your circuits should work in just the right way. But sometimes, things can go wrong. If they do, these troubleshooting pages should help you find and fix the problem.

Be safe

The projects in this book all have low-voltage power supplies—batteries or USB sockets—so there is almost no danger of you receiving an electric shock. However, it is best to disconnect the power supply when you are investigating what is wrong with your circuits. Also, don't try to use the skills you learn here to investigate other electric circuits, as they can be dangerous.

It may be a problem with the batteries...

The first thing to check is the power source. Make sure your batteries are connected in the right way, and that they have power. If there is heat—or even smoke—when you turn the circuit on, remove the batteries immediately. If the circuit is powered via USB, unplug the USB cable.

1 Make sure the batteries are inserted correctly. In a battery pack, the batteries' flat ends should be pressing against the springs.

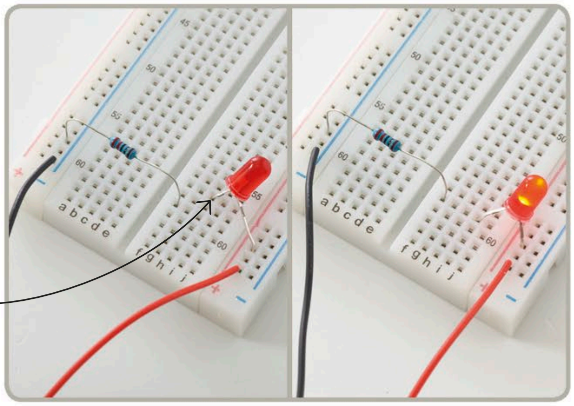
2 Test that your batteries are working with a multimeter. Set your multimeter to "volts", and hold the red metal prong against the positive (+) battery terminal and the black metal prong against the negative (–) terminal. If the reading is zero or close to zero, the battery is dead and will need to be replaced.

It is normal for the meter to read a little lower than the marked voltage on the battery.

If you have an analog multimeter, set it to the next voltage range above the battery's voltage.

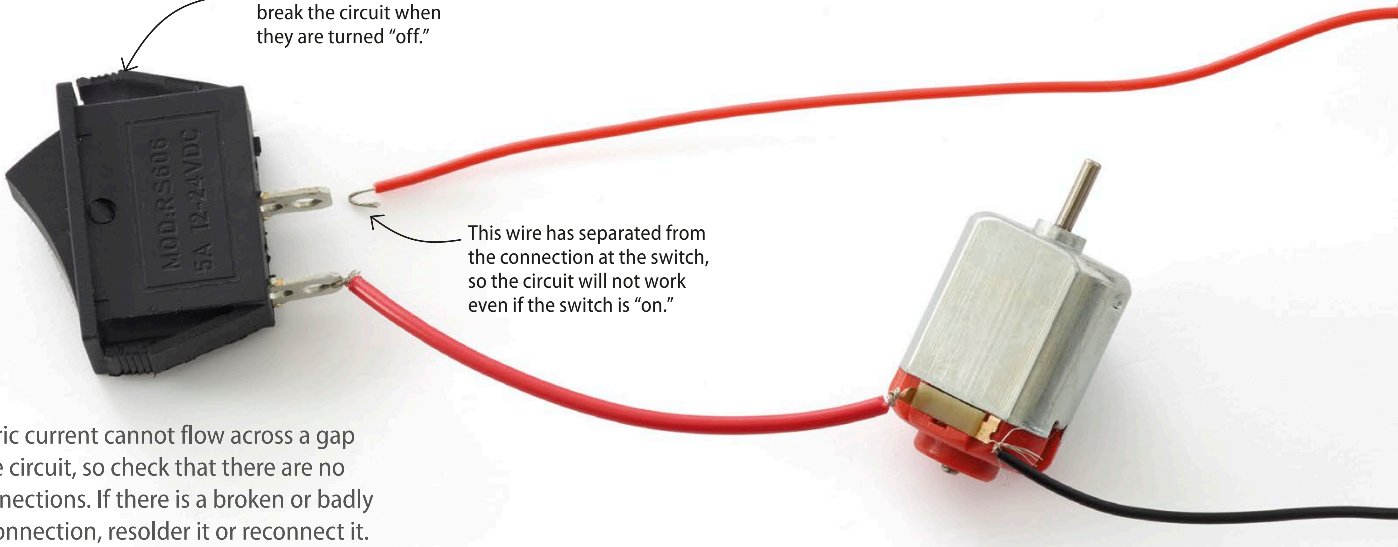
The circuit may be wired incorrectly...

The circuits in this book have been carefully designed to allow electric current to move through the wires and components in just the right way to make things happen—such as lighting an LED or making a speaker produce sound. If just one wire or component is out of place, or one component has the wrong value, the circuit will not work.



Here, the LED leg is sitting in row 57 of the breadboard, but it needs to be in row 59 to complete the circuit and light the LED.

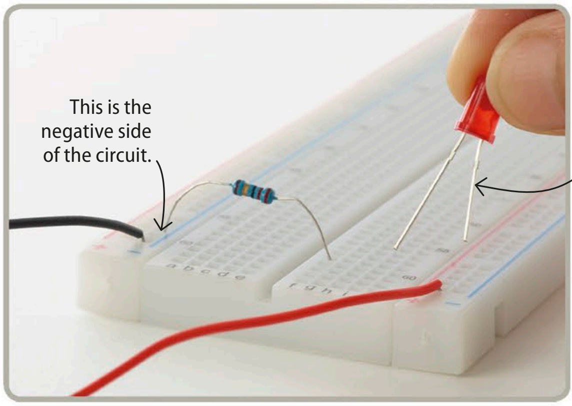
1 If your circuit is on a breadboard, take extra care to make sure each wire or component's leg is in its correct place. Pay attention to the grid references given in the project description.



Switches are designed to break the circuit when they are turned "off."

This wire has separated from the connection at the switch, so the circuit will not work even if the switch is "on."

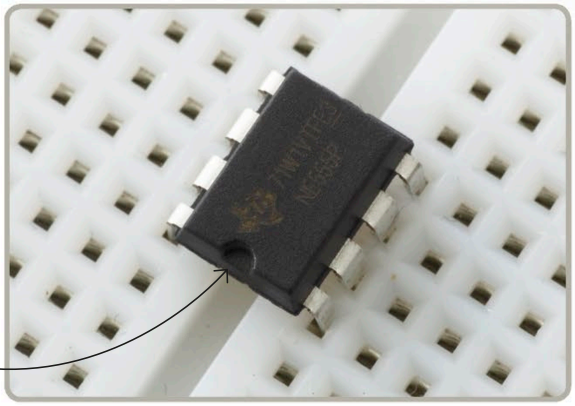
2 Electric current cannot flow across a gap in the circuit, so check that there are no loose connections. If there is a broken or badly formed connection, resolder it or reconnect it.



This is the negative side of the circuit.

The shorter leg of an LED is the negative side, so this LED should be turned around before being inserted into the breadboard.

3 Check that components such as LEDs, transistors, and electrolytic capacitors are connected the right way. Each of these has a polarity, which means they have a (+) and a (–) side, which must be correctly connected to the circuit for them to work.

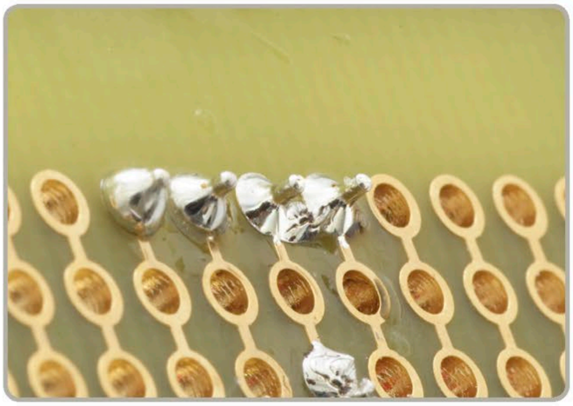


Notch

4 Integrated circuits (ICs) have equal numbers of legs either side. It is easy to put these into a circuit the wrong way—you can check by making sure the semicircular "notch" at one end is in the same position as it is in the project steps.

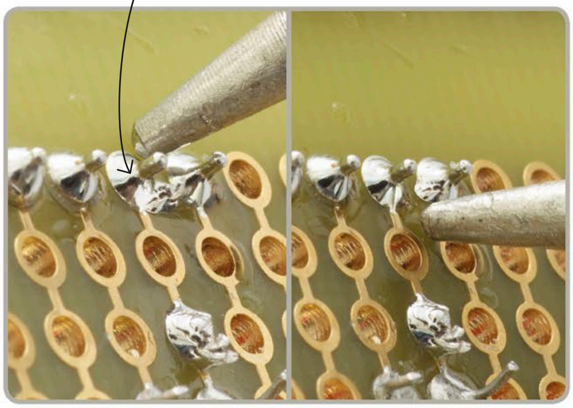
It might be a short circuit...

A short circuit occurs when two metal parts—the stripped ends of wires or the legs of components, for example—are touching but shouldn't be. In a short circuit, electric current flows through a shortcut, missing out part of the circuit. The circuit will not work, and too much current will flow through one part of the circuit, which can damage components or cause the circuit to heat up.

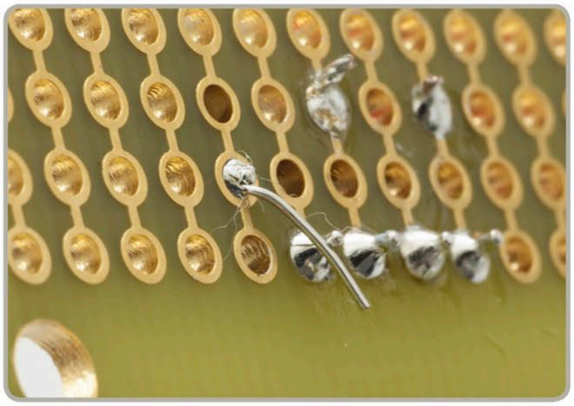


1 Solder becomes liquid when it is heated, and just like any liquid, it will cling together. When it hardens, nearby blobs of solder may become joined and form a short circuit.

Some solder bridges can be very small, so you may need a magnifying glass to see them.



2 If you find a solder bridge, use a soldering iron to melt the solder again and break the bridge, so the two connections are separate.

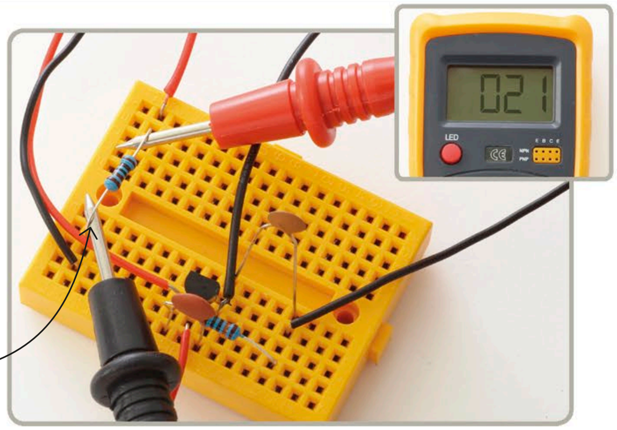


3 Short circuits also happen when the legs of two nearby components are touching but shouldn't be, so make sure you trim all legs.

It might be faulty components...

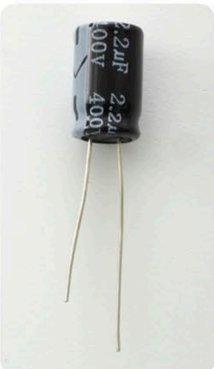
Sometimes a circuit doesn't work because one of the components in it is faulty. The most common faulty components are capacitors and resistors. You can use your multimeter to test each component while they are still connected in the circuit—but turn off the circuit before you do this.

This resistor is 110 Ω, so we set our multimeter at 200.



1 To test a resistor, set your multimeter to the next resistance setting above what the resistor's value is (Reading a resistor, see p.15). Touch the metal prongs to each leg of the resistor. The meter should read very close to the value of the resistor, if it is not faulty.

2 To test a capacitor, unplug the power supply from the circuit and wait at least 30 seconds—this is to allow the capacitor to discharge the electrical energy it stores. Set your multimeter to the capacitance setting, and test the capacitor by touching the metal prongs to each leg. If the value is a lot higher or a lot lower than it should be, change the capacitor. If your multimeter doesn't have a capacitance setting, set the multimeter to the lowest resistance setting.

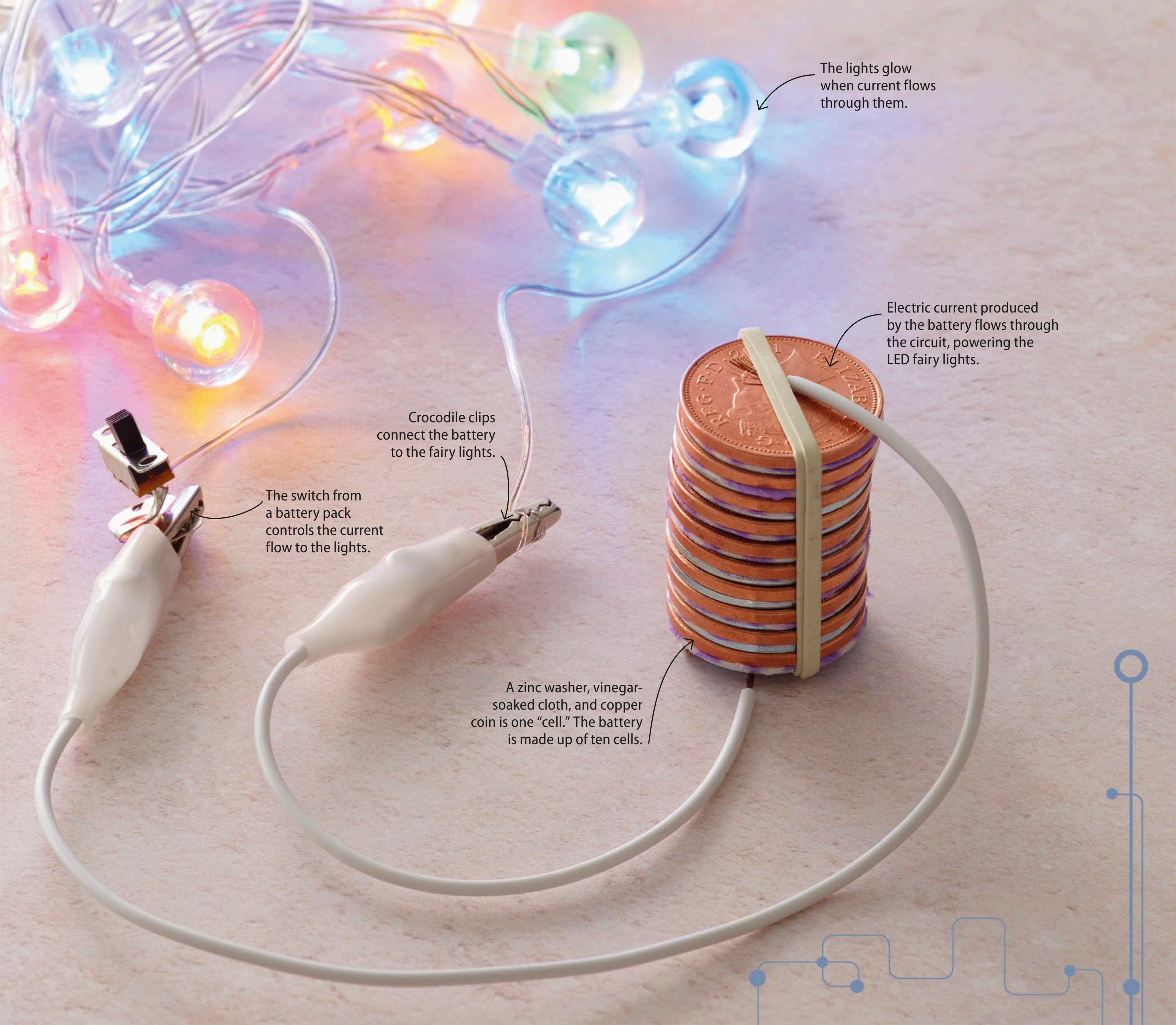


Electrolytic capacitors

Electrolytic capacitors have a polarity—electric current can only flow through them in one direction. When testing one of these kinds of capacitors, make sure you touch the negative metal prong to the negative leg, which is usually shorter and marked with a "–" on the capacitor's body.

Coin battery

We use batteries to power many small devices—but how do they produce electric current? There's no better way to understand how batteries work than to build your own! In this project, you'll build a battery made of coins, washers, and pieces of dishcloth—and use it to power a set of fairy lights.



How to make a
Coin battery

To make this battery work well, you first need to make the coins sparkling clean—the solution you use to do this will also be part of the battery. Make sure you use galvanized washers: "galvanized" means "coated with zinc," and the metal zinc is a very important part of your battery.

Time
20 mins

Difficulty
Easy

What you need

From the toolbox:

- Pencil
- Scissors
- Multimeter

(10x)
Galvanized
(zinc-coated) washers

(1x)
Rubber band

(1x)
Small dish of
table salt

(10x)
"Copper"
(copper-coated) coins

(1x)
3-volt fairy lights with a
2 x AA battery pack

(1x)
Small dish

Vinegar
1 fl oz (30 ml)

(1x)
Absorbent cloth

(1x)
Paper towel

(1x)
Spoon

(1x)
Wire with a
crocodile clip
at each end

When no more
salt dissolves,
the solution
is saturated.

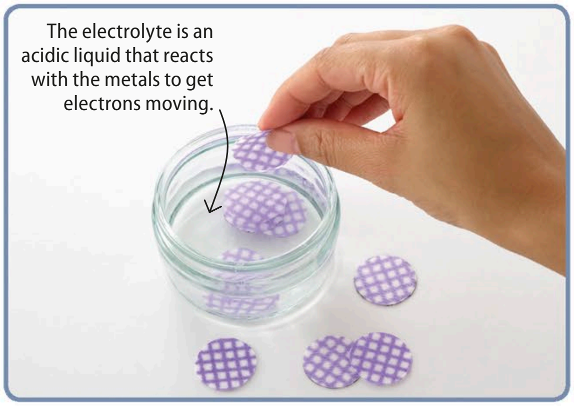
1 Pour about 1 fl oz (30 ml) of vinegar into the small dish. Keep adding salt and stirring until no more salt will dissolve.

The salt and
vinegar clean the
coins' surface layer.

2 Place the copper coins into the salt and vinegar solution. Leave them for about five minutes, until they turn shiny. Remove and dry them with a paper towel, then wash and dry your hands.

3 Using a coin as a template, cut out 10 circles from the absorbent cloth.

By folding the cloth,
you can cut out more
than one at a time.



4 Place the disks of kitchen cloth into the dish of salt and vinegar solution, and let them soak for a few minutes. The vinegar will be the electrolyte in your battery.

5 Lay down a galvanized washer, stack a cloth disc on top, and then a copper coin on top of that. Repeat in this order until all the materials are in a neat pile, making sure that the top disk is a coin.

Using a multimeter see pp.28–29

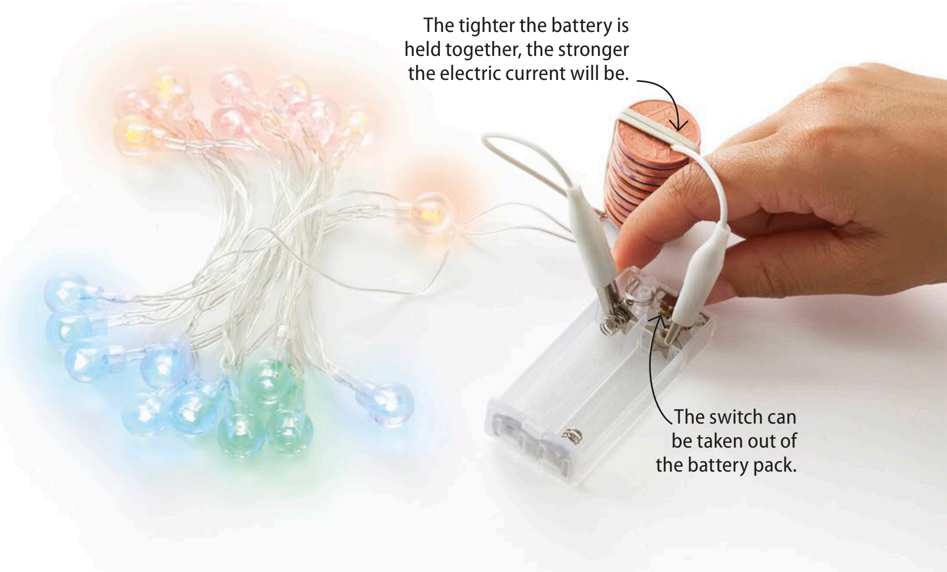
6 Set the multimeter to read voltage, in the range between 1 and 10 volts. Touch the prongs to the top and bottom of the stack. The voltage should read between 6 and 8 volts.

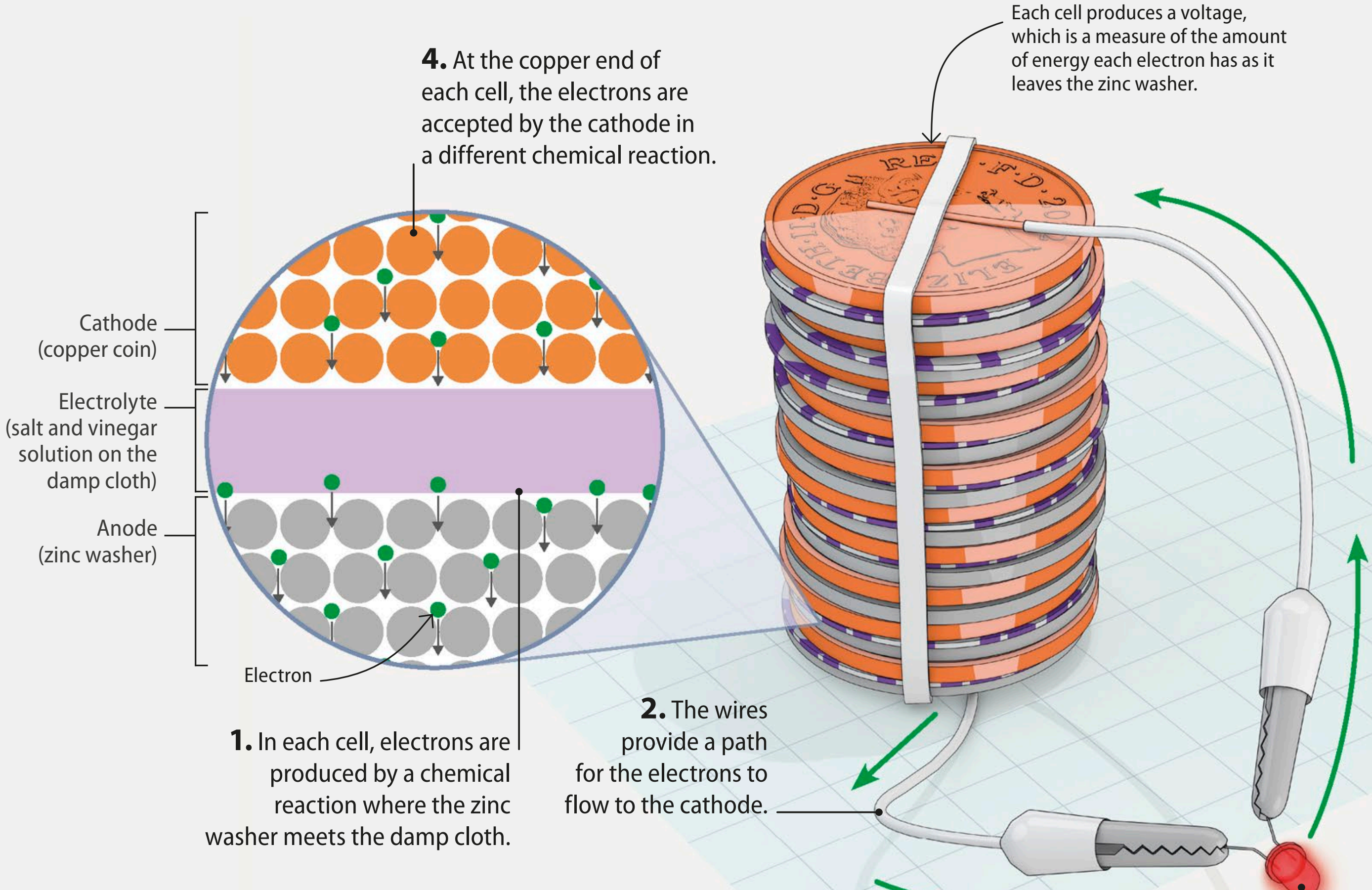
Preparing wires see p.24

7 Cut the crocodile-clip wire in half, and strip the freshly cut ends of the two wires. Fix each wire to the top and bottom of the battery. Secure the wires in place by wrapping the rubber band around the pile.

8 Clip the crocodile clips to the metal connections inside the battery pack: the wire from the washer should be attached to the springy connection.

9 Flip the switch on the battery pack, and the fairy lights should illuminate.





How it works

A battery converts chemical energy into electrical energy through a chemical reaction. In each cell, the zinc washer (called the anode) produces electrons, as zinc atoms dissolve in the salt and vinegar solution (the electrolyte). Electrons flow through the wires, and are taken in at the copper end (the cathode), where they take part in another chemical reaction in the electrolyte. The voltages of all of the cells add up, giving the electrons that leave the battery at the bottom enough energy to light the LEDs.

Real-world inventions

The first battery

Italian scientist Alessandro Volta invented the battery in 1799. Just like the battery you have built, it was made with copper and zinc disks. Volta used cloth disks soaked in brine (salty water), rather than disks of dishcloth soaked in salt and vinegar.

Motor

Electric motors convert electrical energy into kinetic (movement) energy. In this project, you'll build a simple motor using electric current supplied by a battery. The current flows through a coil, producing a magnetic field that interacts with the magnetic field of a permanent magnet. The magnetic forces between the coil and the magnet make the coil spin at high speed.

How to make a
Motor

The part of your motor that turns (the rotor) is a coil made of copper wire. The wire has a coating that prevents electricity from passing through the circuit, so it is important to scrape the ends of the wire so an electrical connection can be made.

Time
15 mins

Be aware
Requires utility knife use. The motor can get hot if left to run.

Difficulty
Easy

What you need

From the toolbox:

- Utility knife
- Wire cutters
- Ruler

1x Magnet

Enameled copper wire (28 gauge) 25½ in (65 cm)

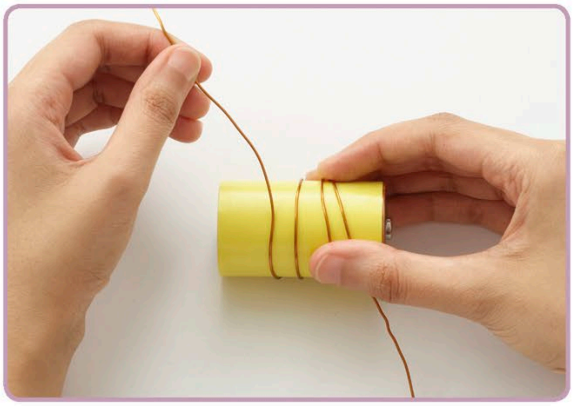
1x 1.5-volt D battery

2x Safety pins

2x Rubber bands

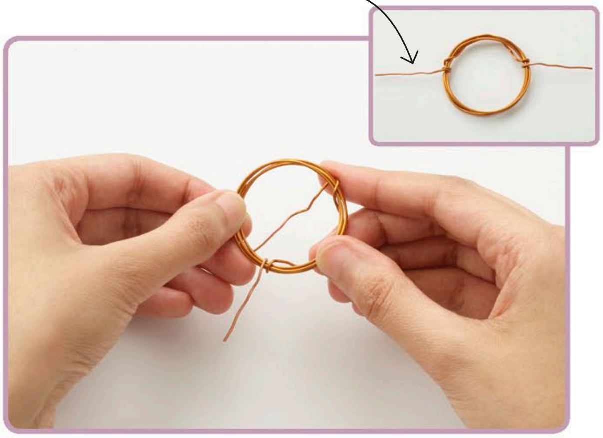
1x Base
4 x 4 in (10 x 10 cm)

This is a cork tile, but anything that the pins can be stuck into can be used for the base.



1 Wind the enameled copper wire around the battery five times. Leave about 2 in (5 cm) of wire on each end.

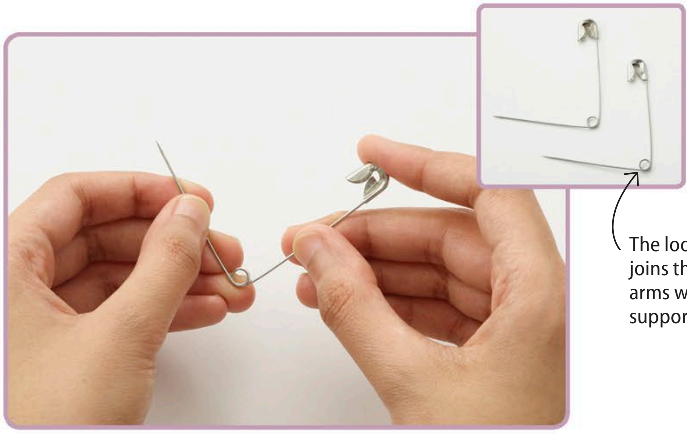
The two ends should stick out from each side of the coil.



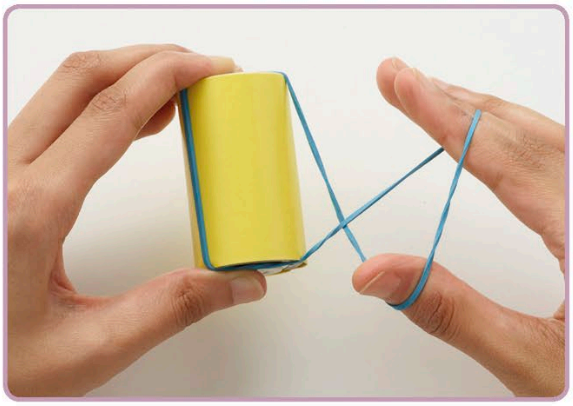
2 Take the wire off the battery. Flatten it into a circle, then wrap the two ends around the coil at opposite sides of the circle to hold the coil together.

3 Using the utility knife, scrape off the enamel coating on the free ends of the wire, right up to the coil, so that the shiny copper is exposed.

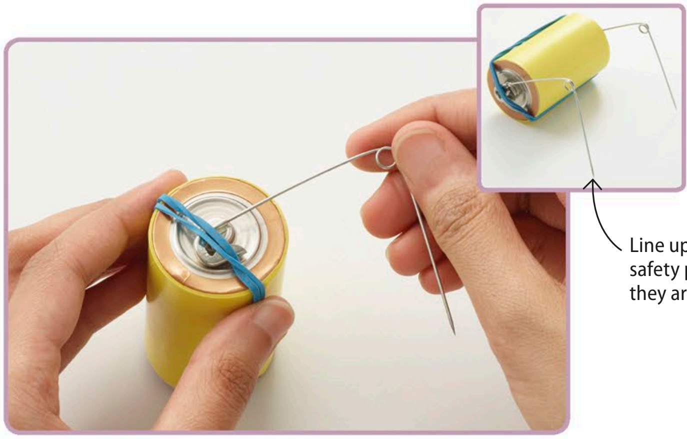
Utility knife see p.20



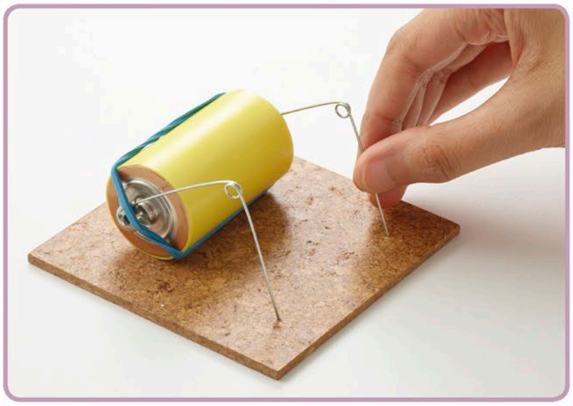
4 Bend open both safety pins so that the arms on each form a 90° angle. Be careful with the sharp points.



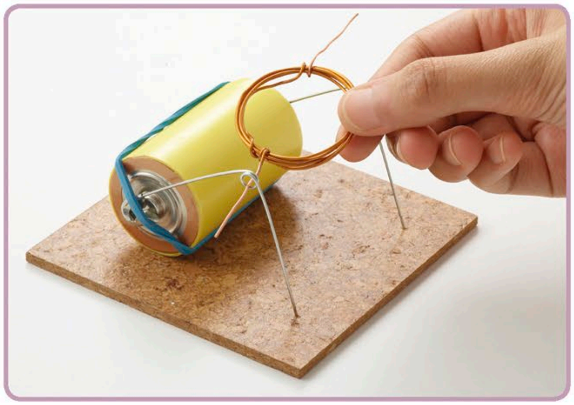
5 Wrap the rubber band around the battery. It needs to be tight, so double it up if necessary to increase the tension.



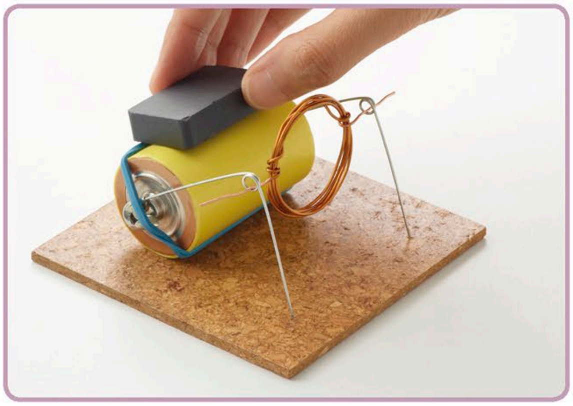
6 Push the clasps of the safety pins underneath the rubber band, one at each end of the battery, so that they are held firmly against the battery's terminals.



7 Place the construction onto the base. Push the sharp points into the cork, making sure the loops are at the same height.



8 Gently feed the ends of the copper wire through the loops in the safety pins, so that the coil is suspended. Straighten the pins again afterward.



9 Place the magnet on top of the battery. It will stay there without any glue because the battery case is made of steel, a magnetic material.

10 Now give the coil a spin. If the motor is working, the coil should continue spinning on its own!

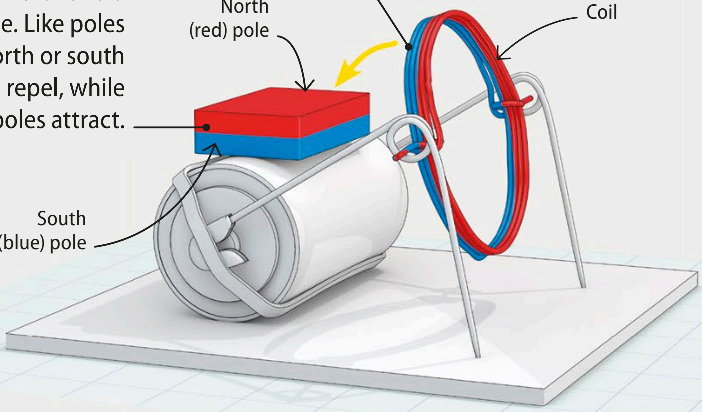
Be aware
Don't leave the motor running for long periods, as it can get quite hot. Take the coil out to stop the motor.

How it works

Electricity and magnetism are closely linked, and when electricity flows through the coil, it creates a magnetic field around it.

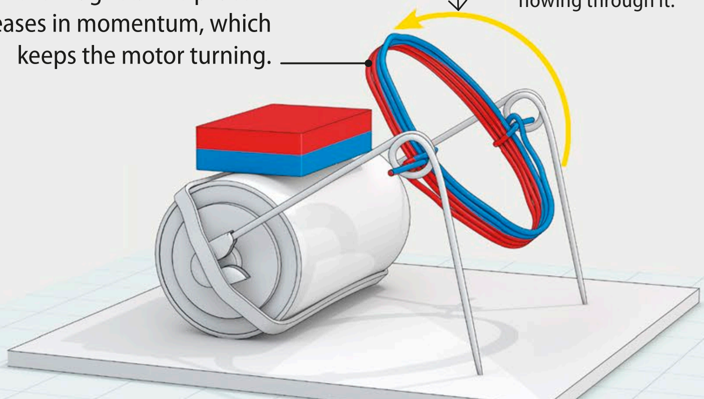
1. The permanent magnet and the magnetized coil each have a north and a south pole. Like poles (north and north or south and south) repel, while opposite poles attract.

2. When you spin the coil, its south magnetic pole is attracted to the north pole of the magnet. The spin's momentum takes the coil's south magnetic pole beyond the north magnetic pole of the magnet.



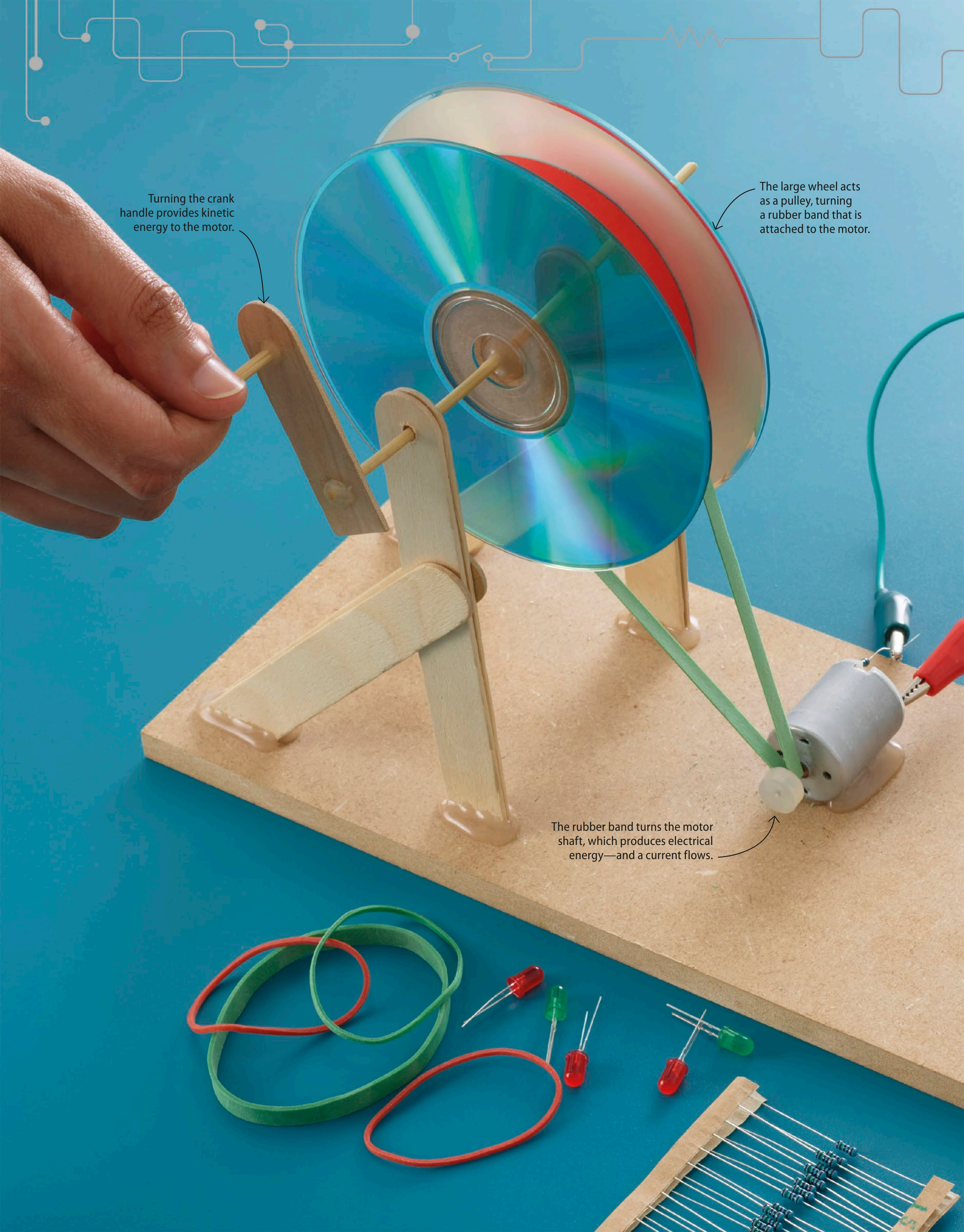
3. The north pole of the coil is then repelled by the north magnetic pole of the magnet. This process increases in momentum, which keeps the motor turning.

The coil's spin is affected by the coil's size, the material it is made of, and the amount of current flowing through it.



Real-world inventions
Robot arm

Motors are used in many tools and machines, including cordless drills, small toys, and even robot arms. The fine precision needed by a robot is achieved by motors located in each joint of the arm.


Turning the crank handle provides kinetic energy to the motor.
The large wheel acts as a pulley, turning a rubber band that is attached to the motor.
The rubber band turns the motor shaft, which produces electrical energy—and a current flows.

Generator

Most of the electricity supplied to homes is produced by machines called generators, which convert kinetic (movement) energy into electrical energy. A generator contains coils of wire arranged around a spinning shaft, surrounded by magnets—just like a motor. In fact, you can use a motor to generate electricity—and that's just what you'll be doing in this activity.

The LED lights up when a current flows.

How to make a
Generator

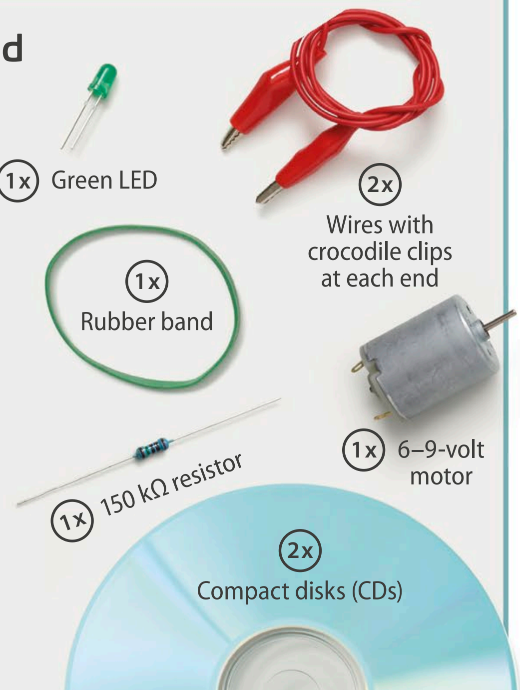
Make sure you follow the instructions carefully, as this build relies on the supporting frame being sturdy. Try to find a medium-sized rubber band—if it is too big or too small, it will not drive the motor shaft around effectively. It's okay if you can't find any old CDs—try to find something sturdy with the same dimensions of 4¾ in (12 cm) in diameter.

Time	Be aware	Difficulty
45 mins	Requires hot glue gun, hacksaw, drill, utility knife, and wire cutter use.	Medium

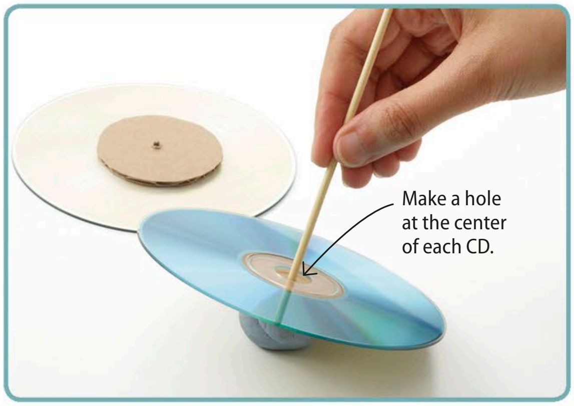
What you need

From the toolbox:

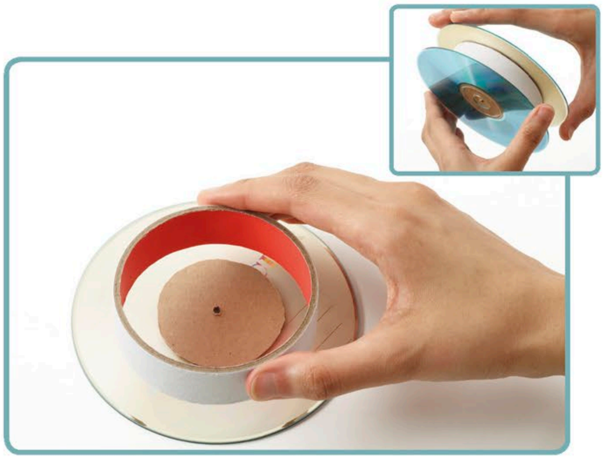
- Utility knife
- Cutting mat
- Hot glue gun
- Adhesive putty
- Ruler
- Scrap wood and clamps
- Hacksaw
- Drill
- ⅛ in (3 mm) drill bit for wood
- Wire cutters



1 Cut out two cardboard disks, with diameters smaller than the inside diameter of the tape roll. Using the hot glue gun, stick the disks over the holes in the centers of the CDs.



2 Use a wooden skewer to poke a hole through the center of each cardboard disk. A lump of adhesive putty will help you make a clean hole.



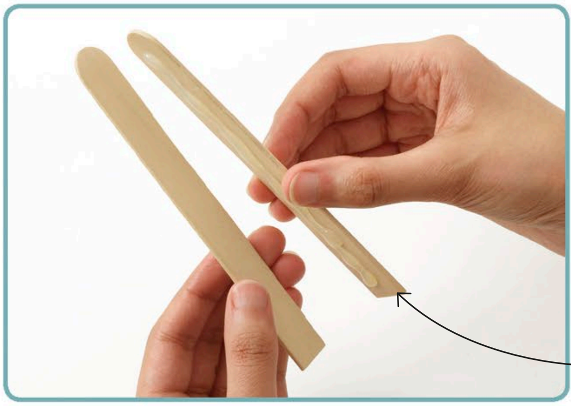
3 Run glue around the edges of the empty tape roll. Press the roll onto one of the CDs, over the cardboard disk, making sure it is centered. Next, press the other CD onto the tape roll, with the cardboard disk facing inward.

The main pulley wheel is complete.

4 Once the glue has dried, push the skewer through the centers of the cardboard disks to form the shaft. Make sure there is an equal length of skewer on each side, then glue the shaft to the cardboard on each side.

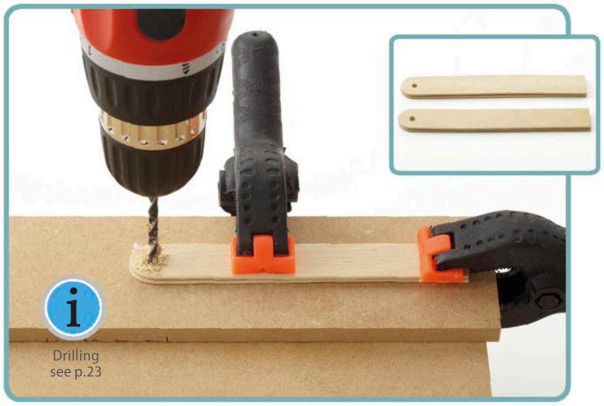
Clamping the sticks to a scrap piece of wood will help to hold them in place.

5 Using a hacksaw, cut ⅜ in (1 cm) off one end of four craft sticks. Next, cut one end off four more craft sticks at a 45° angle, starting ¾ in (2 cm) up one side.



Make sure the sticks are aligned.

6 Glue together two of the straight-cut craft sticks, then repeat with the other two. These are the legs that will support the generator's pulley wheel.



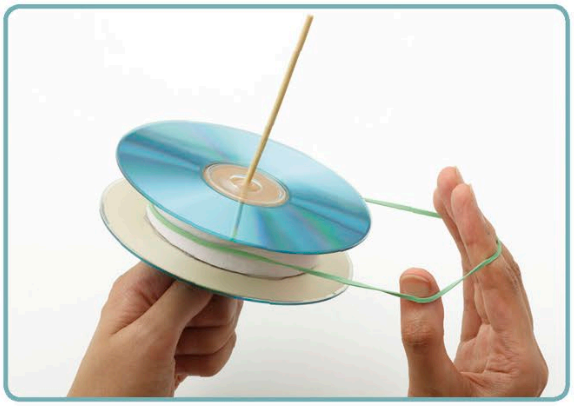
7 Using a drill bit slightly wider than the wooden skewer, drill a hole through the middle of each of the legs, about ⅜ in (1 cm) from the rounded end.

8 Using a utility knife, cut two disks, each about ¼ in (6 mm) thick, from an unused glue gun stick.

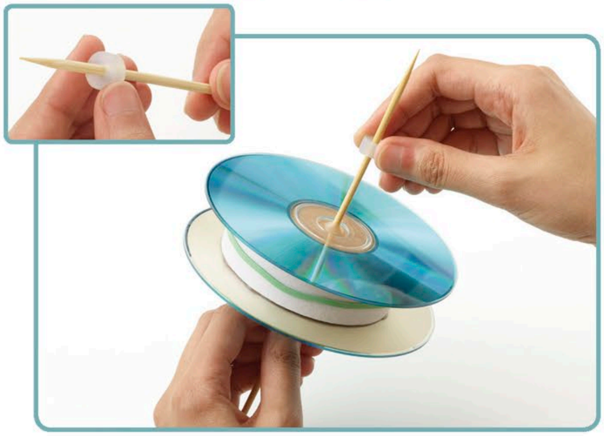
!
Hold the glue firmly so it doesn't roll as you are cutting it.

Use a cutting mat to protect your work surface.

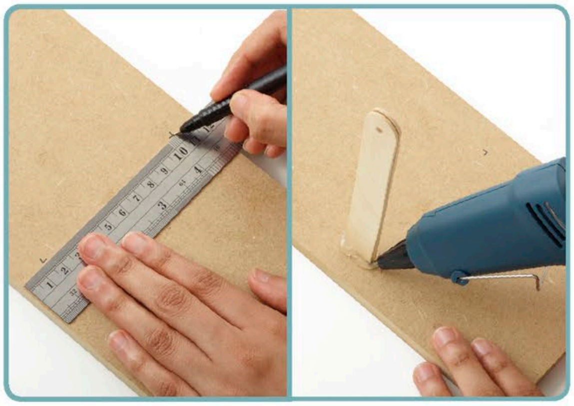
The disks will help keep the generator's shaft in place.



9 Stretch the rubber band around the tape roll. This will be the belt of the pulley system that attaches to the motor and turns the generator.

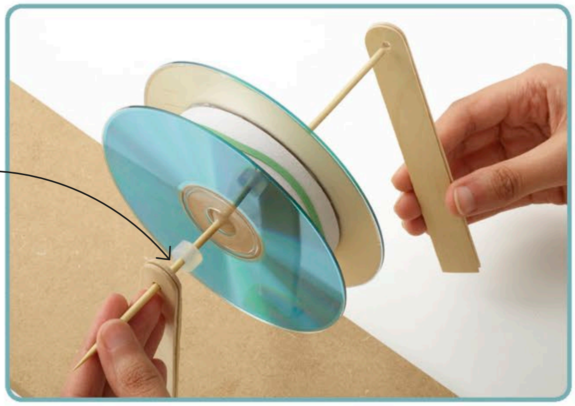


10 Using the pointed end of a skewer, make a hole in the center of each glue stick disk. Push one of the disks onto one side of the shaft of the pulley wheel. Set aside the second glue disk.



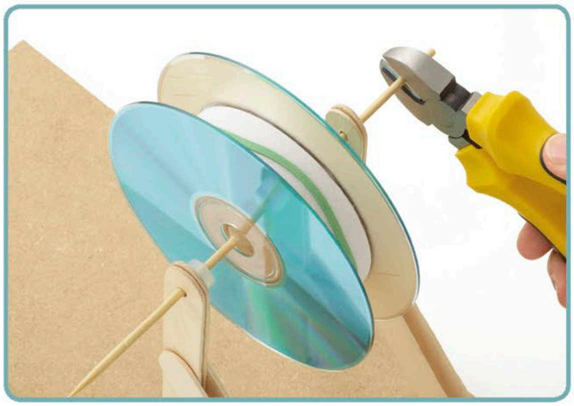
11 On the wooden base, make a mark about ¾ in (2 cm) in from each side, about 5 in (12 cm) from one end. Glue one of the legs on top of one of the marks, and wait for the glue to dry.

Make sure the shaft can turn freely.



12 Push one end of the shaft through the hole in the leg already in place, and feed the other end through the hole in the other leg. Glue the second leg on top of the second mark.

13 Use the angle-cut craft sticks to make supports for the legs. Glue the rounded ends to the legs, one on each side of each leg, and the flat angled ends to the base.

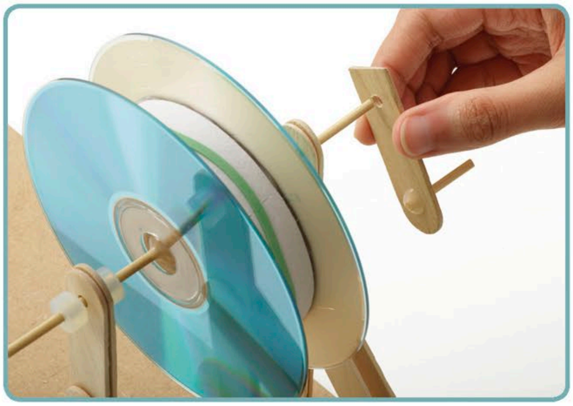


14 Use the wire cutters to carefully trim the ends of the pulley shaft on both sides, leaving about 1½ in (4 cm) on each side of the legs.

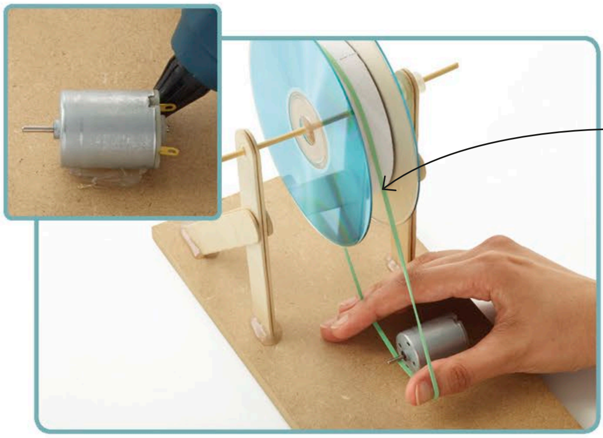
15 Using the last craft stick, cut a length of about 2½ in (6 cm) from it for the generator's crank handle. Drill a hole about ⅜ in (1 cm) in from each end.

16 Cut a piece of wooden skewer about 1 in (2½ cm) long and glue it into the hole at the rounded end of the handle.

17 Push the second glue disk (see step 8) onto the end of the pulley shaft—at the same end as the first glue disk.

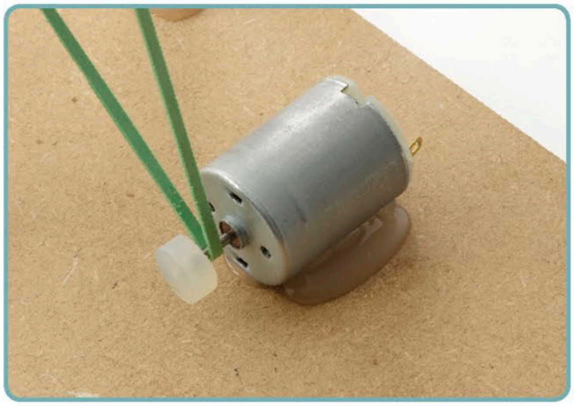


18 Push the crank handle onto the other end of the pulley shaft, making sure that the wooden skewer on the other end is facing outward. Secure it with hot glue.

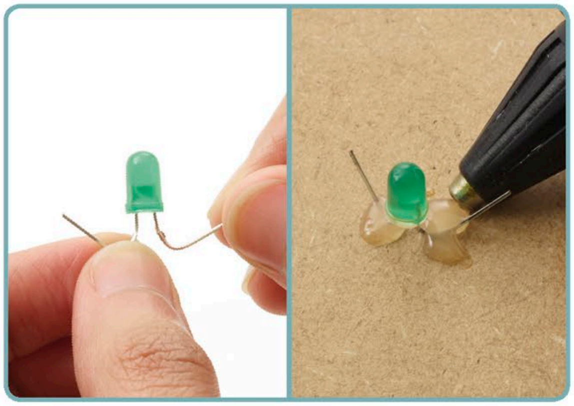


Make sure that the center of the pulley is in line with the motor's shaft.

19 Find a place for the motor in the center of the base, far enough from the pulley that the rubber band is taut. Glue the motor down, then stretch the rubber band over the motor's shaft.

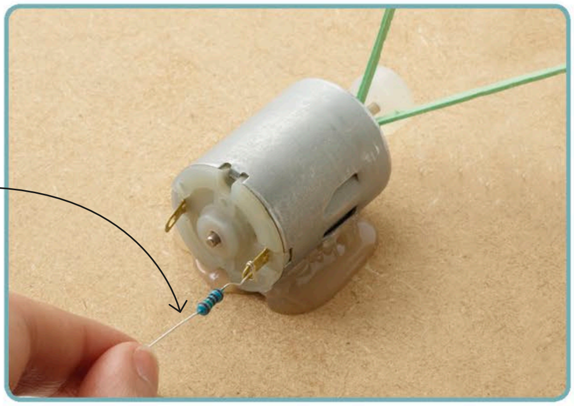


20 Cut another ¼ in (6 mm) thick disk from the glue gun stick. Push the point of a skewer into its center, but do not push all the way through. Push the glue stick disk onto the shaft of the motor.

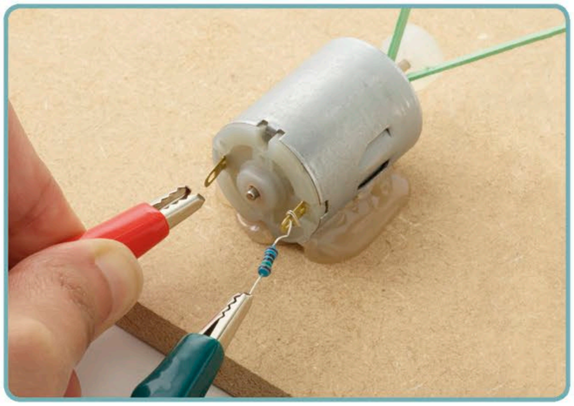


21 Carefully bend the legs of the LED up. Next, glue it to the base with a blob of hot glue.

The resistor will help limit how much current flows through the LED.



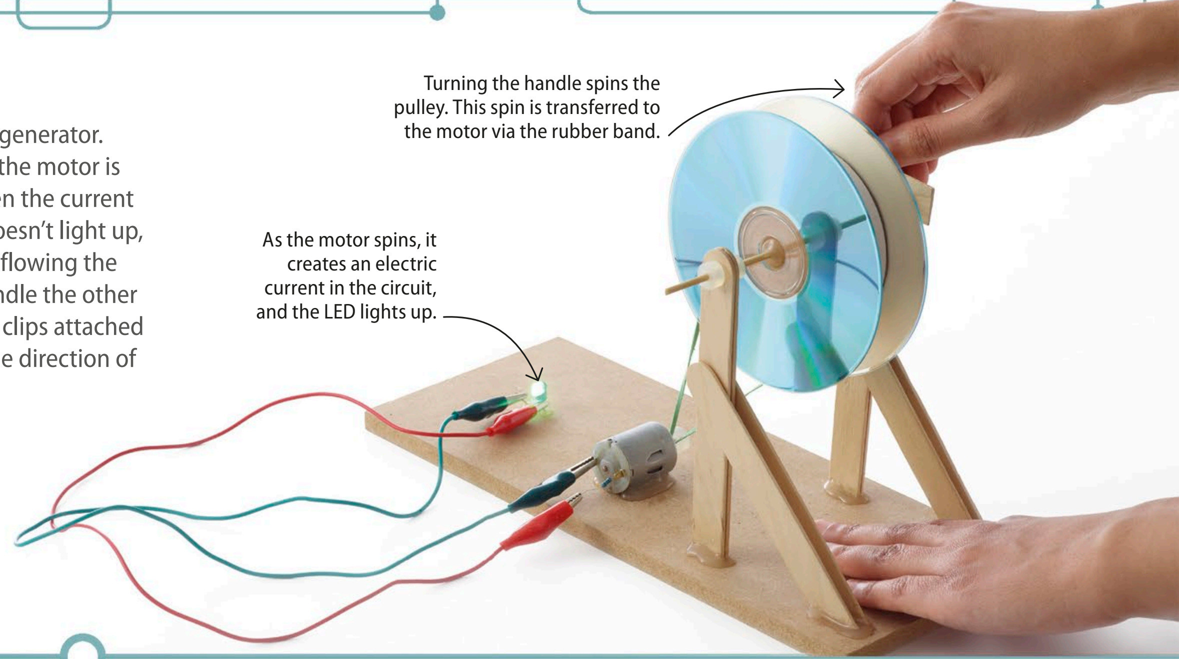
22 Attach one end of the 150 kΩ resistor to one of the terminals of the motor. It doesn't matter which one.



23 Using the crocodile wires, connect the clip of one of the wires to the free end of the resistor, and the clip of the other wire to the other terminal of the motor.

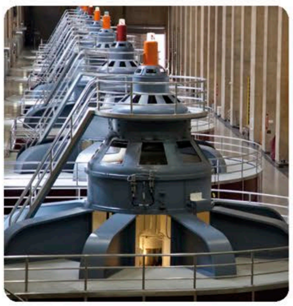
24 Connect the other ends of the two wires to the two legs of the LED. The generator is ready to operate.

25 Turn the handle of the generator. Make sure the shaft of the motor is turning. LEDs only light up when the current flows in one direction, so if it doesn't light up, it may mean that the current is flowing the wrong way. Try turning the handle the other way, or switching the crocodile clips attached to the LED, as this will switch the direction of current from the motor.



How it works

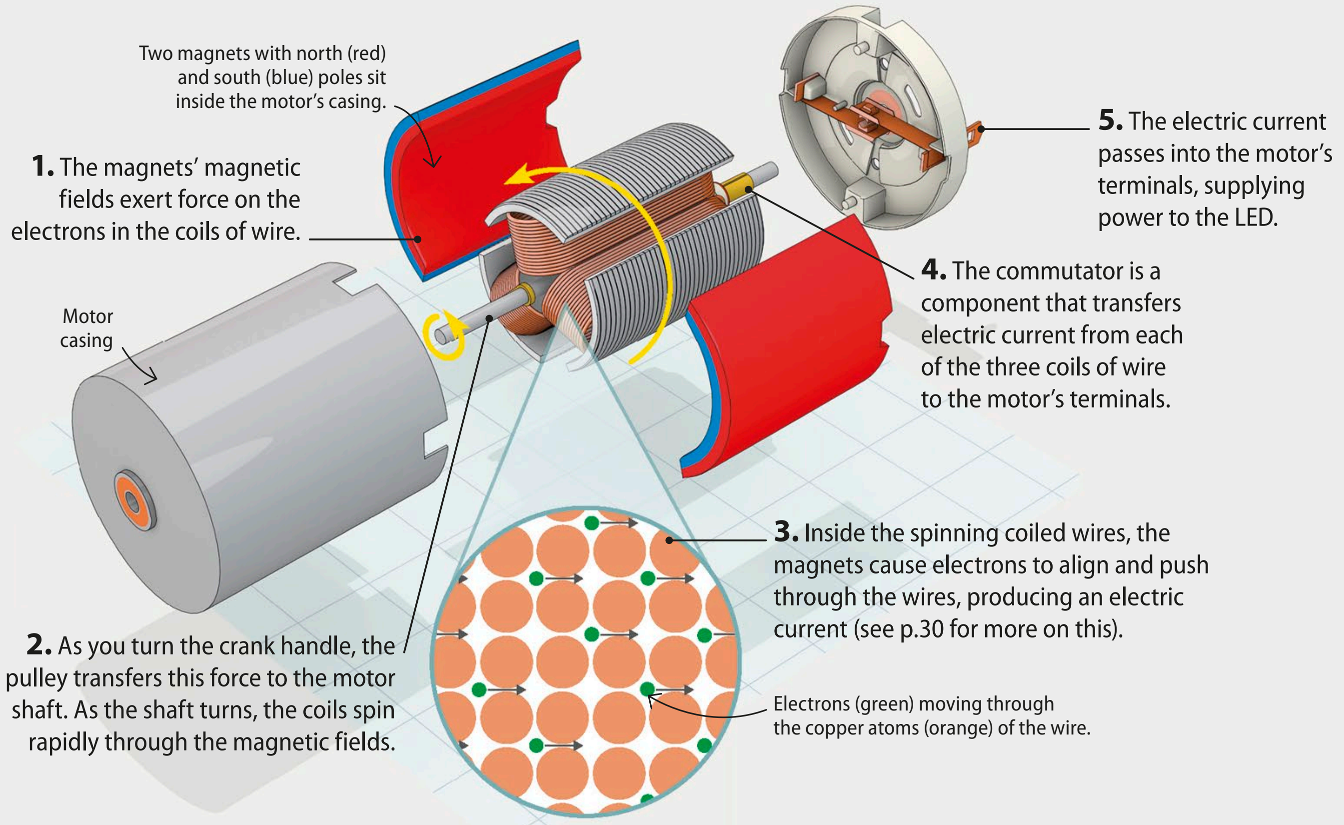
A motor is designed so that its shaft spins when electric current flows through it. However, this process can be reversed: spinning the motor's shaft can be used to produce an electric current. Inside the motor are static magnets as well as three coils of wire that can spin.



Real-world inventions

Hydroelectric power

Nearly one-fifth of the world's electricity is generated by hydroelectricity (the energy of moving water). The machines in this picture are turbines at the Hoover Dam in Nevada. The turbines spin as water pushes through them, turning generators that supply electricity.



Handheld fan

The propellers spin as electric current from the batteries passes through two motors mounted on the top of the fan.

Keep cool with this useful handheld fan! In this project, you'll be using batteries to power two motors with propellers attached, to produce a cooling breeze. You will be wiring the motors in parallel, which means that each of the motors is on a separate branch of the circuit, so that each one receives the full voltage the batteries provide.

How to make a

Handheld fan

For this project, you will need a battery pack with a built-in switch. You will also need to find pieces of plastic or wood to act as a platform for the motors. They need to be wide enough to hold the motors, and long enough that the propeller blades won't touch once they are installed.

Time	Be aware	Difficulty
30 mins	Requires hot glue gun and soldering iron use.	Easy

What you need

From the toolbox

- Hot glue gun
- Wire strippers
- Soldering iron and solder

2x Fans

1x AA battery pack with built-in switch

2x AA batteries

2x 3-volt motors

Black stranded wire 3 in (8 cm)

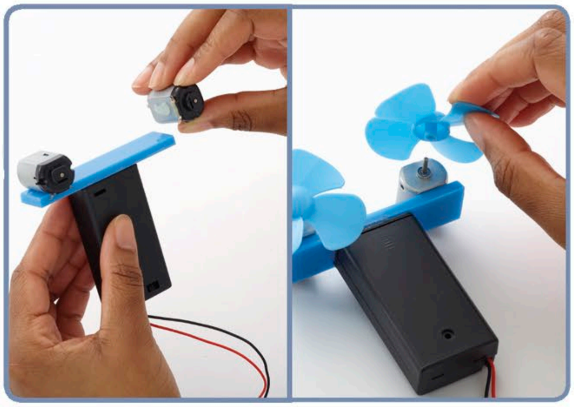
Red stranded wire 3 in (8 cm)

1x Material for handle 6 in (15 cm) long and same width as battery pack

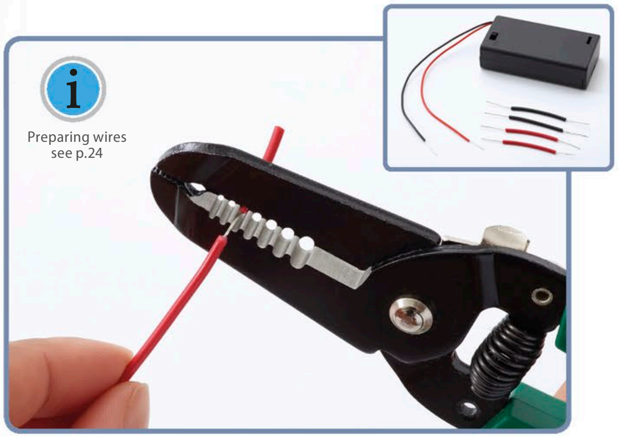
1x Platform for motors 3 x ¾ in (8 x 2 cm)

Using a glue gun see p.22

1 Glue the motor platform to the top of the battery pack, making sure it is in the center. Make sure that you can still open the battery pack.

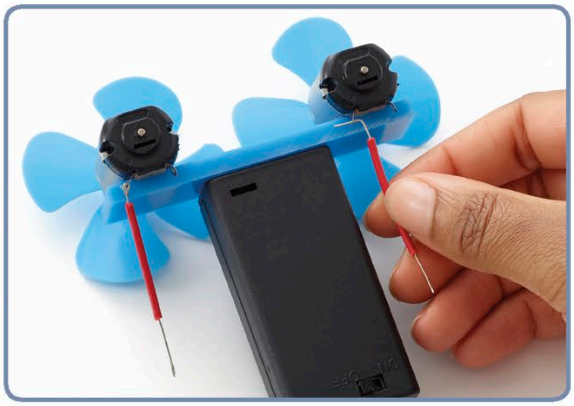


2 Glue one motor onto each end of the platform, with the shafts pointing away from the side of the battery pack with the switch, and the motor terminals facing down. Next, slide on the propellers.

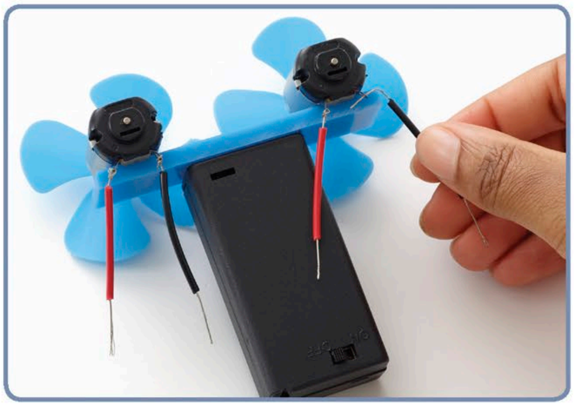


Preparing wires see p.24

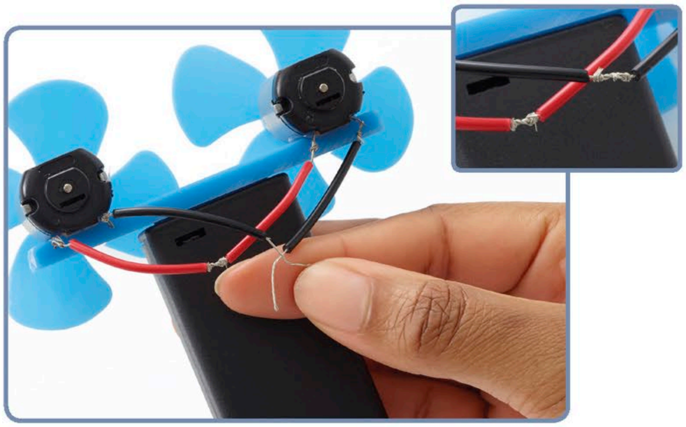
3 Cut and strip two black wires and two red wires, each about 1½ in (4 cm) long, and strip the battery pack wires.



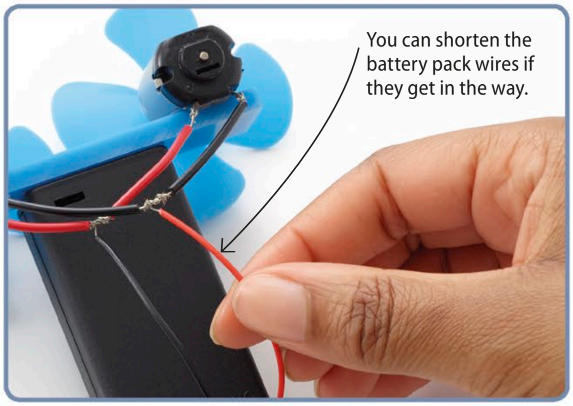
4 Twist the stripped ends of the red wires onto the left terminals of each motor.



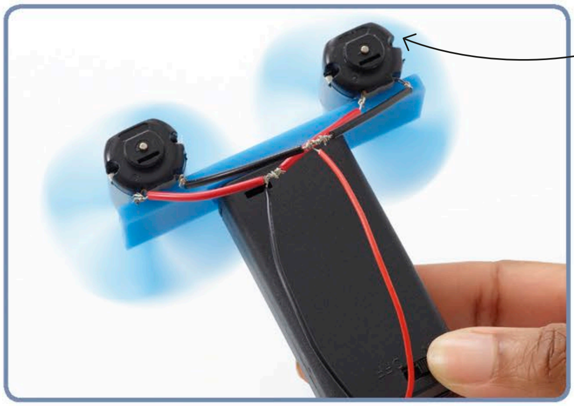
5 Twist the stripped ends of the black wires onto the right terminals of each motor.



6 Twist the ends of the red wires together, and the ends of the black wires together.

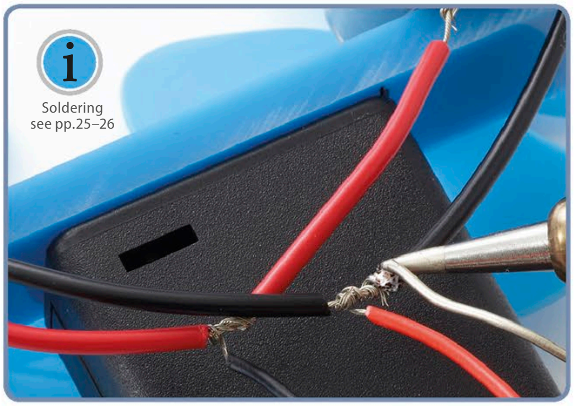


7 Twist the end of the red battery wire around the twisted black wires. Then twist the end of the black battery wire around the twisted red wires.

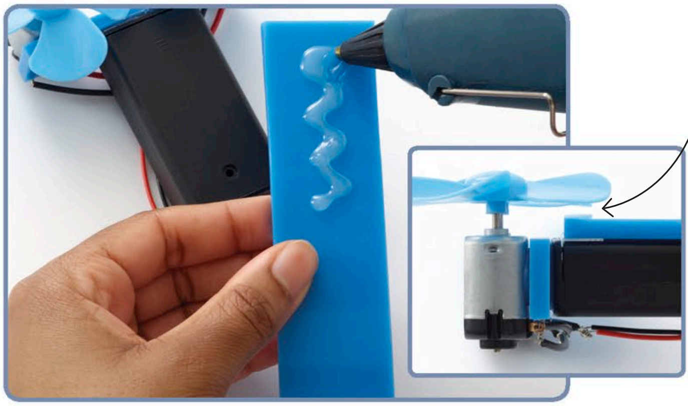


The direction the fans rotate in is determined by the polarity of the motors, which you can find out by testing them.

8 Flip the switch on the battery pack to test whether the propellers create a forward-blowing breeze. If the air is blowing backward, switch the black and red battery pack wires around.



9 Once you are happy with the flow of air, solder all of the wire connections.

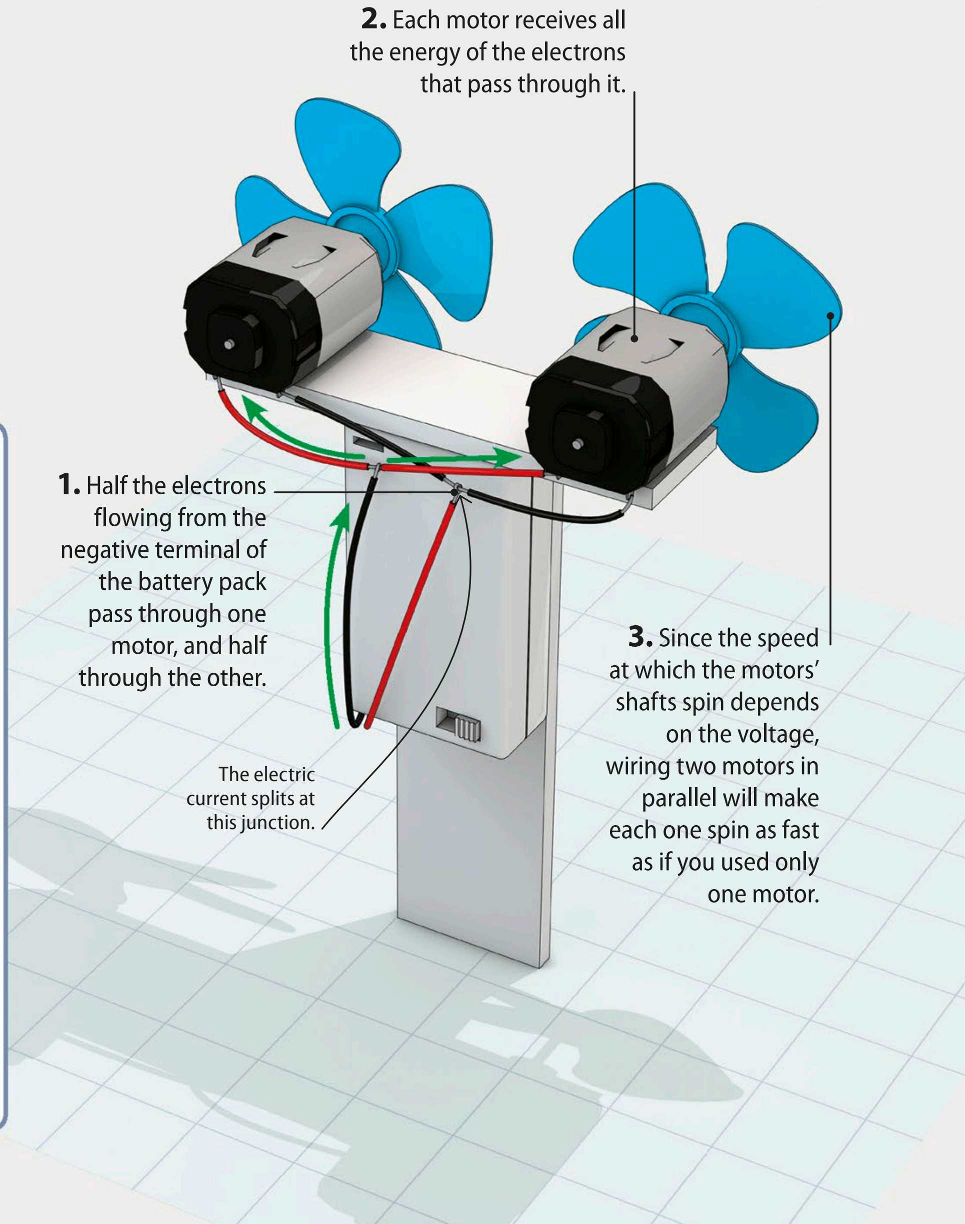


10 Glue a handle to the front of the battery pack that is the same width as the pack.

11 Your fan is now finished. When you turn it on, it will create a refreshing breeze.

How it works

When you wire circuit components in parallel, each component receives the same voltage, so in your handheld fan, each motor receives the full 3 volts from the battery pack. Two motors in parallel will use twice the power, however, so the batteries will run down more quickly.



Real-world inventions

Car headlights

Car headlights are wired in parallel. If they were wired in series, then if one light stopped working, the other one would also not work, and both would gradually get dimmer as the battery drains.

Matchbox microphone

A microphone transforms sound waves into an electrical signal, and allows the original sound wave to be heard when that signal is converted back. With this matchbox microphone you'll be using a pencil lead to capture sound waves, and some earphones to help you hear the sounds it picks up.

How to make a
Matchbox microphone

The safest and easiest way to get the pencil leads you need is to buy mechanical pencil lead refills. Also, it is best to use old or cheap earphones, in case they get damaged.

Time
15 mins

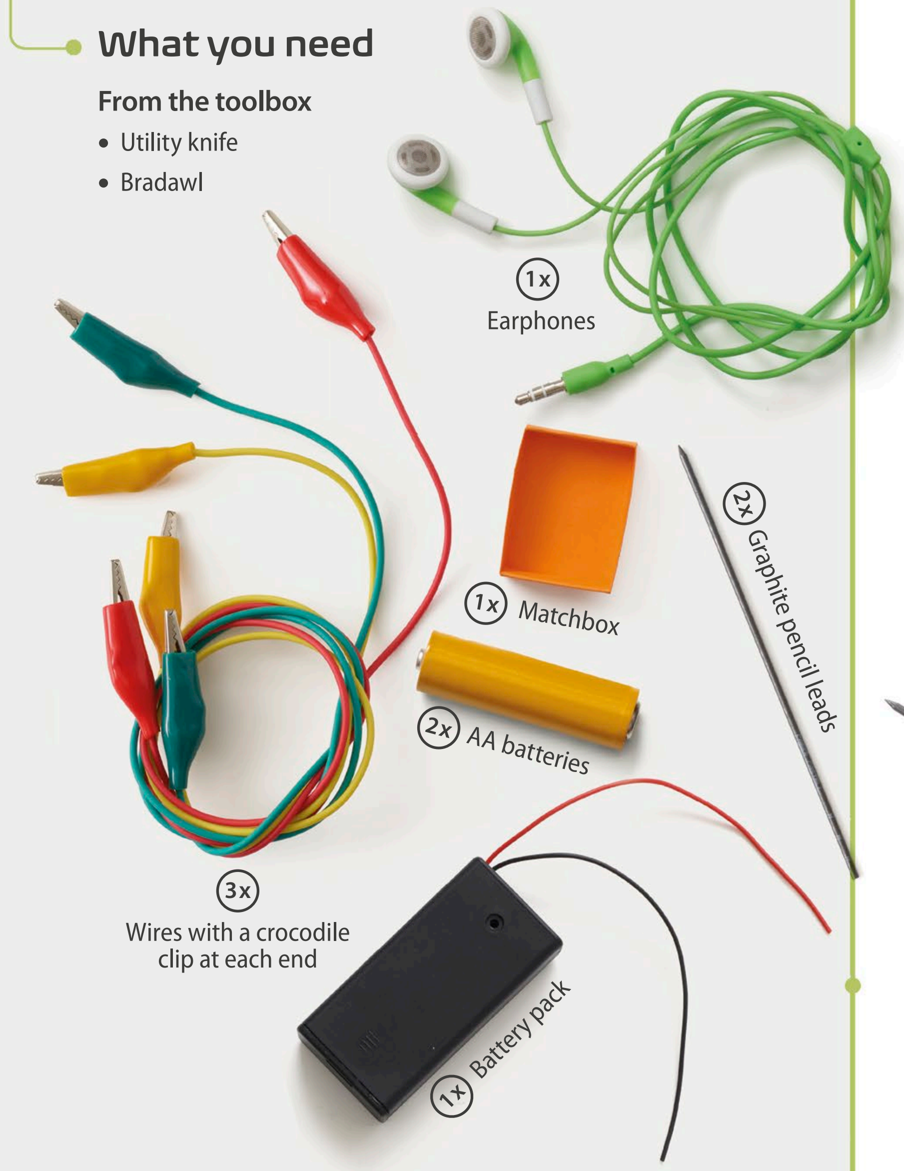
Be aware
Requires bradawl and utility knife use.

Difficulty
Easy

What you need

From the toolbox

- Utility knife
- Bradawl



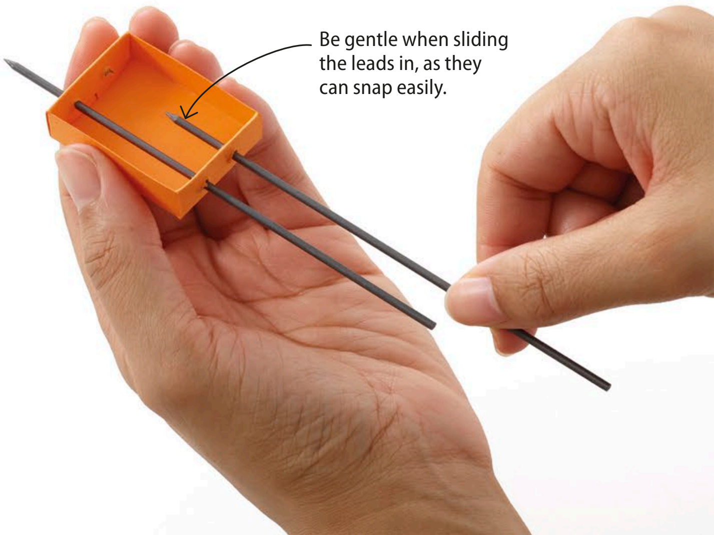

Using a bradawl see p.24

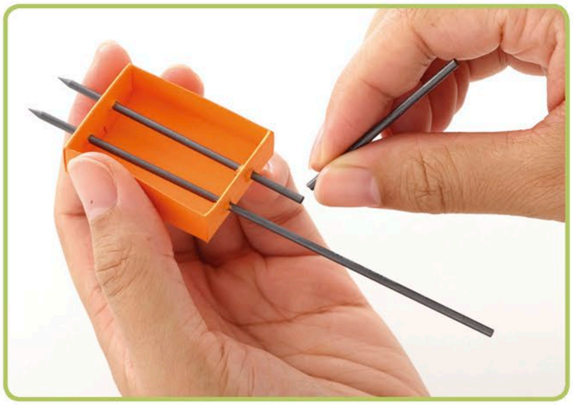
1 Use the bradawl to pierce two holes about ⅜ in (1 cm) apart in one end of the box, then repeat for the other end. Be careful not to hurt your hand when making the piercing.


Utility knife see p.20

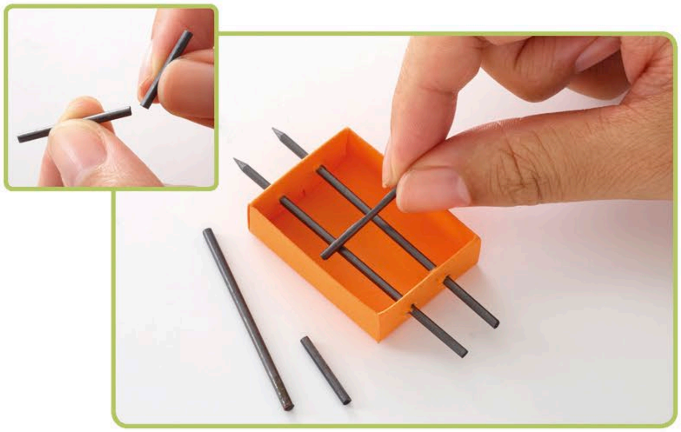
2 Gently scratch one side of both pencil leads with the sharp edge of the utility knife to create a flat side on each.

3 Push the pencil leads through the holes in the box, as shown. Let the pencil leads stick out from each end of the box. Twist them around so the flat side faces up.

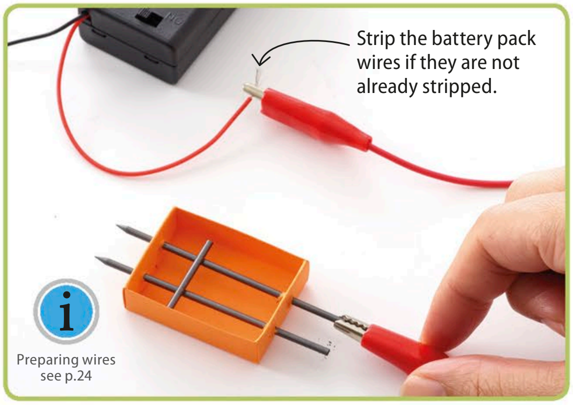




4 Snap the ends of the pencil leads, so that about $\frac{3}{8}$ in (1 cm) remains sticking out from the box.

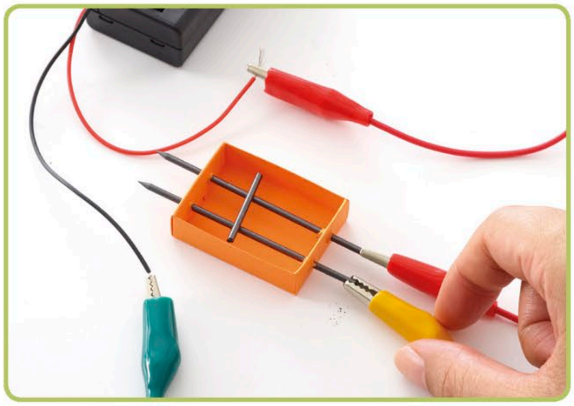


5 Snap a piece of pencil lead that's slightly shorter than the width of the box from one of the leftover pieces. Place it flat-side down across the other two leads, to bridge the gap between them.

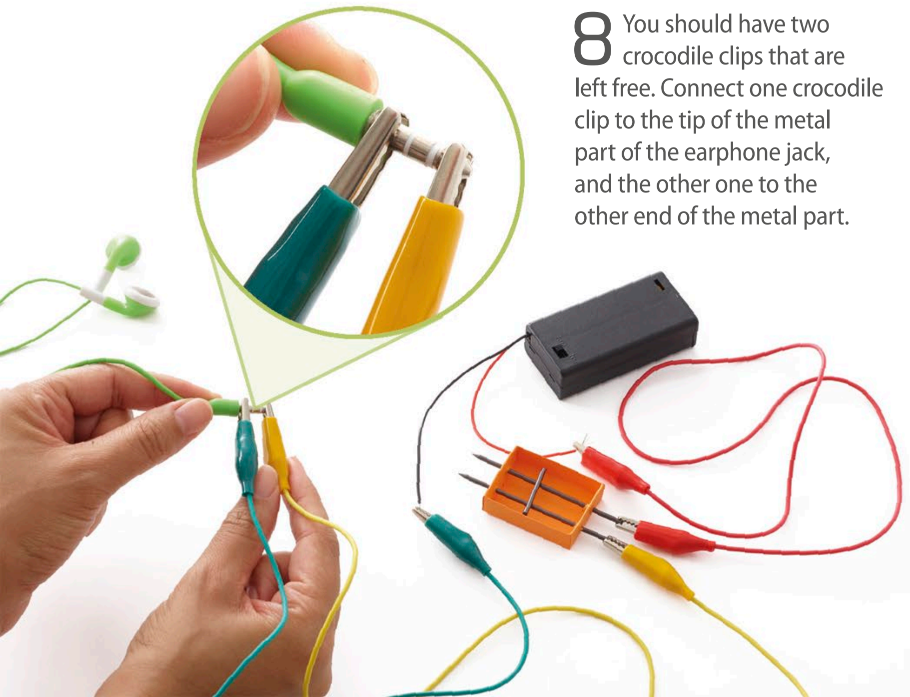


Preparing wires see p.24

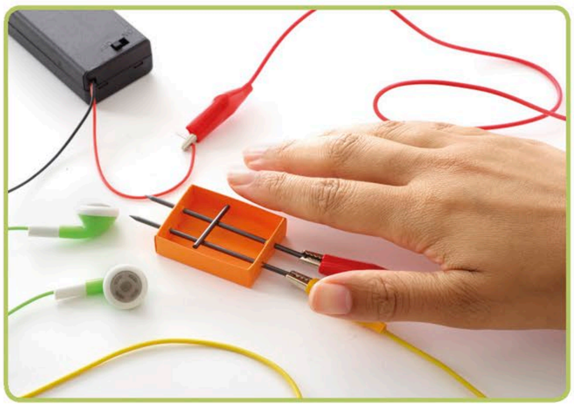
6 Using one of the crocodile clip wires, connect one of the pencil leads to one of the battery pack wires.



7 Use a different crocodile clip wire to connect to the remaining battery pack wire. Finally, take a third crocodile clip wire and connect it to the remaining pencil lead.



8 You should have two crocodile clips that are left free. Connect one crocodile clip to the tip of the metal part of the earphone jack, and the other one to the other end of the metal part.



9 Insert the earphones into your ears, switch on the battery pack if it has a switch, and then gently tap the box. You should hear the tapping sound through one of the earphones. Next, try speaking into the box!

How it works

Pencil "leads" are not made of lead: they are made of a material called graphite mixed with clay. Graphite conducts electricity, but not very well: it has a high resistance to electric current.

Real-world inventions

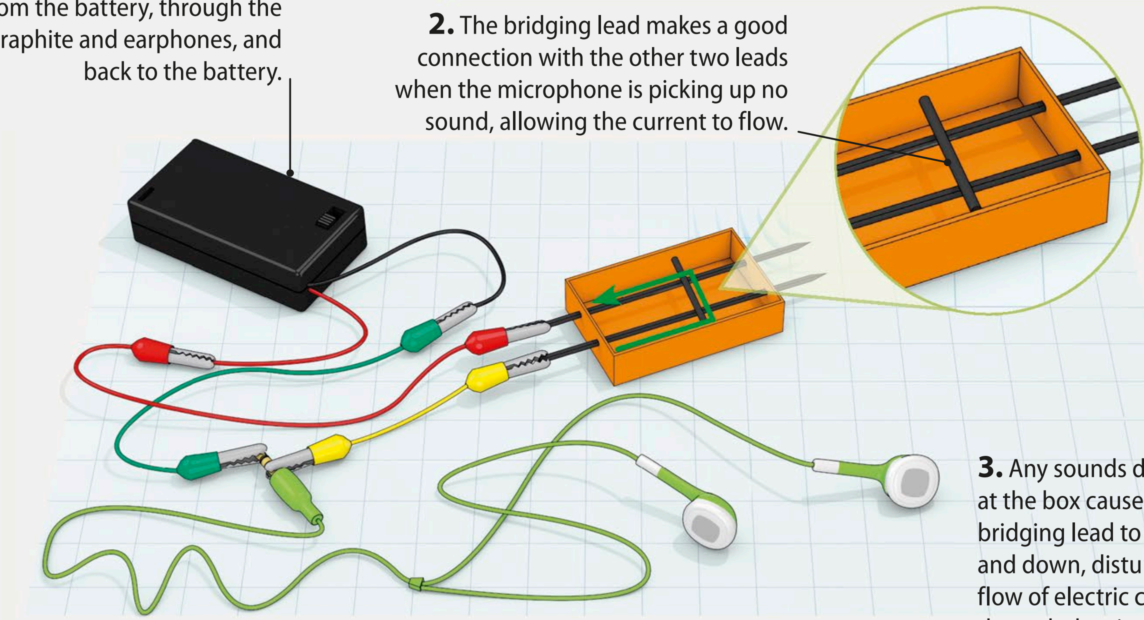
Audio signal

The varying electric current microphones produce is called an audio signal. It is a copy of the changes in air pressure of a sound wave. The audio signal can be recorded digitally, and then be displayed and manipulated by using a computer.

No sound

1. When you connect the circuit, an electric current flows from the battery, through the graphite and earphones, and back to the battery.

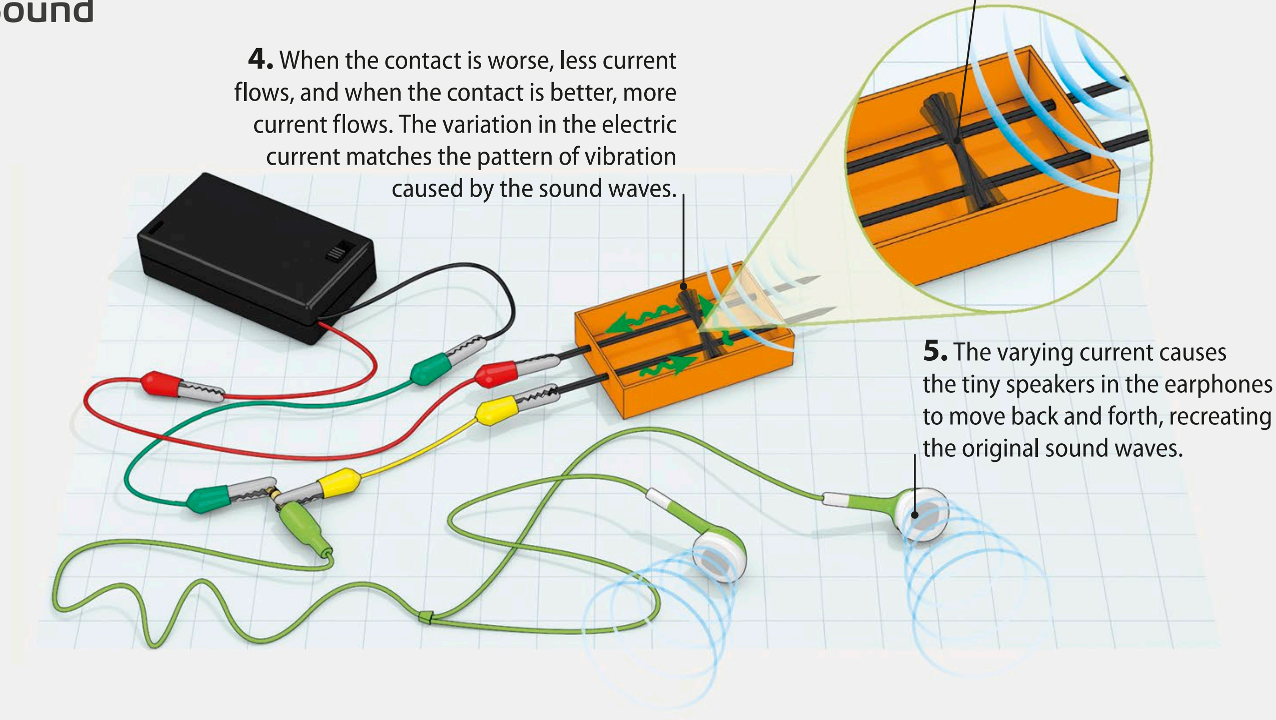
2. The bridging lead makes a good connection with the other two leads when the microphone is picking up no sound, allowing the current to flow.



3. Any sounds directed at the box cause the bridging lead to jump up and down, disturbing the flow of electric current through the circuit.

Sound

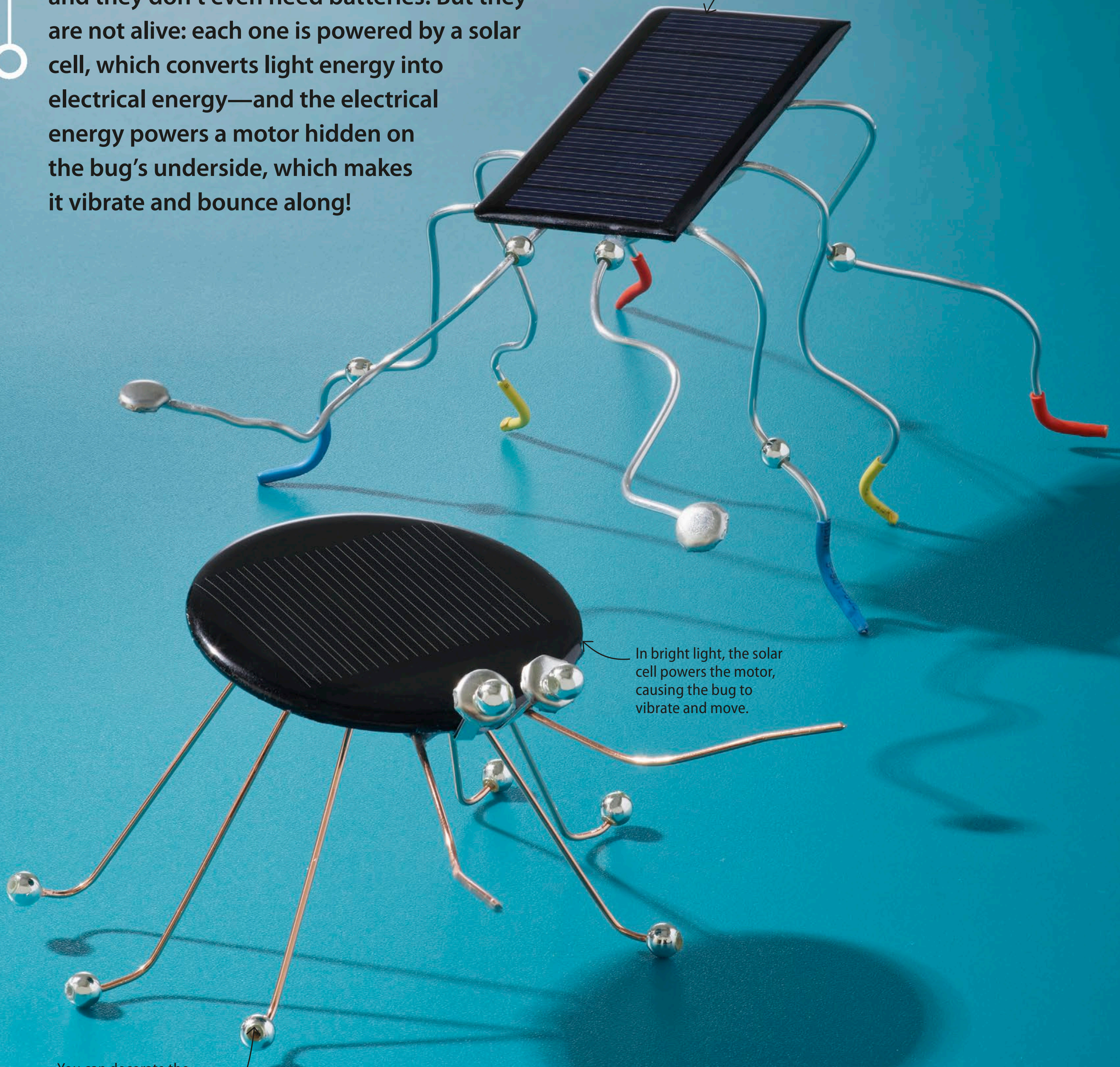
4. When the contact is worse, less current flows, and when the contact is better, more current flows. The variation in the electric current matches the pattern of vibration caused by the sound waves.



5. The varying current causes the tiny speakers in the earphones to move back and forth, recreating the original sound waves.

Bugbot

These amazing creatures seem to come alive in bright light. They move without being pushed, and they don't even need batteries. But they are not alive: each one is powered by a solar cell, which converts light energy into electrical energy—and the electrical energy powers a motor hidden on the bug's underside, which makes it vibrate and bounce along!



The bugs will react to sunlight or a strong halogen bulb, but there is not enough energy in LED light to make them move.

In bright light, the solar cell powers the motor, causing the bug to vibrate and move.

You can decorate the bug's legs with beads or the plastic coating from wires.

How to make a

Bugbot

For this project, you need a solar cell and a vibrating motor. There are various kinds of these motors—look for a “coin” or “pancake” one, and make sure it has two leads, not three. Avoid any labeled a “linear resonant activator,” as they will not work in this build.

Time
15 mins

Be aware
Requires soldering and hot glue gun use

Difficulty
Easy

What you need

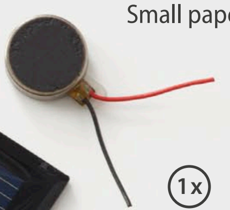
From the toolbox

- Wire cutters
- Soldering iron and solder
- Pliers
- Hot glue gun

3x Large paper clips

2x Small paper clips

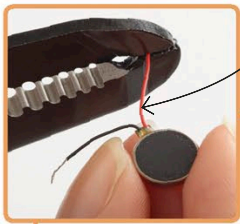
1x Mini 3-volt solar cell



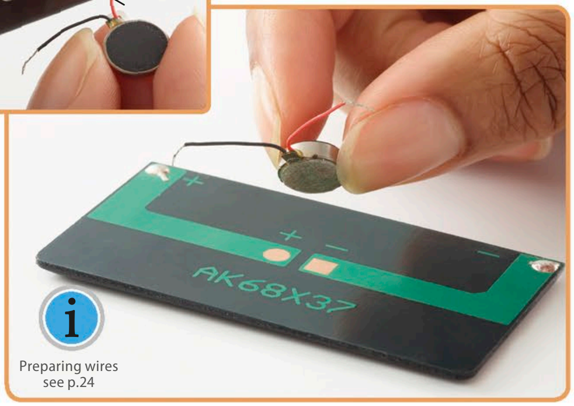
1x 3-volt “coin” or “pancake” vibration motor

2x Small silver beads

1x Red stranded wire 1½ in (4 cm)



The motor wires are usually very thin, so be careful not to snip them as you’re stripping them.

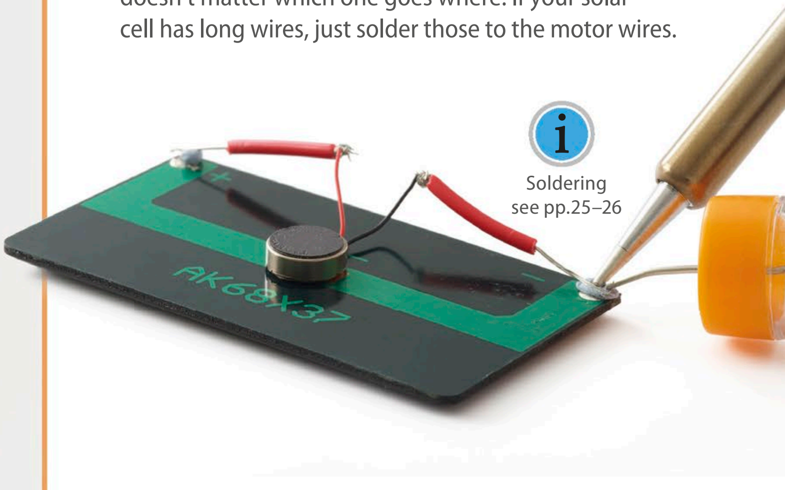


Preparing wires see p.24

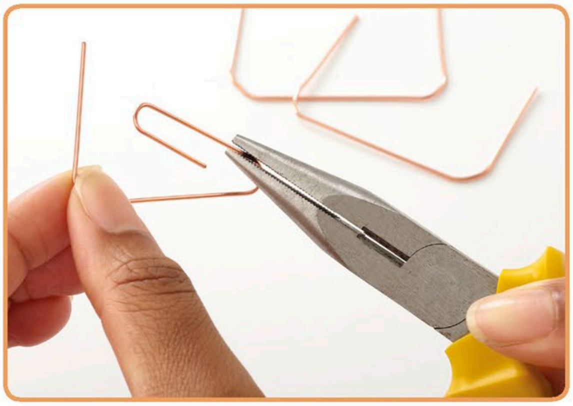
1 Strip the motor’s wires. If your motor has a self-adhesive pad, use it to stick the motor to the middle of the solar cell’s underside—otherwise use a little hot glue.

2 If your motor’s wires can reach the solar panel’s terminals, skip this step. If not, cut and strip two short stranded wires just long enough to reach from the ends of the motor wires to the terminals of the solar cell, to bridge the gap.

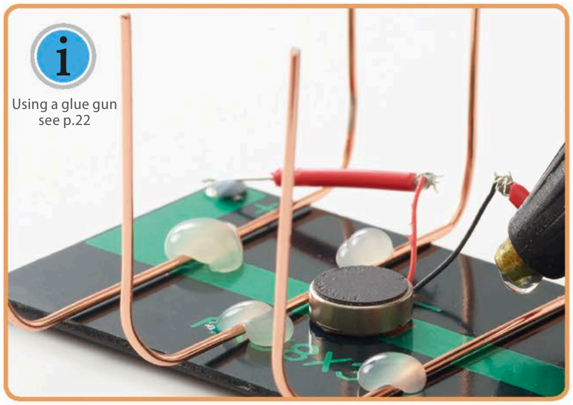
3 Use the short wires and solder to connect each motor wire to a terminal of the solar cell—it doesn’t matter which one goes where. If your solar cell has long wires, just solder those to the motor wires.



Soldering see pp.25–26

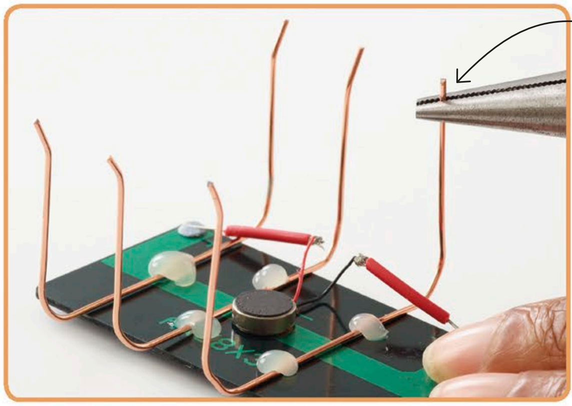


4 Using the pliers, unfold three paper clips, then trim the ends and bend them into wide "U" shapes, so each one looks like a pair of insect legs.



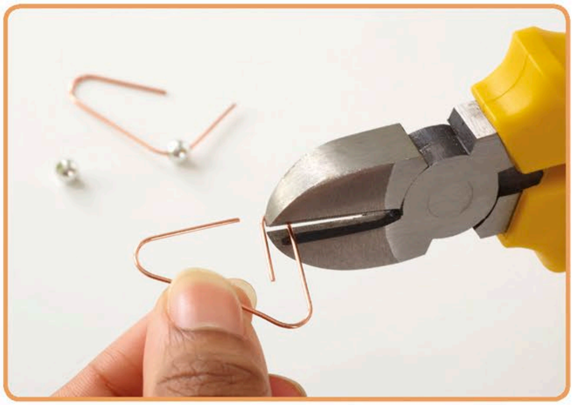
Using a glue gun see p.22

5 Use the hot glue to attach each pair of legs to the underside of the solar cell. Make sure the legs don't touch the exposed parts of the wires, to avoid causing a short circuit.

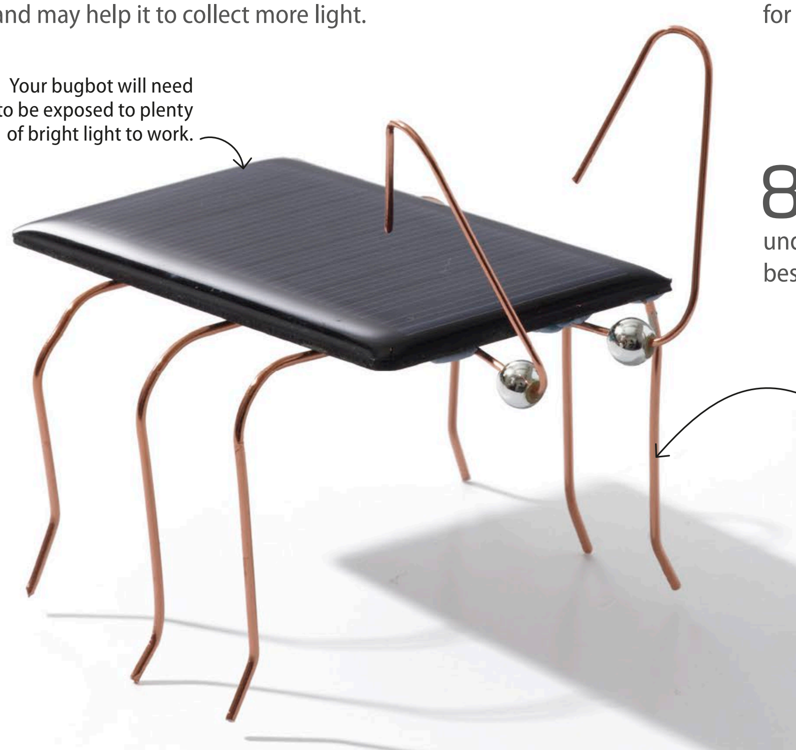


Use the pliers to bend the ends of the wire to create little feet.

6 Use the wire cutters to trim either the front or the back set of the bugbot's legs so that they are slightly shorter than the rest. This will angle the solar cell, and may help it to collect more light.



7 If you like, you can make eyes and antennae using smaller paper clips and beads. But don't add too many things, or your bugbot will become too heavy for the motor to move.



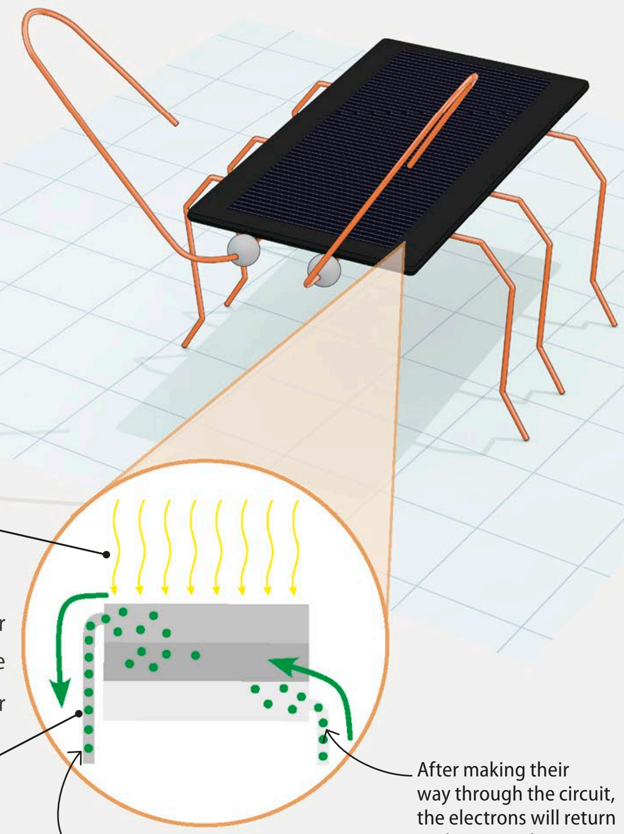
Your bugbot will need to be exposed to plenty of bright light to work.

The vibrating bug will glide across the surface.

8 To make it move, take your bugbot outside if it is very sunny, or place it underneath a halogen lamp. It will work best on a smooth, flat surface.

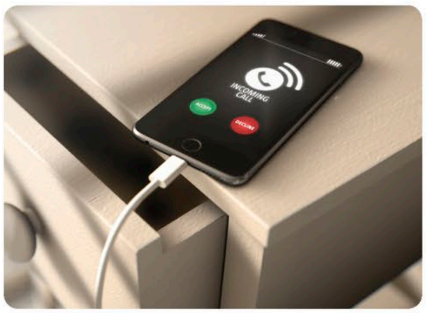
How it works

The bugbot is a simple circuit—the solar panel provides electrons that are used to power the vibration motor, which makes the bugbot move.



1. The solar panel is made up of two layers—the N-type and the P-type, which are separated by a barrier called the depletion zone. When bright light shines on the solar panel, electrons are dislodged from their atoms in the depletion zone.

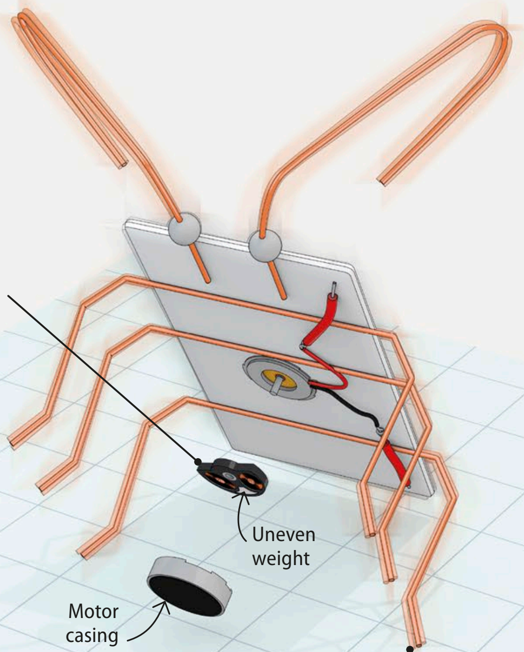
2. The electrons are pushed up through the N-type layer, and into the circuit. This is the electric current that powers the bugbot.



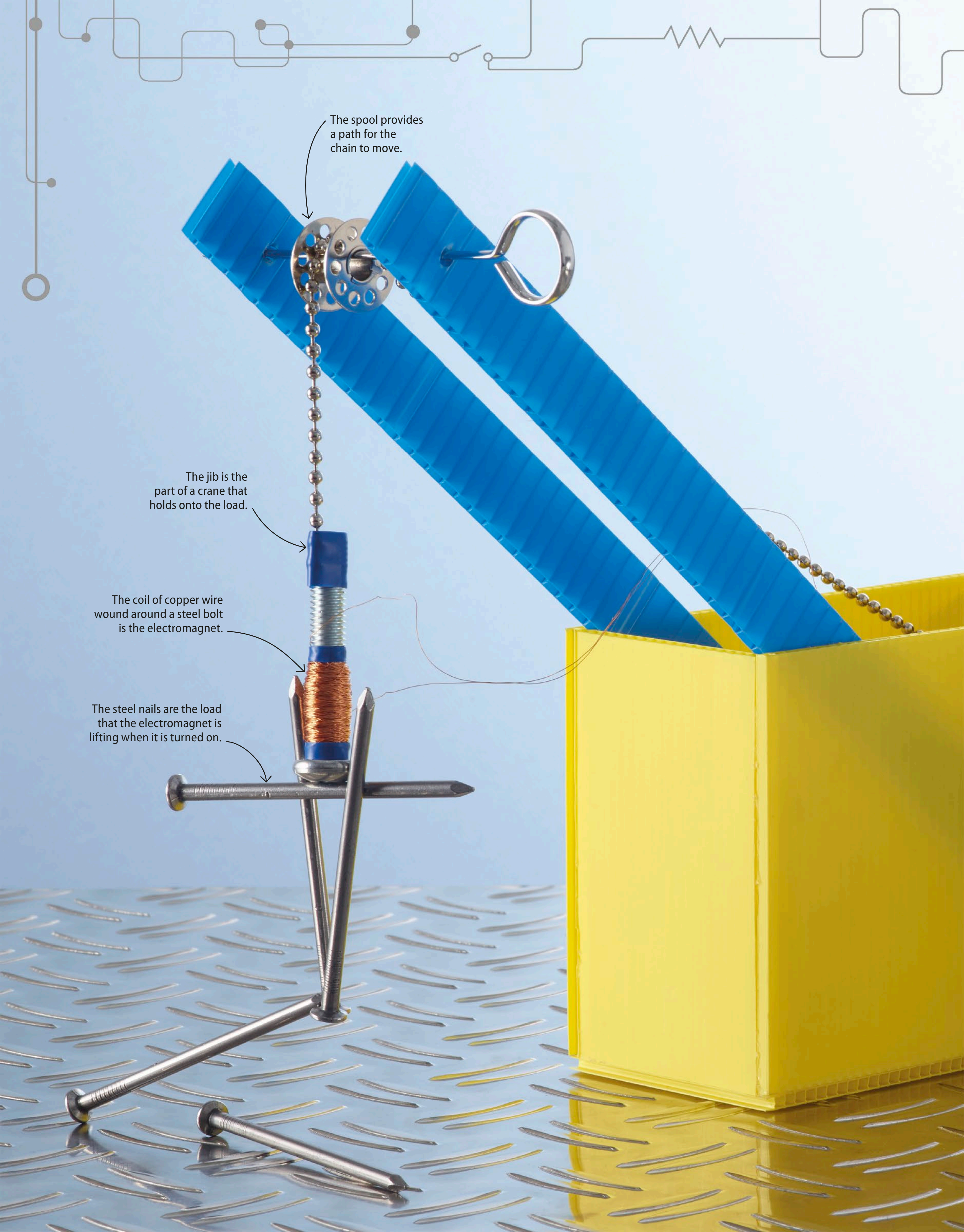
Real-world inventions
Smartphone

There is a vibration motor inside every smartphone. In most smartphones, it is the only moving part. When a call comes in, the motor activates, whirring and making the whole phone vibrate. This is particularly useful when the phone's ringer is turned to silent.

3. Inside the motor is an unevenly distributed weight. When electrons flow into the motor, the uneven weight spins. Its unevenness causes the motor to vibrate.



4. The vibration makes the whole bugbot shake, and as it does, it lifts off the surface and lands again many times each second, so the bugbot bounces along the surface in tiny hops.


The spool provides a path for the chain to move.
The jib is the part of a crane that holds onto the load.
The coil of copper wire wound around a steel bolt is the electromagnet.
The steel nails are the load that the electromagnet is lifting when it is turned on.

Electromagnetic crane

Whenever an electric current flows through a wire, it causes the wire to become slightly magnetic. Wind a current-carrying wire into a coil and you have an electromagnet, which works just the same as an ordinary magnet, except that you can turn it on and off! Electric motors, computer hard drives, and loudspeakers are just some of the familiar devices that contain electromagnets. In this project, you'll make a crane that uses an electromagnet to lift steel objects.

How to make an
Electromagnetic crane

The key to this build is to make it as strong as possible, so you can test the strength of the crane by lifting a heavy load. We have used corrugated plastic sheets to make the box, but you can use a similar material as long as it is sturdy. We have used a metal chain to support the crane's jib—if you can't get your hands on one, you could use string or wire.

Time
45 mins

Be aware
Requires bradawl, hot glue gun, and heat-shrink tubing use.

Difficulty
Easy

What you need

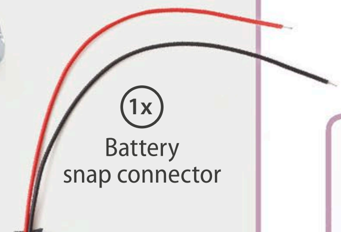
From the toolbox:

- Ruler
- Utility knife
- Cutting mat
- Bradawl
- Adhesive putty
- Hot glue gun
- Marker
- Wire cutters
- Electrical tape
- Sandpaper
- Wire strippers
- Double-sided tape


1x
SPST switch


32–36-gauge enameled copper wire
8 ft 8½ in (28 m)


1x
Bolt 2 in (50 mm)


1x
Battery snap connector


1x
Piece of heat-shrink tubing


1x
9-volt battery


1x
Box
At least 5⅛ x 4 x 2½ in (13 x 10 x 6 cm)

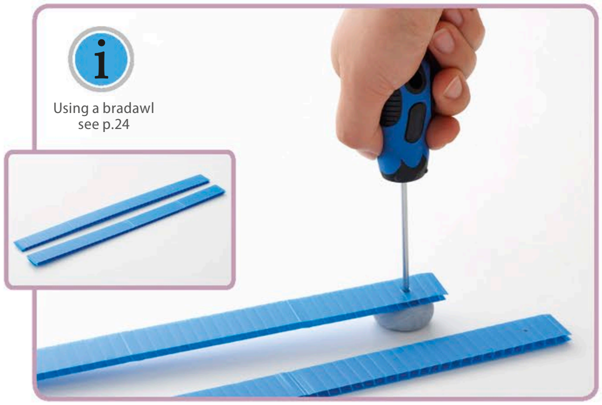
1x
Metal chain
1 m (3 ft)

1x Corrugated plastic sheet

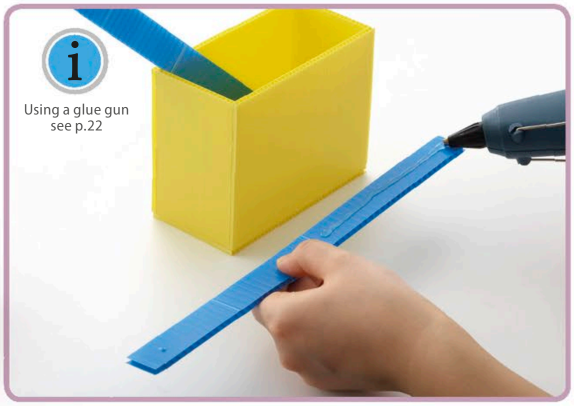
1x Grill lighter

2x
Metal skewers
6 in (15 cm)

1x
Metal bobbin


Using a bradawl see p.24

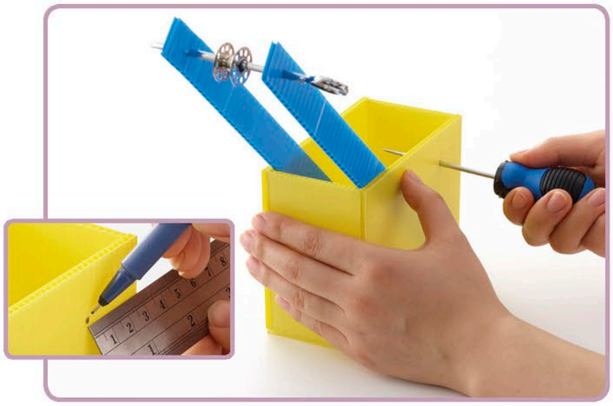
1 Cut two strips of corrugated plastic 12 in (30 cm) by ¾ in (2 cm). Use the bradawl to make a hole in the center of each strip about 1 in (2½ cm) from one of the ends.


Using a glue gun see p.22

2 Glue the strips to the inside of the box. Make sure the two holes at the top are aligned.

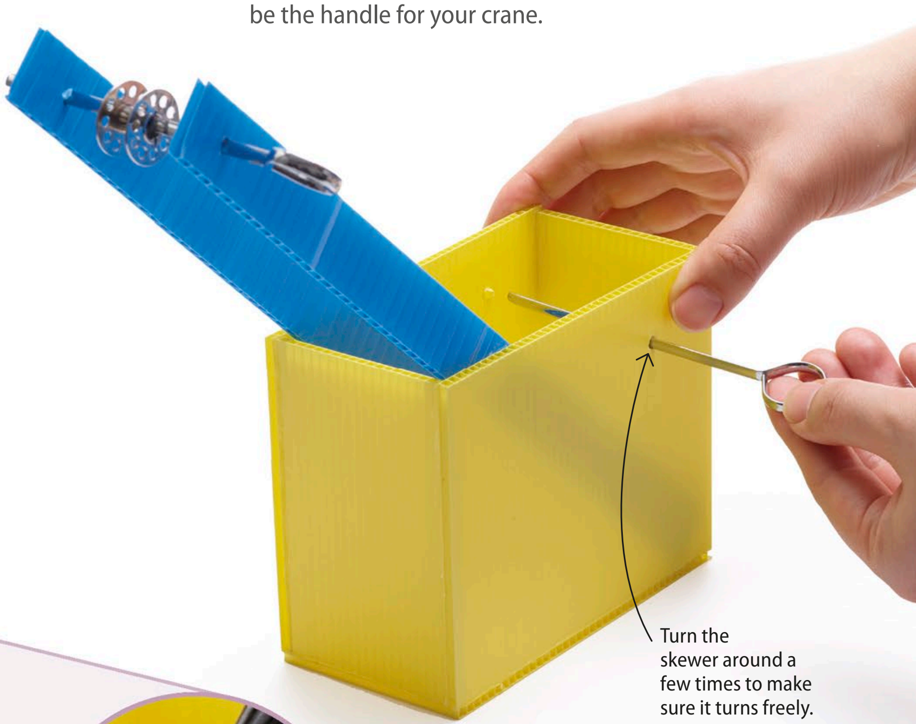
You can glue around the holes to secure the skewer in place, if you like.

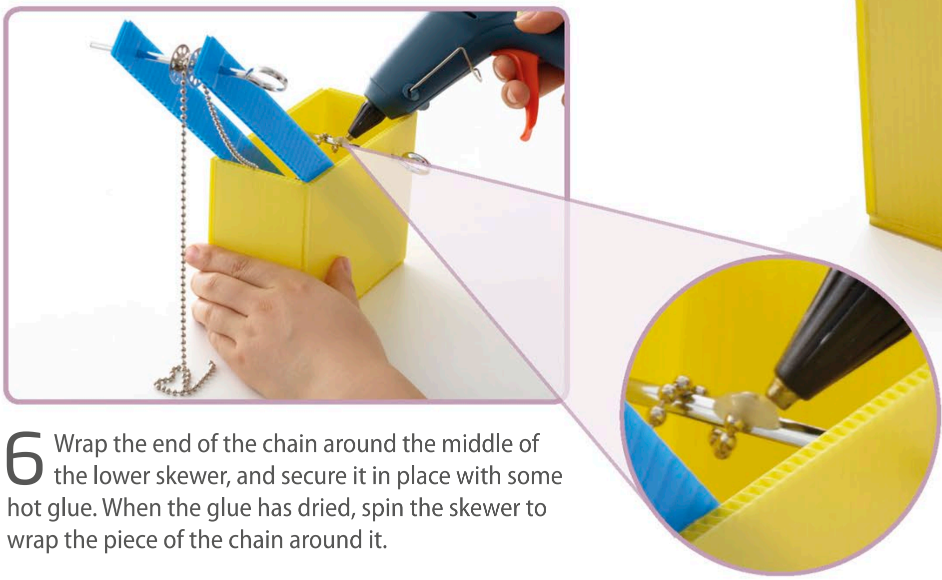
3 Place one of the metal skewers through one of the holes, slip the metal bobbin onto the skewer, then stick the skewer through the other hole.



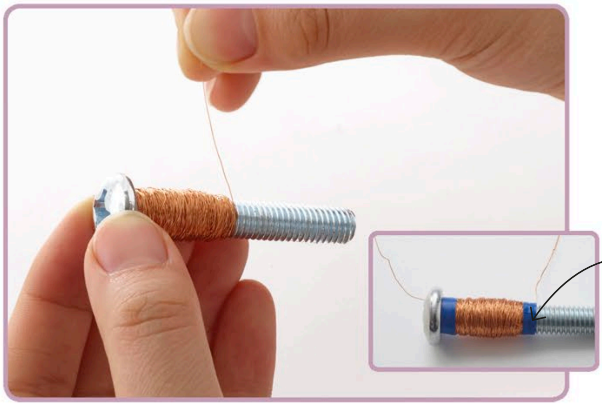
4 Mark a dot ¾ in (2 cm) down and 1⅛ in (3 cm) in from the opposite corner of the box on both sides, as shown. Use the bradawl to poke a hole through both dots.

5 Slide the other metal skewer all the way through both holes in the box. Make sure the skewer can turn freely, as it will be the handle for your crane.



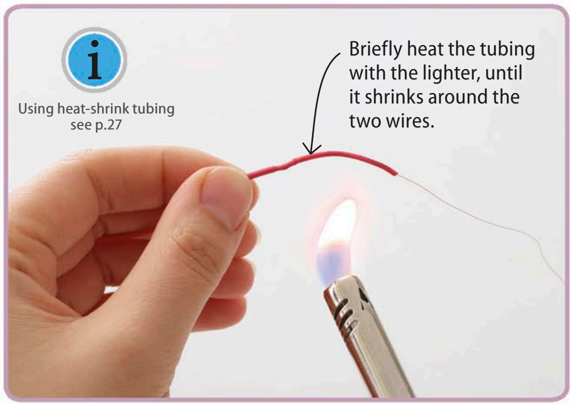


6 Wrap the end of the chain around the middle of the lower skewer, and secure it in place with some hot glue. When the glue has dried, spin the skewer to wrap the piece of the chain around it.



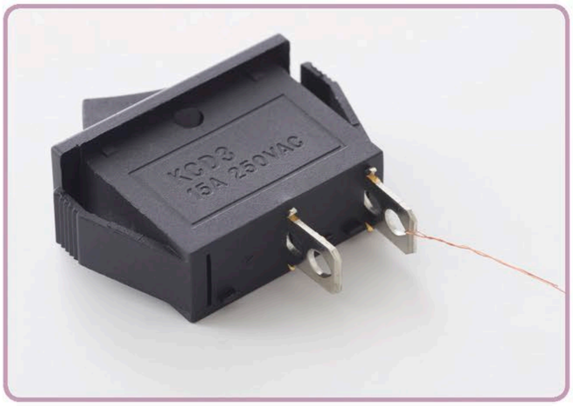
7 Next, starting at least 6 in (15 cm) in from one end, wrap the enameled copper wire tightly around the bolt about 600 times. Cut the wire, leaving another 6 in (15 cm) free at the other end.

8 Use the sandpaper to scrape 1 in (2½ cm) of the coating off both ends of the enameled wire to reveal the shiny copper. This will allow you to make an electrical connection at each end.

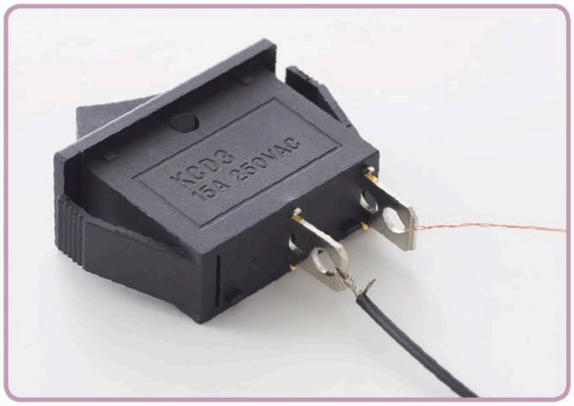


Using heat-shrink tubing see p.27

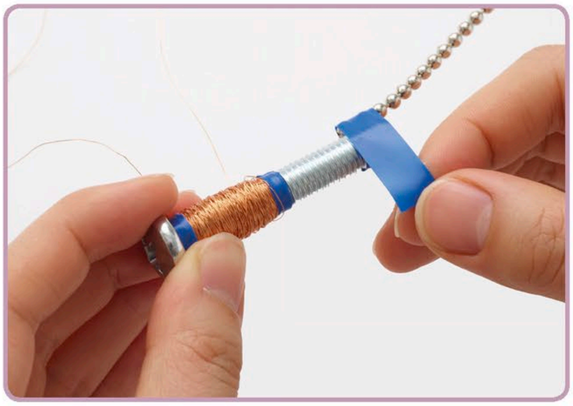
9 Strip the battery snap connector wires. Slip some heat-shrink tubing over one of the copper wires, and wrap the wire around one of the battery wires. Cover the joint with the tubing and heat-shrink it.



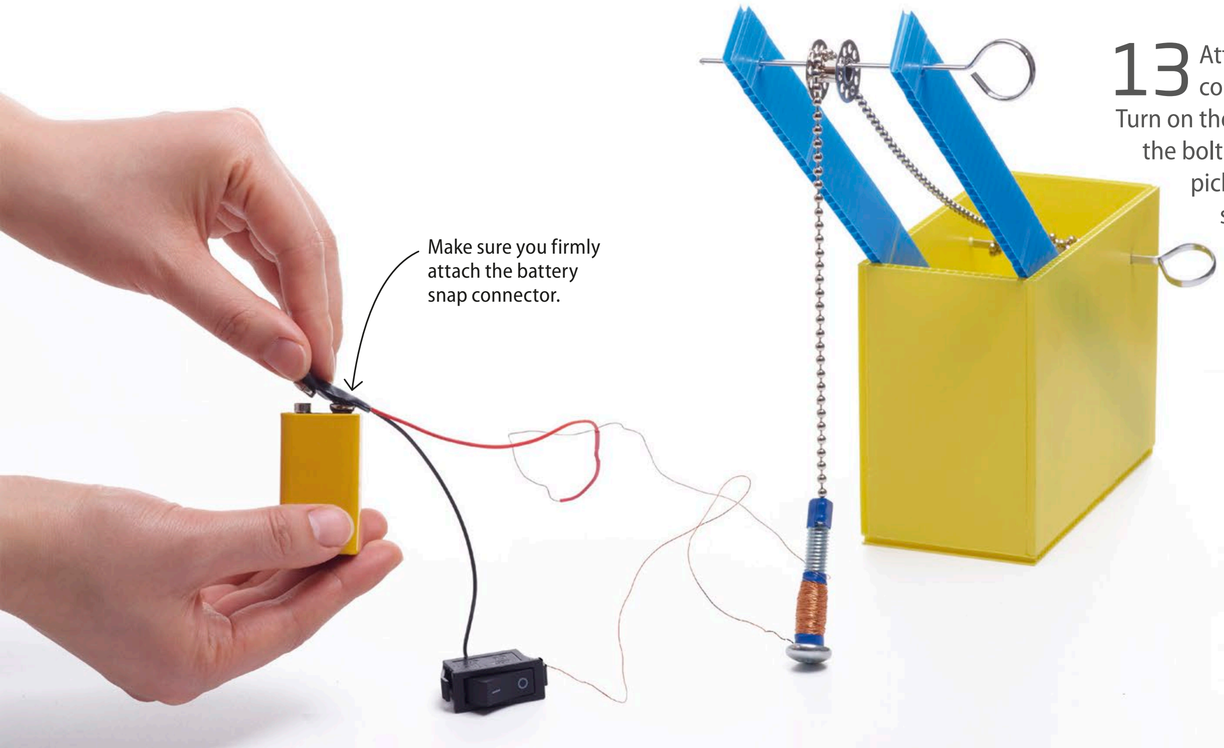
10 Wrap the other end of the copper wire around one of the terminals on the switch. If you want to make it more secure, you can solder it in place, but it is not necessary.



11 Wrap the remaining wire from the battery snap connector to the other terminal of the switch. Again, if you wish to make it more secure, you can solder it in place.



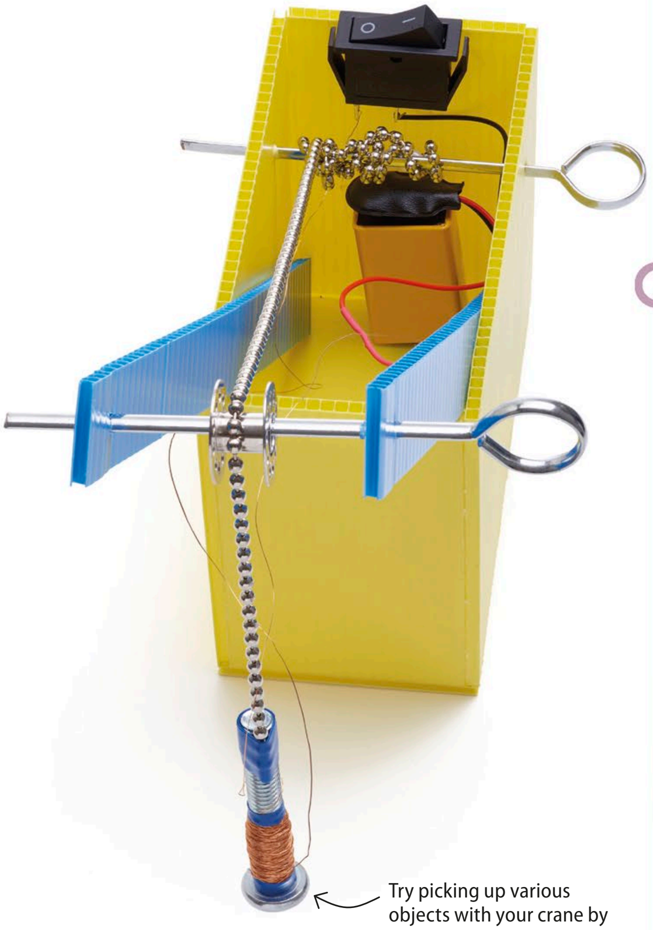
12 Now, take the bolt from step 7. Tape the free end of the metal chain securely to the smaller end of the bolt.



13 Attach the battery snap connector to the battery. Turn on the switch, and check that the bolt is magnetic by trying to pick up some paperclips or steel nails.

Don't leave the switch on for too long, as the wire and battery can get hot.

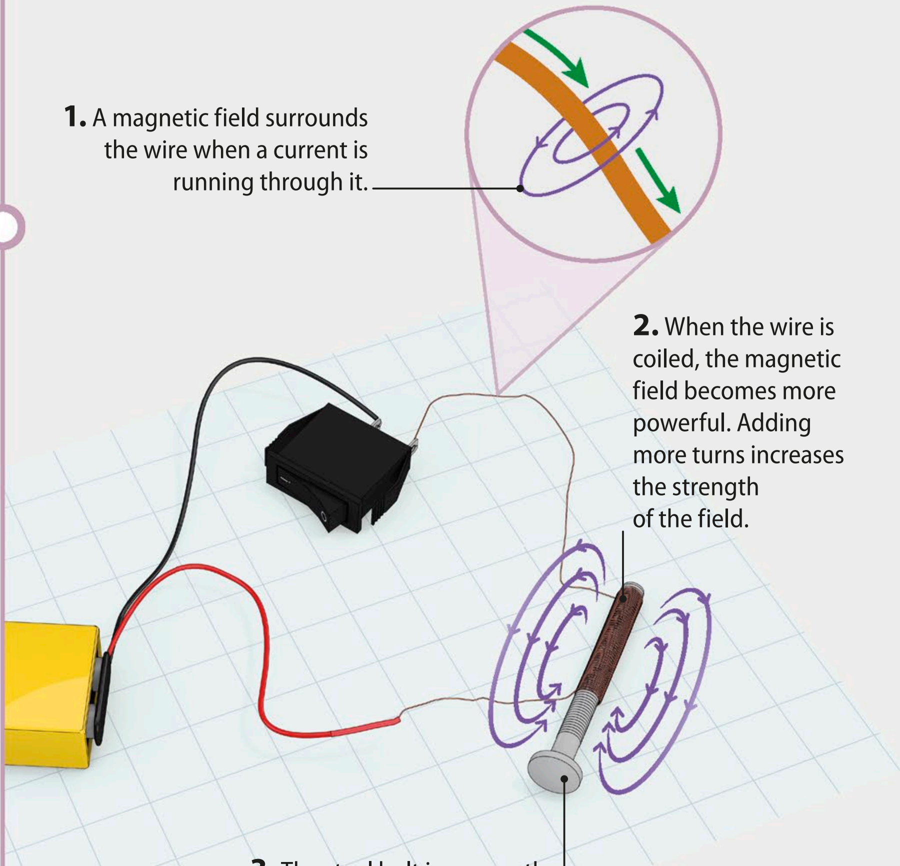
14 Turn off the switch, and use the double-sided tape to stick the battery and the switch inside the box. Your electromagnetic crane is ready!



Try picking up various objects with your crane by turning on the switch and winding the handle to bring up the jib.

How it works

When an electric current is flowing, a magnetic field is created. The stronger the current, the stronger the magnetic field. In your electromagnetic crane, this effect is increased by coiling the wire and adding the bolt. This increased magnetic field attracts the steel nails.



1. A magnetic field surrounds the wire when a current is running through it.

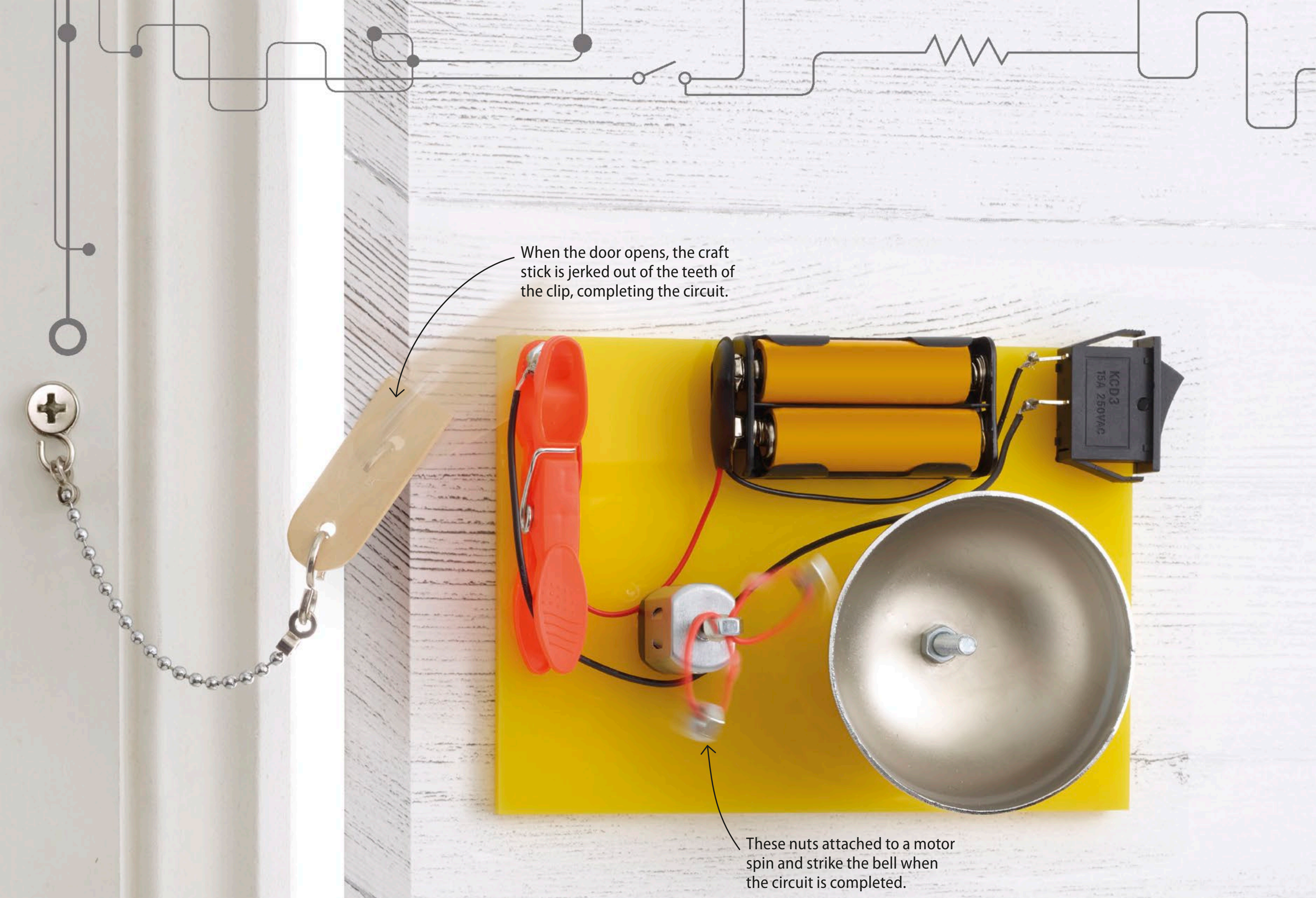
2. When the wire is coiled, the magnetic field becomes more powerful. Adding more turns increases the strength of the field.

3. The steel bolt increases the strength of the magnetic field yet again, as the bolt itself becomes magnetized.

Real-world inventions

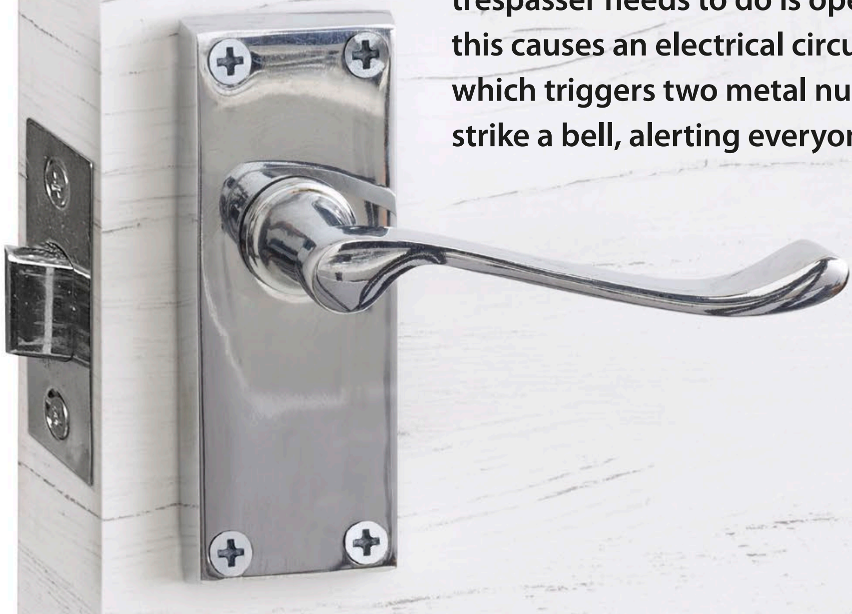
Scrap-metal crane

Large, powerful electromagnetic cranes are used in scrapyards to pick up scrap metal. It only works on ferrous metals—those containing iron. Since most scrap metal is steel, which is a combination of iron and carbon, these cranes are perfect tools. Similar cranes are used in factories to move around large sheets of steel.



Door alarm

Frighten intruders away from your room with this mechanical door alarm, which rings out when someone trips the system. All the trespasser needs to do is open the door: this causes an electrical circuit to complete, which triggers two metal nuts to repeatedly strike a bell, alerting everyone nearby!



How to make a
Door alarm

In this project, you'll need to screw into a door frame—so make sure you ask permission first! We have used a call bell that we've taken apart, but anything that makes a ringing noise when struck will work. You also need a bolt to hold the bell slightly above the base.

Time
45 mins

Be aware
Requires drill, soldering iron, and hot glue gun use.

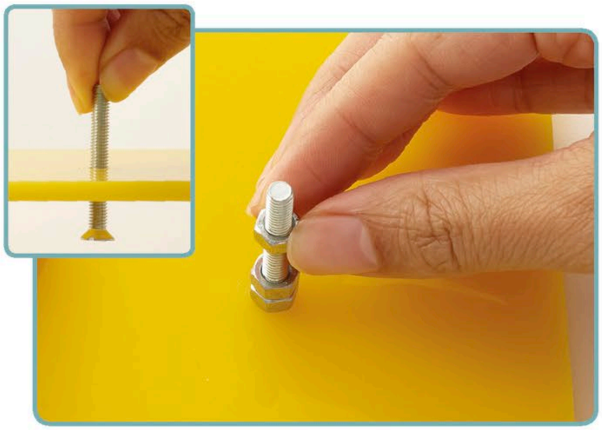
Difficulty
Medium

What you need

From the toolbox:

- Drill and drill bit
- Scrap wood and clamps
- Ruler
- Wire strippers
- Wire cutters
- Soldering iron and solder
- Hot glue gun
- Double-sided foam tape

1 Use a drill bit that is slightly wider than the diameter of your bell bolt to drill a hole in the base board about 2 in (5 cm) from two edges.



2 Slide the bolt upward through the hole and screw three nuts all the way down the bolt to hold it in place.

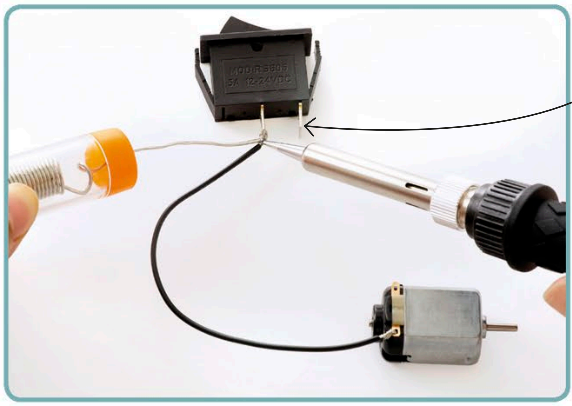
3 Place the bell upside down on top of the three nuts and secure it with another nut.

Use clamps to hold the base board in place when drilling.

4 Drill a ⅛ in (3 mm) hole about 1½ in (4 cm) from the rim of the bell, in line with the bolt. This will create a seat for the motor to rest in.

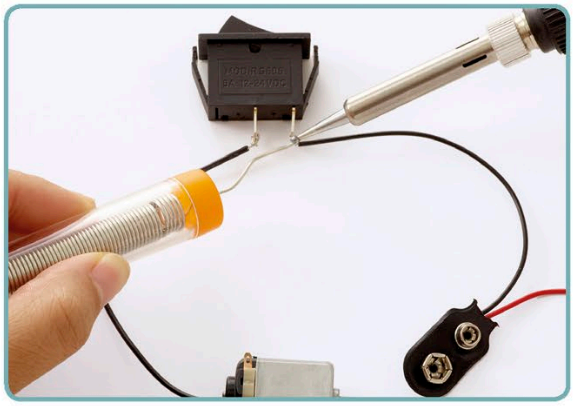
Soldering see pp.25–26

5 Cut and strip a piece of black stranded wire about 4 in (10 cm) long. Twist it around one of the motor terminals and then solder it in place.

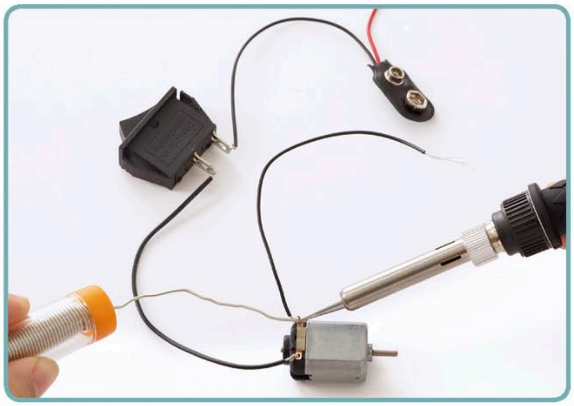


It doesn't matter which terminal you solder to—either end can be open or closed on a SPST switch.

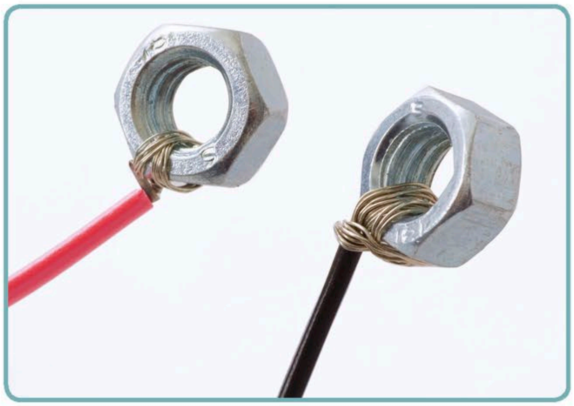
6 Solder the other end of the wire to one of the SPST switch terminals.



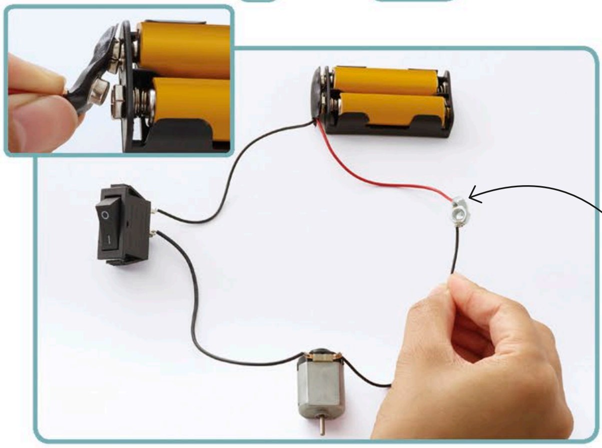
7 Strip about 1⅛ in (3 cm) of insulation off the red wire on the battery snap connector. Strip and solder the black wire to the remaining SPST switch terminal.



8 Cut and strip both ends of a piece of black stranded wire about 4 in (10 cm) long, taking about 1⅛ in (3 cm) of insulation off one end. Solder the other end of this wire to the remaining motor terminal.



9 Wrap the bared end of the red wire from the battery snap connector around a nut, and the black wire attached to the motor around another nut. Make sure each nut is tightly secured to each wire.



You might see a little spark when the nuts come near each other.

10 Insert the batteries into the battery pack and connect the snap connector. Test the circuit by flipping the SPST switch: the motor should whirr when you touch the two nuts together. Turn the switch off.

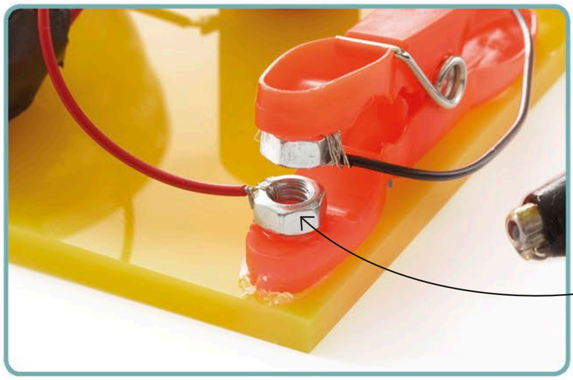
Using a glue gun see p.22

11 Apply hot glue to one side of the clip, and stick it onto the base board, so that the mouth of the clip is roughly in line with the battery pack.

12 Next, use the hot glue gun to glue the battery, switch, and motor onto the base board. Glue the motor directly over the hole you drilled in step 4—but make sure no glue gets near the motor's shaft.

Turning the switch on readies the alarm, but no current will flow to the motor until the two nuts touch.

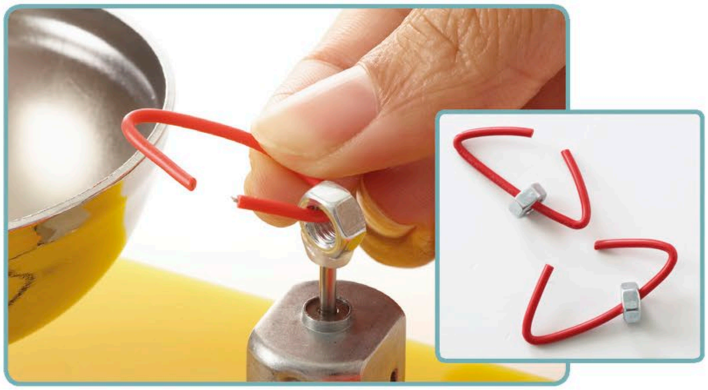
To give the motor extra stability, you can glue an L-shaped wooden bracket onto the motor's side and the base board.



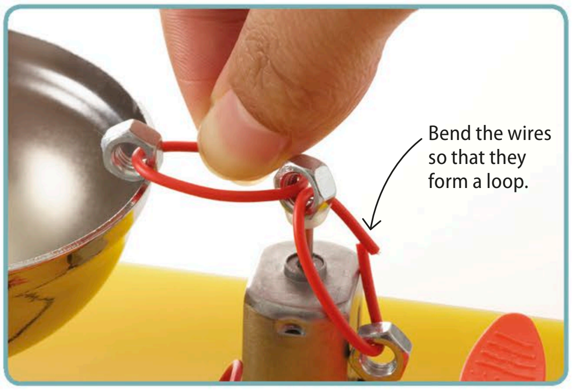
Carefully glue the nuts one at a time, so they don't end up glued together.

13 Take the two wired nuts from step 9 and glue one each to the upper and lower jaw on the clip's mouth.

14 Take another nut and glue one side of it to the top of the motor shaft. Be careful not to let glue drip down into the motor, and make sure the hole in the middle of the nut is clear.

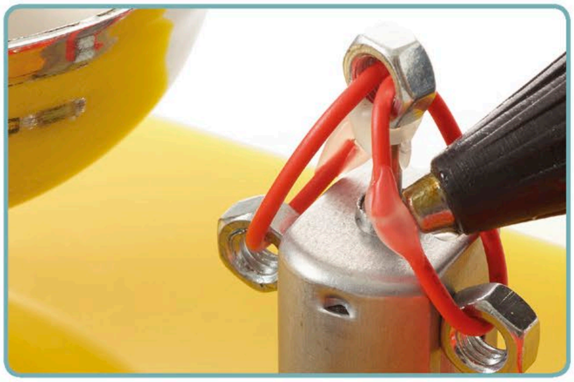


15 Cut two wires into equal lengths, which, when bent in half, are long enough to reach the motor shaft and bell. Thread the wires through a nut each and then bend each wire into a "U" shape.



Bend the wires so that they form a loop.

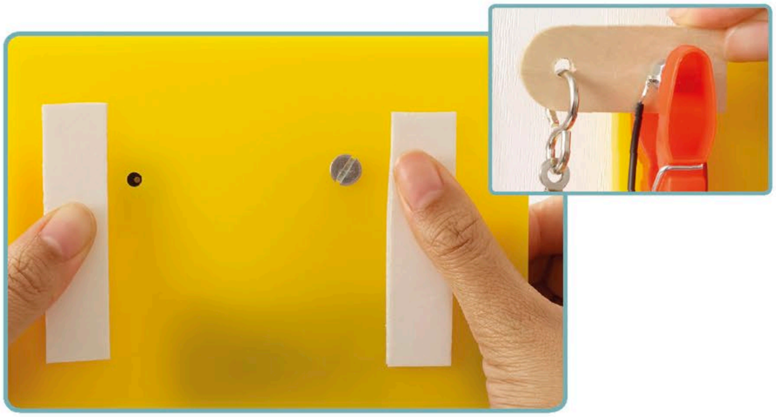
16 Thread the wires with the nuts through the motor nut. Adjust the length of the wires to make sure that the nuts can reach the edge of the bell.



17 Now glue the wire loops closed. Each wire loop should have a nut on it, and each of these nuts should be able to hit the bell when the motor turns.

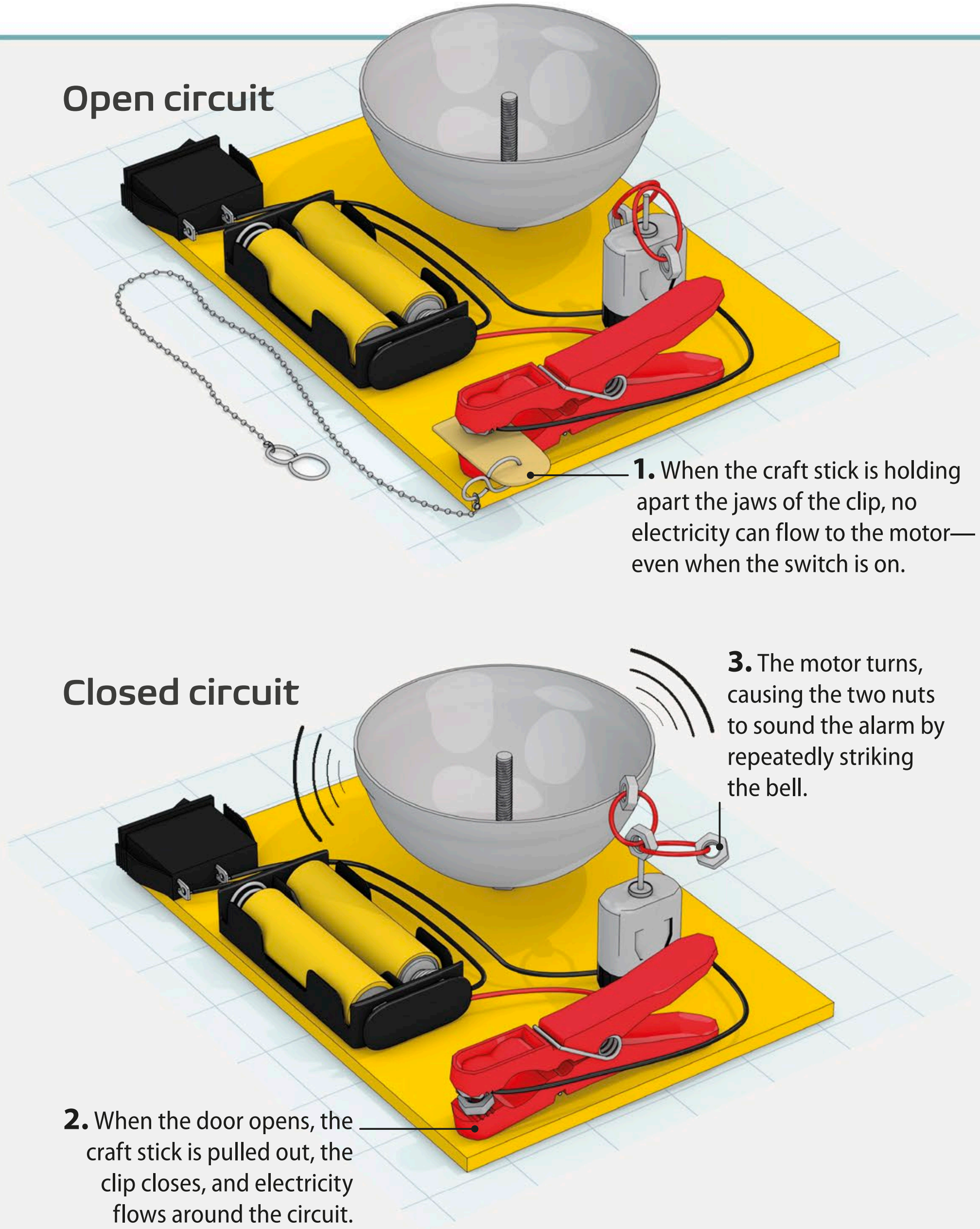
Clamp the stick to a piece of scrap wood before drilling.

18 Cut the craft stick in half, then drill a hole near the end of one half. Attach one end of the chain to the hole, and secure the other end to the door frame with a screw (ask permission first!).



19 Use double-sided foam tape to attach the alarm to the door. Place the craft stick between the nuts in the clip's jaw.

20 Flip the switch. The next time the door is opened, the craft stick will slide out of the clip, causing the circuit to complete and the alarm to sound.



How it works

The piece of craft stick is made of wood, which does not conduct electricity, and when it is removed, the circuit is complete.

Real-world inventions

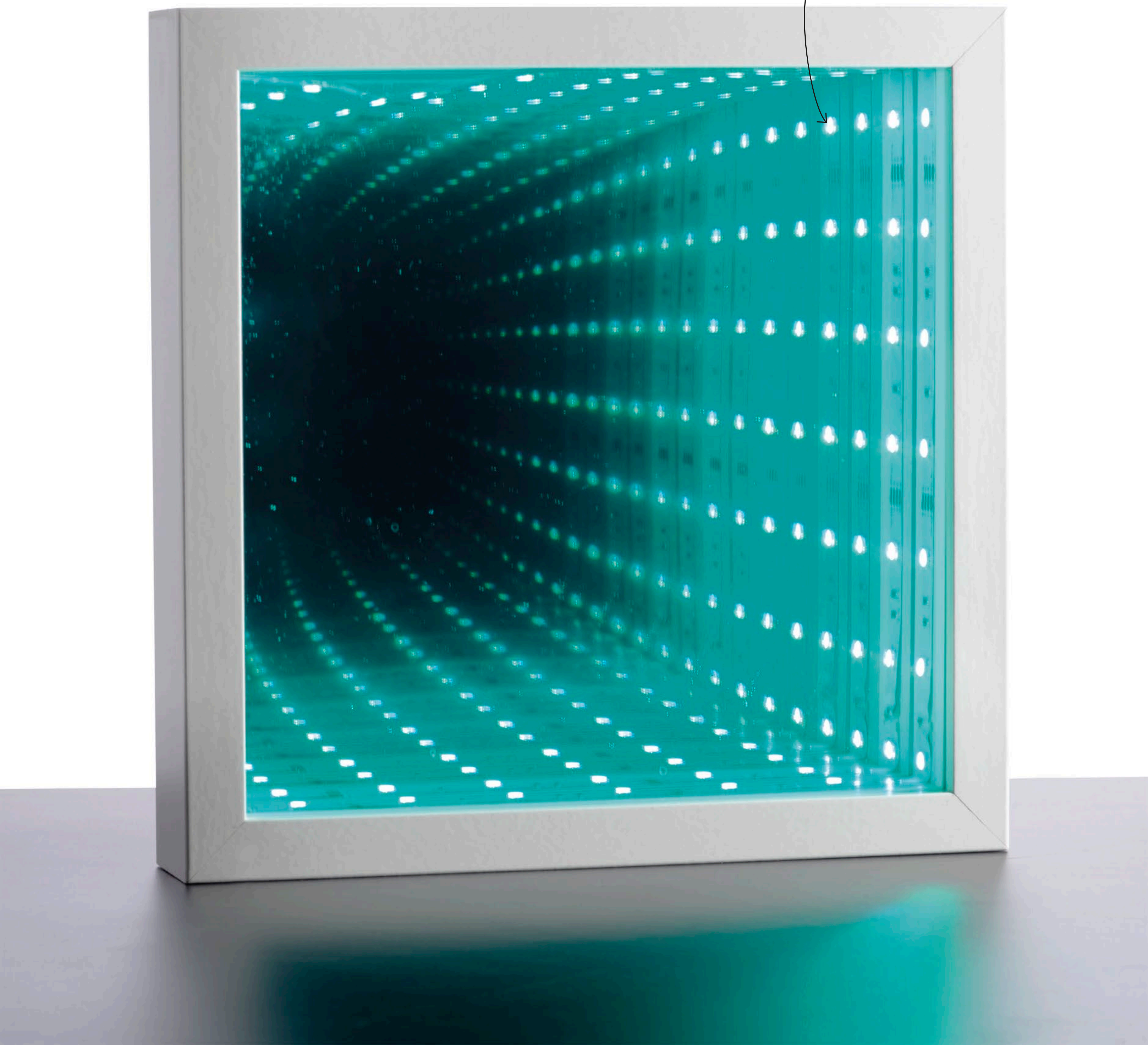
Refrigerator light

When you open a refrigerator door, the light inside the refrigerator comes on automatically. There is a spring-loaded switch just inside the door that is off when the door is closed. When you open the door, it causes the switch's contacts to complete a circuit, which turns the light on.

Infinity mirror

How can you make a normal mirror look like it stretches on forever? All you need to achieve this illusion is a strip of LED lights, some mirrored film, a picture frame, and a mirror. The lights from the LED strip are reflected again and again inside the frame, creating images that appear to fade far into the distance!

Each reflection of the LED strip is dimmer and smaller than the last one, which gives the effect of great depth.



How to make an
Infinity mirror

For this project, you will need a “deep-box” frame with a removable inner frame. Any size frame will work, but the mirror must fit perfectly into the outer frame. Either match the frame’s size to the mirror’s size, or get the mirror cut by a professional to match the frame. Finally, be careful handling the mirror and glass, as they can cut you.

Time
20 mins

Be aware
Requires utility knife, drill, and household power use.

Difficulty
Easy

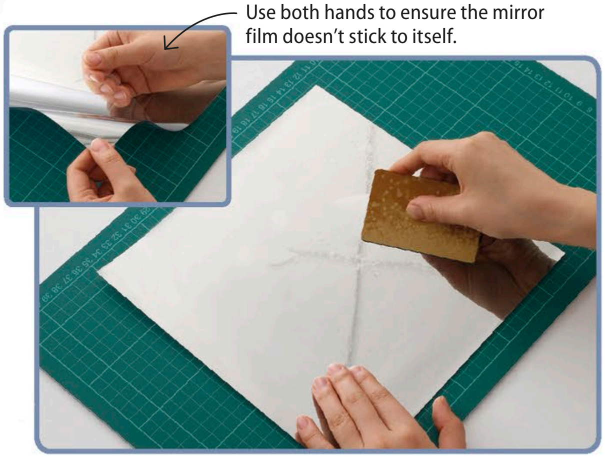
What you need

From the toolbox:

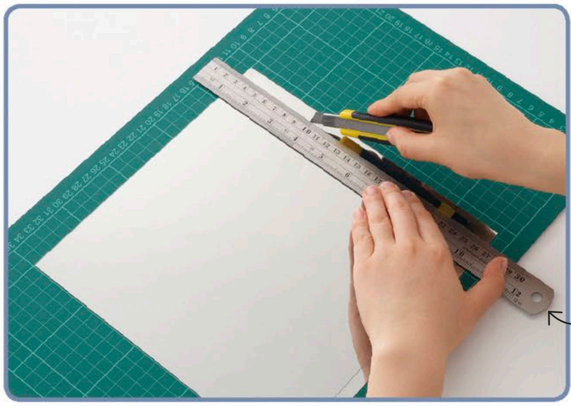
- Utility knife
- Cutting mat
- Ruler
- Drill
- 5⁄16 in (8 mm) drill bit
- Scissors

1 Remove the glass or plastic window from the frame. Use it as a template to cut the one-way mirror film so that it is slightly wider than the window on all sides. If the window has a protective covering, peel it off.

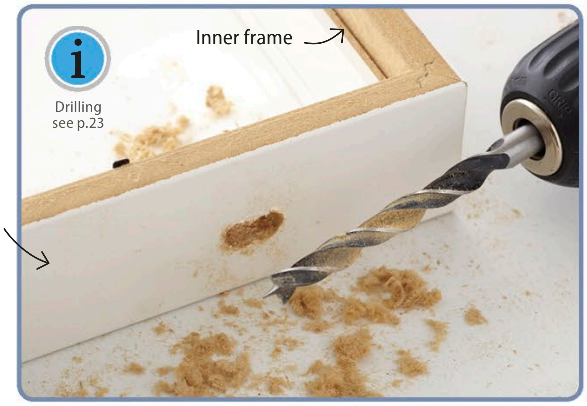
2 Lay the window on a flat surface and spray it with a little soapy water. The water will help the one-way mirror film to stick to the window.



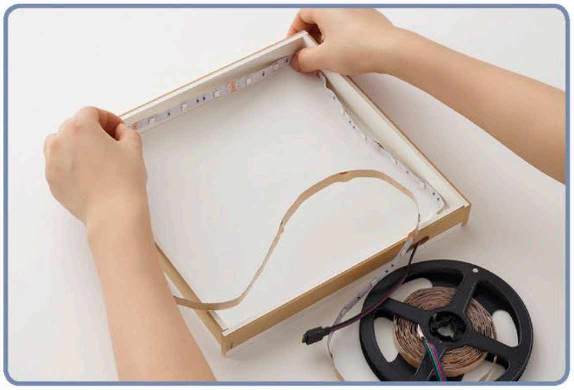
3 Carefully peel off the mirror film’s backing. Place the adhesive side of the mirror film onto the window. Working out from the center, use the plastic card to smooth out any bubbles to create a flat surface.



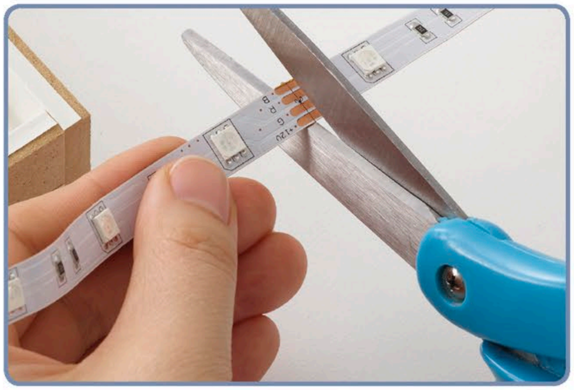
4 Dry the window with a towel, then trim off the excess mirror film with a utility knife.



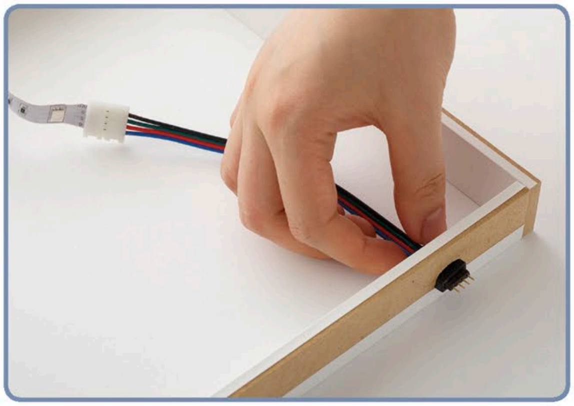
5 Drill a hole through the outer and inner frames. Make it wide enough to accommodate the cord of the LED strip. You may need to drill two holes side by side to allow for this.



6 Remove the inner frame, and measure the LED strip so there is enough to go around the entire length of the inner frame's inside.

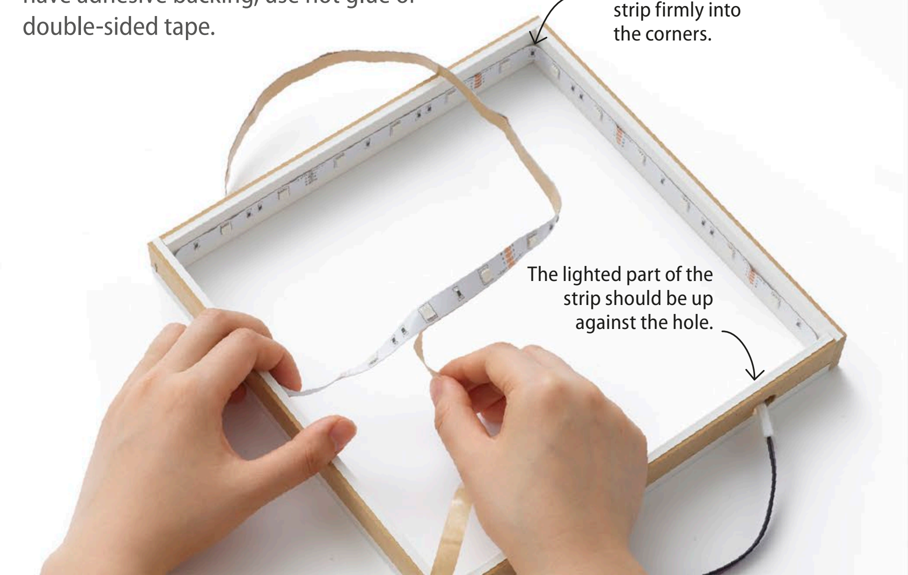


7 Cut the LED strip. Make sure you only cut the strip on the marked cut lines.



8 Feed the end of the LED strip through the drilled hole in the inner frame.

9 Stick the adhesive side of the LED strip inside the inner frame, removing the backing as you go. If your LED strip doesn't have adhesive backing, use hot glue or double-sided tape.

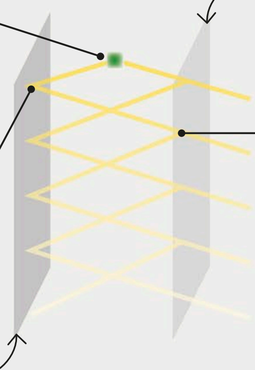


10 Lay the window into the outer frame with the mirror film facing toward you. Feed the cord from the LED strip through the drilled hole in the outer frame, and lay the inner frame on top of the window.

11 Place the mirror into the frame so that the reflective surface faces away from you. Then place the backing board into the frame and secure it in place with the tabs. Plug in the LED strip and turn on the switch.

How it works

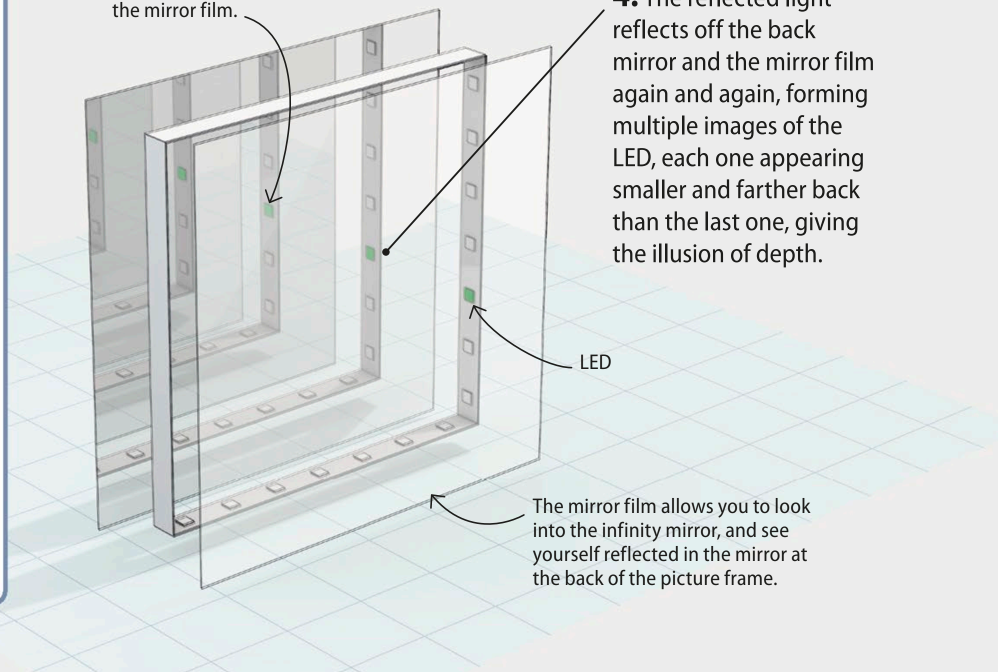
Your infinity mirror works by bouncing the light from the LEDs off the mirror and the mirror film again and again, which gives the impression of an infinite depth to the mirror.



Real-world inventions

One-way mirrors

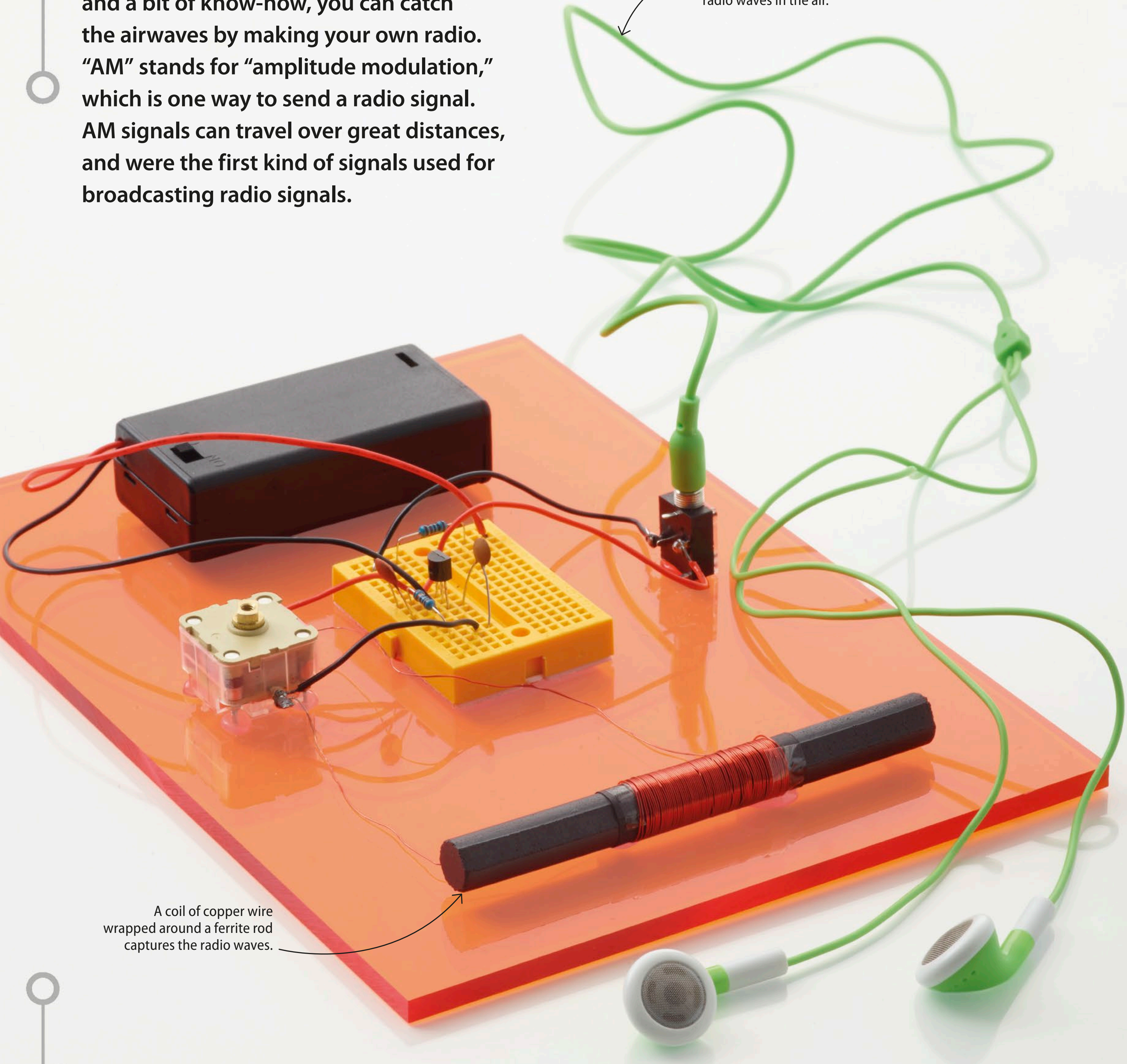
Some police interview rooms have a half-mirrored window like the window at the front of your infinity mirror. To people inside the interview room, it looks like a mirror—but people watching in the next room can see through it, like a window.



AM radio

With just a handful of components and a bit of know-how, you can catch the airwaves by making your own radio. "AM" stands for "amplitude modulation," which is one way to send a radio signal. AM signals can travel over great distances, and were the first kind of signals used for broadcasting radio signals.

The earphones play the sounds extracted by the circuit from radio waves in the air.



A coil of copper wire wrapped around a ferrite rod captures the radio waves.

How to make an
AM radio

Make sure the earphone socket is the right fit for your earphones or headphones. You'll need to use a soldering iron in several parts of the project, so make sure you work somewhere where you can leave it plugged in safely.

Time
40 mins

Be aware
Requires soldering iron and hot glue gun use.

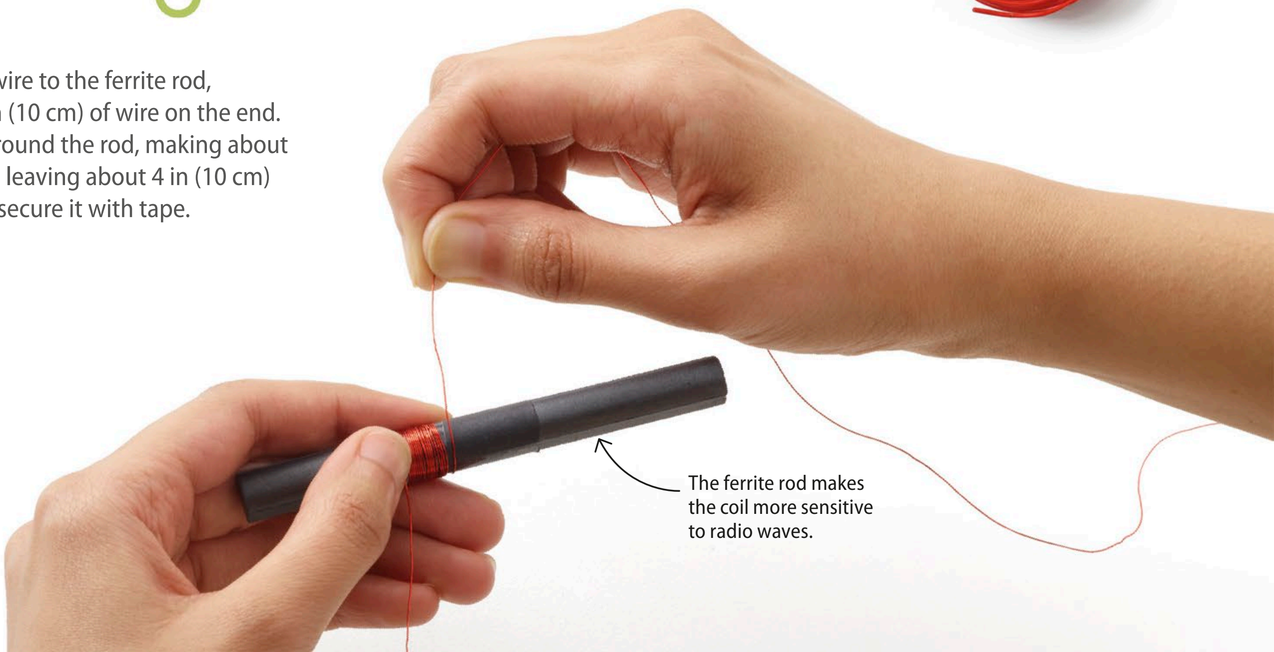
Difficulty
Medium

What you need

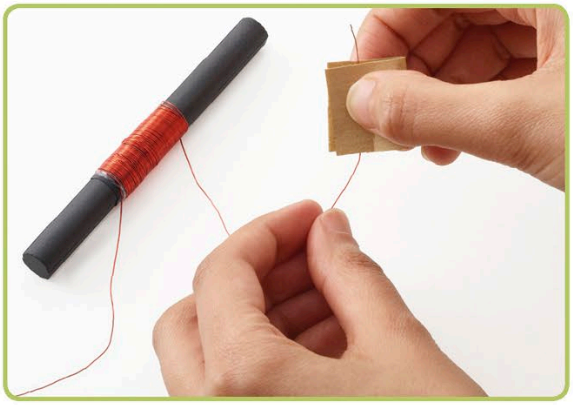
From the toolbox:

- Ruler
- Clear tape
- Wire cutters
- Sandpaper
- Third-hand tool
- Soldering iron and solder
- Wire strippers
- Pliers
- Multimeter
- Hot glue gun

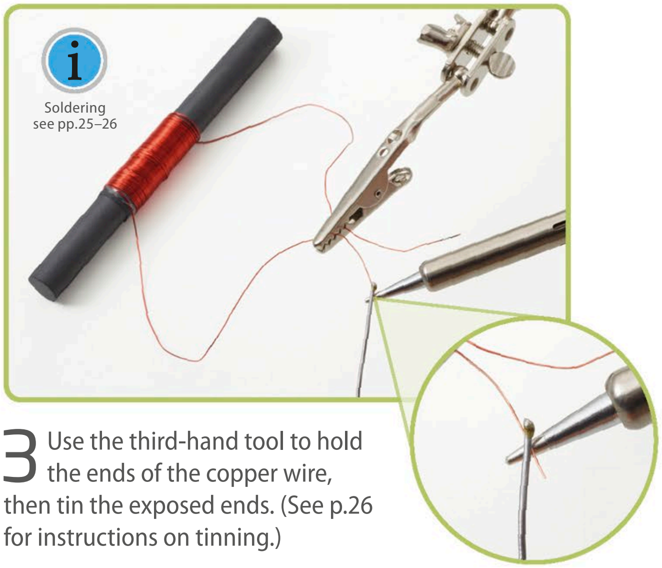
1 Tape the copper wire to the ferrite rod, leaving about 4 in (10 cm) of wire on the end. Next, wind the wire around the rod, making about 80 turns. Cut the wire, leaving about 4 in (10 cm) at the other end, and secure it with tape.



The ferrite rod makes the coil more sensitive to radio waves.



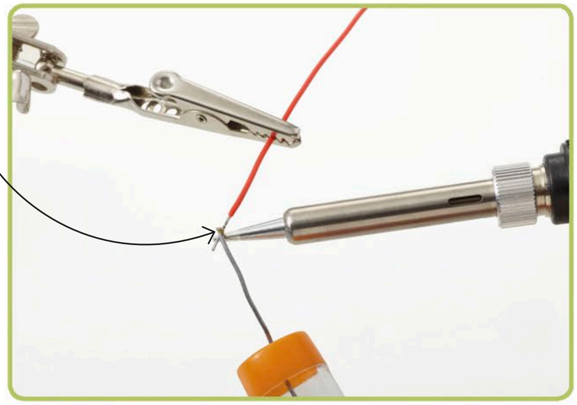
2 Use sandpaper to remove about 1 in (2½ cm) of the coating at each end of the copper wire. This will reveal shiny copper, which will allow you to make an electrical connection at each end.



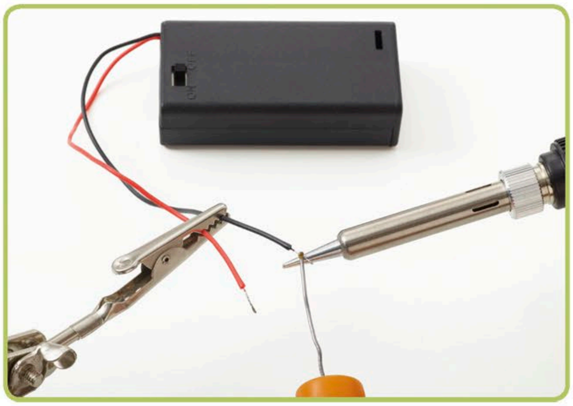
3 Use the third-hand tool to hold the ends of the copper wire, then tin the exposed ends. (See p.26 for instructions on tinning.)

4 Cut a red wire and a black wire each at 3⅛ in (8 cm) long, then another pair each at 4 in (10 cm) long. Use wire strippers to strip about ⅜ in (1 cm) off each end of all four wires.

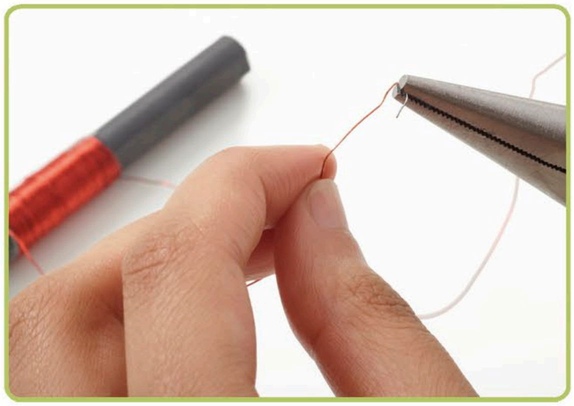
The solder on the tinned ends will melt when you attach the wires.



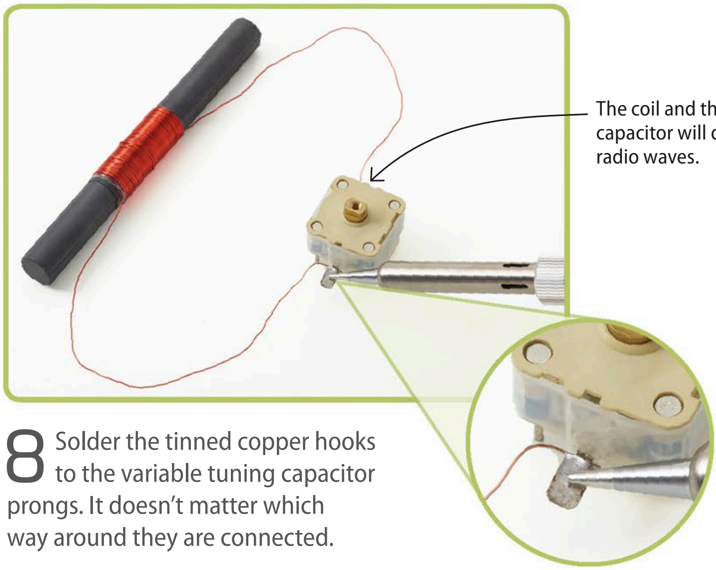
5 Use solder and a soldering iron to tin one end of each of the four wires. The tinned ends of the wires will connect both the tuning capacitor and the headphone socket to the circuit board.



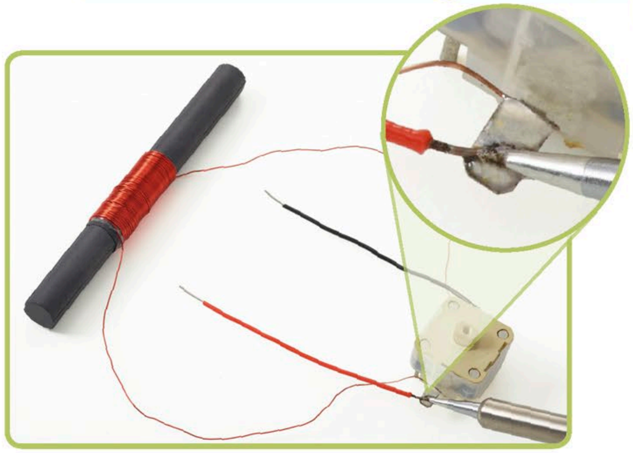
6 Trim the ends of the battery pack wires and strip about ⅜ in (1 cm) off the ends. Twist the stranded wires and tin these too, using the third-hand tool to hold the wires in place.



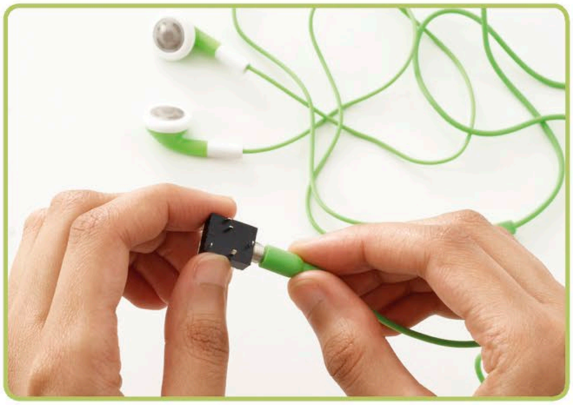
7 Use the needle-nose pliers to bend the tinned ends of the copper coil wire back on themselves, forming small hooks.



8 Solder the tinned copper hooks to the variable tuning capacitor prongs. It doesn't matter which way around they are connected.



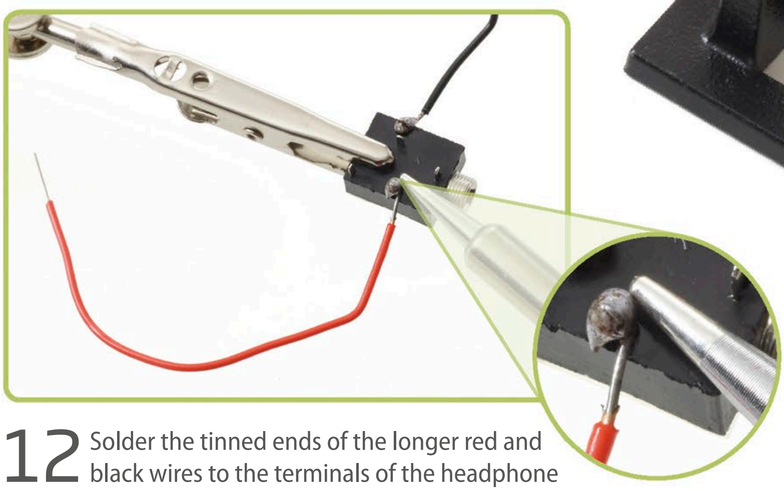
9 Use the needle-nose pliers to bend the tinned ends of the shorter red and black wires into hooks. Solder the hooks to the tuning capacitor prongs. Again, it doesn't matter which wire is connected to which side.



10 Prepare to test the terminals on your earphone socket by plugging in the earphones.

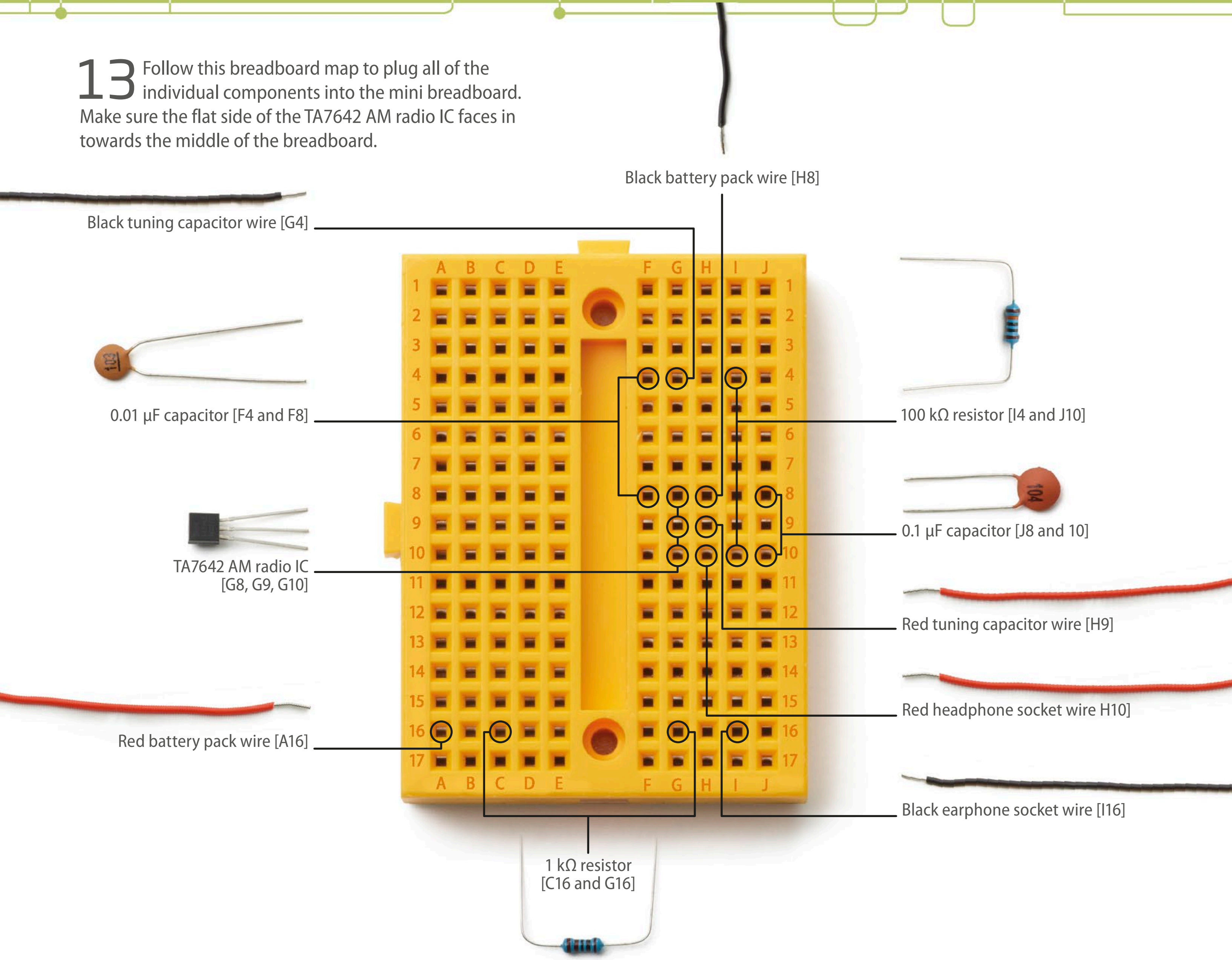
11 Use a multimeter to test the terminals on the earphone socket. Listen to the earphones to work out which terminals to solder the wires to. The correct terminals will be the ones where the static is loudest.

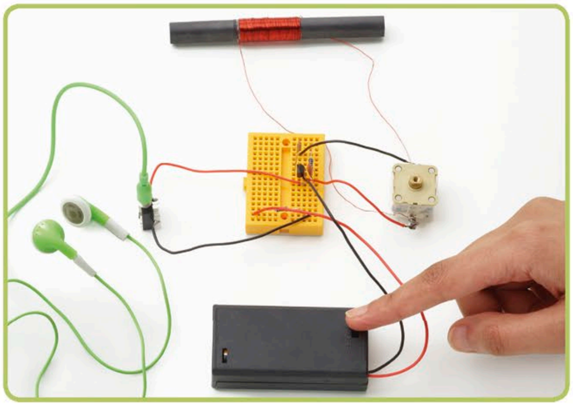
Using a multimeter see pp.28–29



12 Solder the tinned ends of the longer red and black wires to the terminals of the headphone socket. Make sure you connect the black wire to the negative and the red to the positive side.

13 Follow this breadboard map to plug all of the individual components into the mini breadboard. Make sure the flat side of the TA7642 AM radio IC faces in towards the middle of the breadboard.





14 Plug in the earphones and insert the batteries into the battery pack. If the circuit is working, you will hear static noise through the earphones.

15 If you can't hear any static, check all the connections. Once you hear the static, glue down all the components to the base. Tune the knob on the tuning capacitor to pick up AM radio stations.

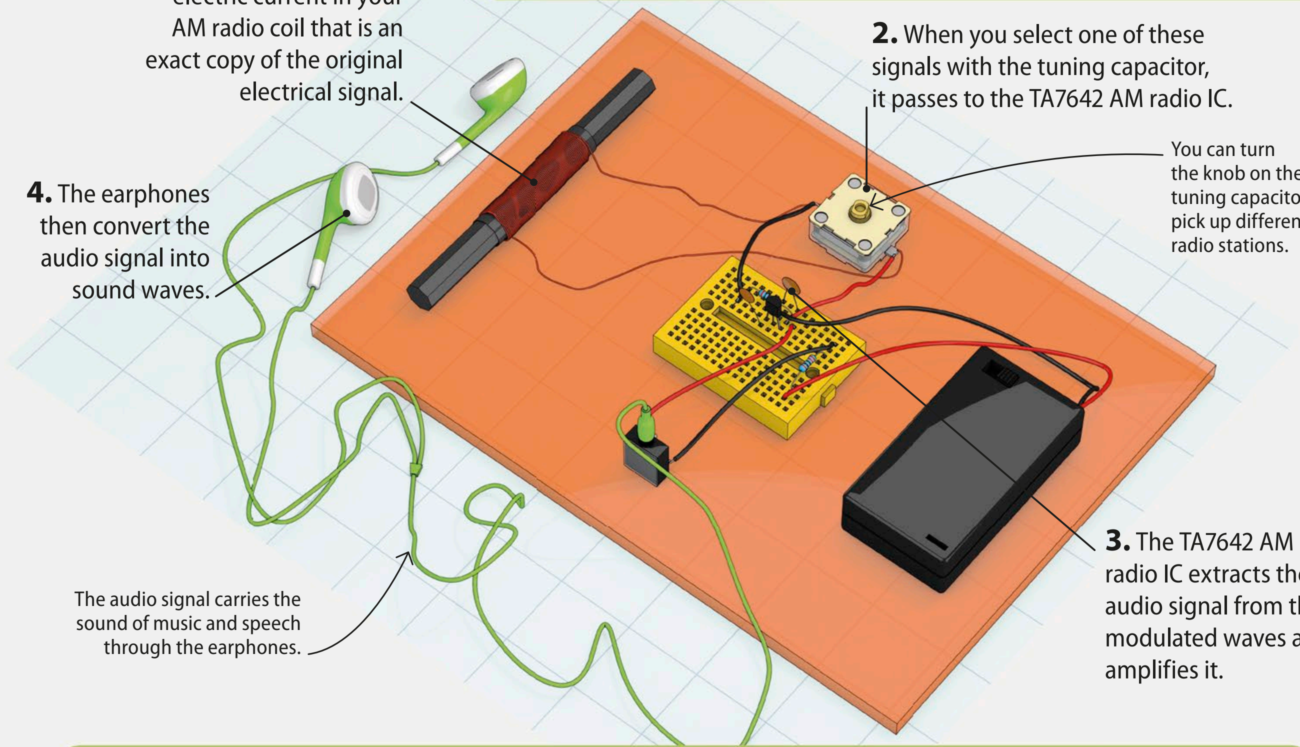
How it works

AM stands for "amplitude modulation." "Amplitude" means the height of a wave, and "modulation" means to change something. AM radio stations take a base carrier wave and change its amplitude to carry sounds, which they then broadcast at a specific address on the radio wave spectrum, called a station's frequency. These waves enter your AM radio through the coil.

Real-world inventions

FM and DAB

Starting in the 1920s, the first radio stations used AM technology, but a rival method of broadcasting, called frequency modulation (FM), overtook it by the end of the 20th century. These days, many radio stations use digital audio broadcasting (DAB), which relies on computers to create the signals they beam out.



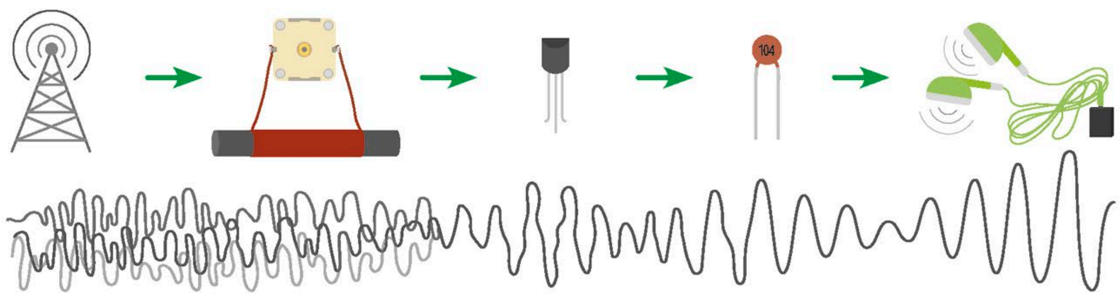
Different radio stations release sound as radio waves.

The coil picks up the radio waves, and you use the tuning capacitor to select a particular frequency.

The TA7642 AM radio IC amplifies the signal.

The fixed capacitor smooths out the signal to become a clear audio signal.

The earphones turn the audio signal into sound so you can hear the original sounds.



Buzzer game

Do you have a steady hand? Find out by making this game! Try maneuvering the copper loop from one end of the twisting path to the other without the loop and wire touching. If they do, a buzzer will sound and an LED will light up to let you know that you've lost the game. Challenge your friends and see who can get the farthest.

How to make a

Buzzer game

Before you start this project, you'll need to prepare the sides of the box. Ask an adult to help you cut out five squares from plastic or wood. Most buzzers will work at a range of voltages from about 3 volts to 20 volts—this circuit uses a 9-volt battery.

Time
60 mins

Be aware
Requires drill, hot glue gun, and soldering iron use.

Difficulty
Hard

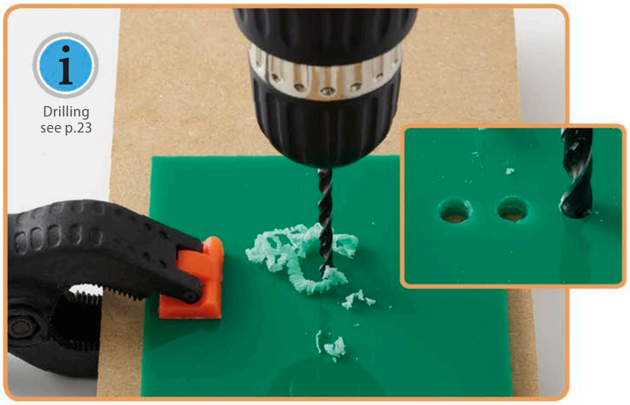
What you need

From the toolbox

- Drill
- Scrap wood and clamps
- $\frac{1}{8}$ in (3 mm) drill bit
- $\frac{5}{16}$ in (8 mm) drill bit
- Sandpaper
- Hot glue gun
- Wire strippers
- Soldering iron and solder
- Wire cutters
- Pliers
- Electrical tape

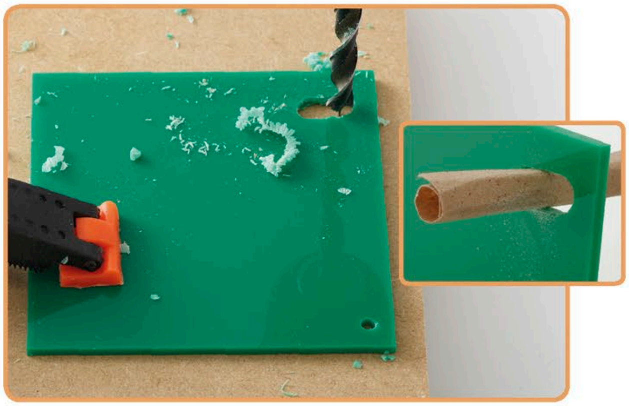
1x
SPST switch

1x
330 Ω resistor



Drilling
see p.23

1 Using the $\frac{1}{8}$ in (3 mm) drill bit, make a hole for the LED's legs in the center of one of the box sides. Drill two more holes big enough to fit the copper wire, each $\frac{3}{8}$ in (1 cm) from the LED hole.

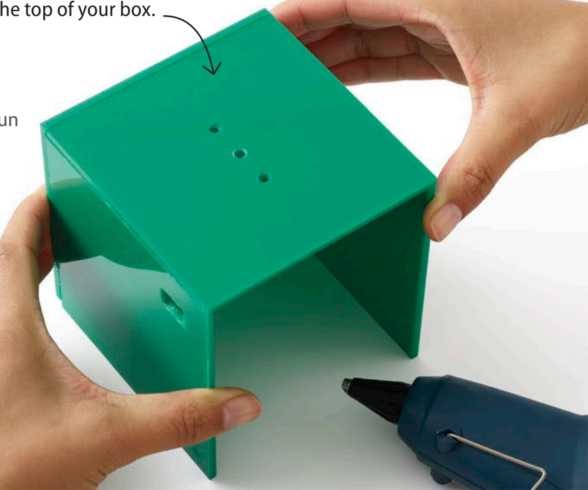


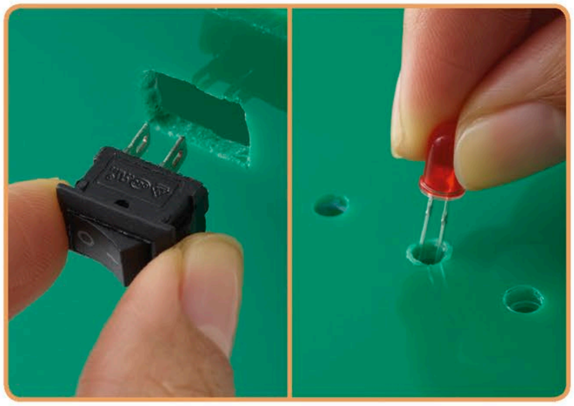
2 On another box side, use the $\frac{1}{8}$ in (3 mm) drill bit to make a hole in the corner. In a different corner, use the $\frac{5}{16}$ in (8 mm) drill bit to create a rectangular slot large enough for the switch to sit in. Use sandpaper to smooth the slot.

3 Use a hot glue gun to join four panels together along their sides as shown below.

Using a glue gun
see p.22

The side with the three holes will be the top of your box.



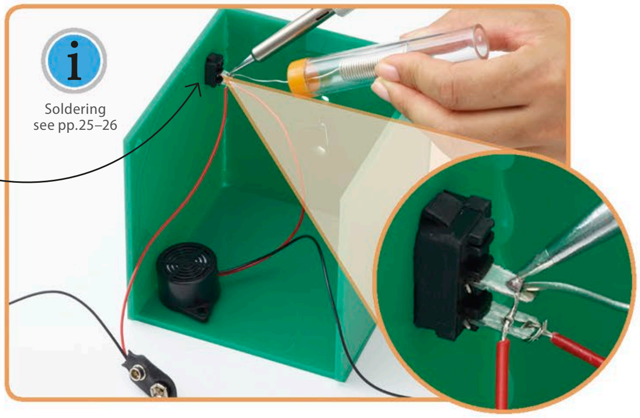


4 Slot the SPST switch and the LED into their holes. Once through, widen the legs of the LED against the inside of the box to secure it in place.

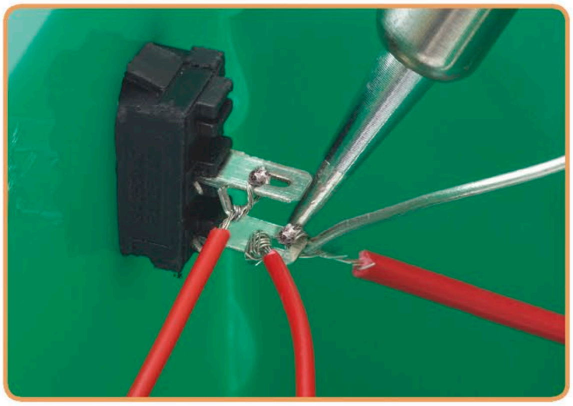
5 Cut and strip a piece of red stranded wire approximately 2⅜ in (6 cm) long. Next, strip the battery snap connector wires.

6 Tip the box on its side, so you can see into it. Glue the buzzer near the bottom of one side, near enough to connect it to the switch.

It doesn't matter which wire you solder to which terminal.

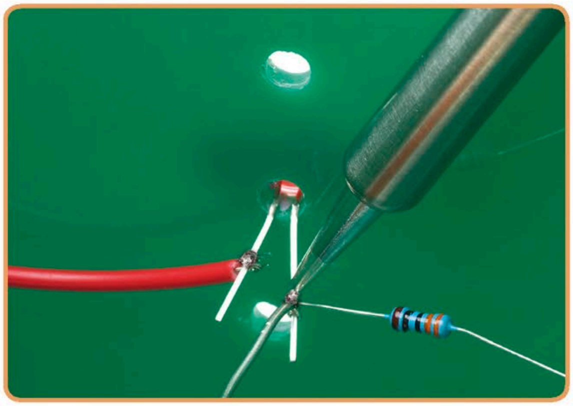


7 Strip the end of the buzzer's red wire. Twist the red battery snap connector wire around one switch terminal, and the red buzzer wire around the other terminal. Solder both in place.



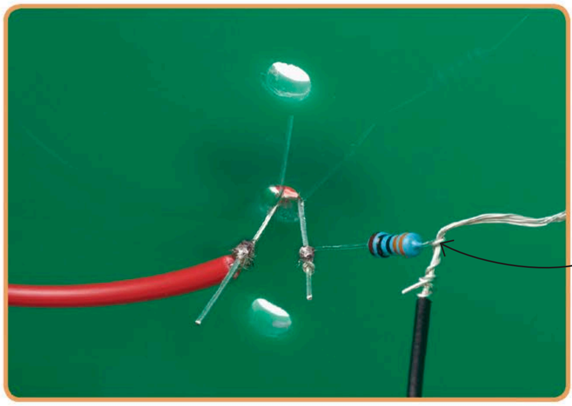
8 Solder one end of the red stranded wire from step 5 onto the same switch terminal as the red buzzer wire.

9 Solder the other end of the stranded wire to the shorter (negative) leg of the LED.



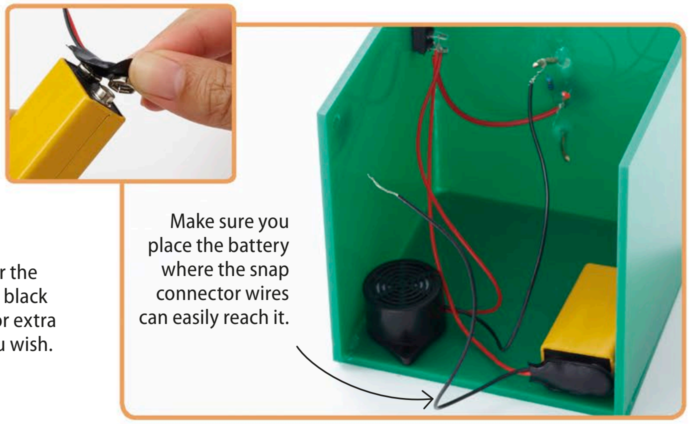
10 Solder one end of the resistor (it doesn't matter which end) onto the longer leg of the LED. Make sure the two legs of the LED are not touching.

11 Strip about 1⅜ in (3½ cm) from the black buzzer wire. This wire will wrap around a resistor and one end of the copper wire.



You can solder the resistor to the black buzzer wire for extra stability, if you wish.

12 Twist the other end of the resistor firmly around the black buzzer. Leave about ¾ in (2 cm) of stripped wire left over.

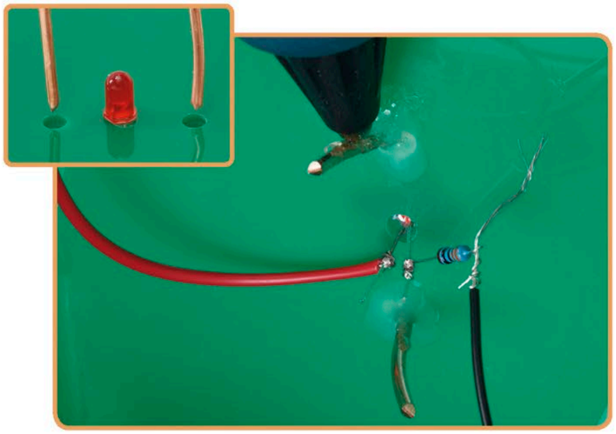


Make sure you place the battery where the snap connector wires can easily reach it.

13 Attach the battery to the snap connector. Glue the LED and switch securely into their slots and glue the battery anywhere inside the box.

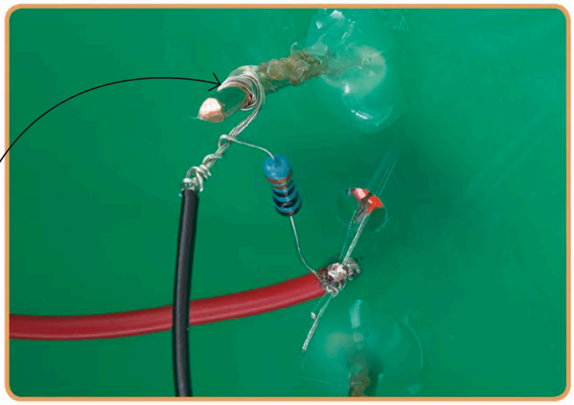
14 Cut about 3¼ ft (1 m) of the thick copper wire. Use the pliers to twist the wire into whatever shape you like. Make sure you keep the last 1 in (2½ cm) of each end of the wire straight.

The more twists, turns, and loops you add, the more challenging the game will be.



15 Insert the two ends of the copper wire into the holes on the top of the box, and glue them into place. Make sure there is about ⅜ in (1 cm) of each end sticking into the box.

Twist the wire tightly around the copper wire and solder if needed to secure it.



16 Twist the end of the buzzer's black wire firmly around one of the ends of copper wire inside the box.

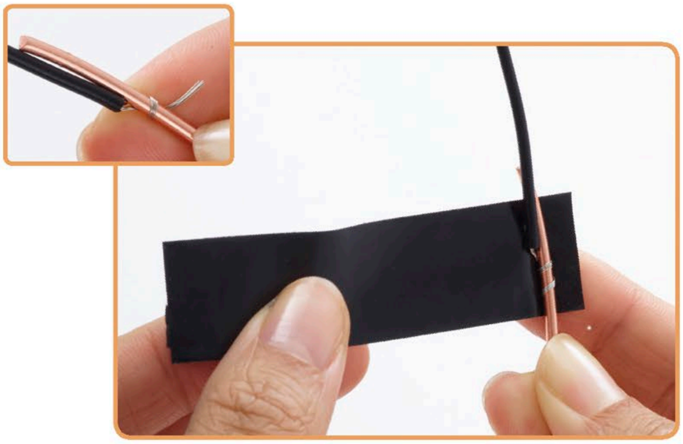
The wire should be long enough to reach from the bottom of the box over the copper wire shape.

17 Cut a piece of black stranded wire about 19¾ in (50 cm) long. Strip about ⅜ in (1 cm) off one end and about 1⅜ in (3½ cm) off the other.

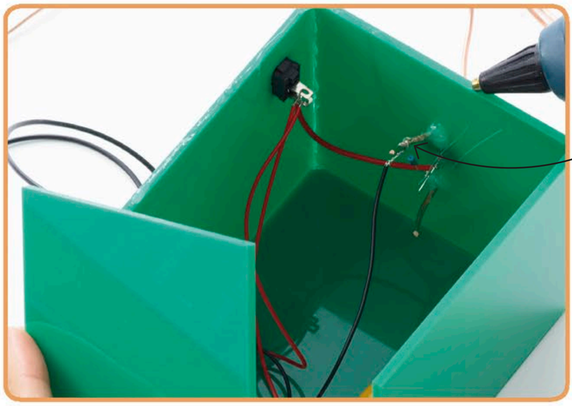
18 Thread the shorter stripped end of the black wire through the remaining hole in the side of the box, and twist it around the black battery wire.

19 Cut another piece of the copper wire, about 6 in (15 cm) long. Use the pliers to bend the end into a loop.

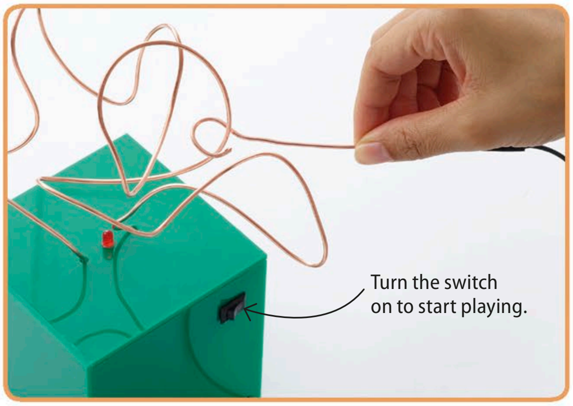
The tighter the loop, the more difficult the game will be.



20 Twist the stripped end of the long black wire around the straight end of the copper loop. Secure the wire connection by wrapping electrical tape tightly around it.



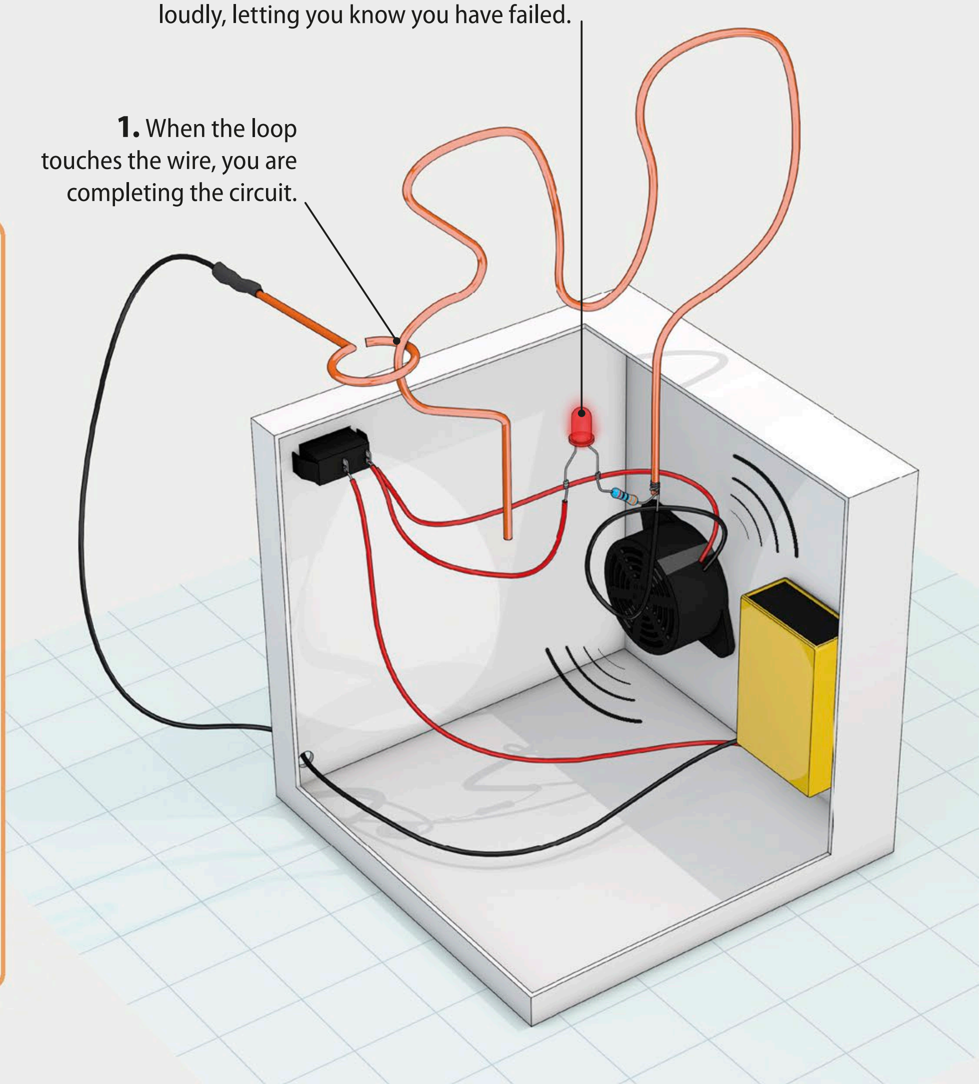
21 Use hot glue to attach the final panel to the side of the box. The bottom of the box should be left open.



22 Your buzzer game is finished. Slide the loop onto the copper wire to play. See if you can get the wire loop from one end of the copper wire to the other. If the loop touches the wire, the buzzer will sound and the LED will light up, and you have failed.

How it works

If you keep the copper loop away from the copper wire, the circuit is incomplete. No current flows, the buzzer will not make a sound, and the LED will not light up. This means you're winning!



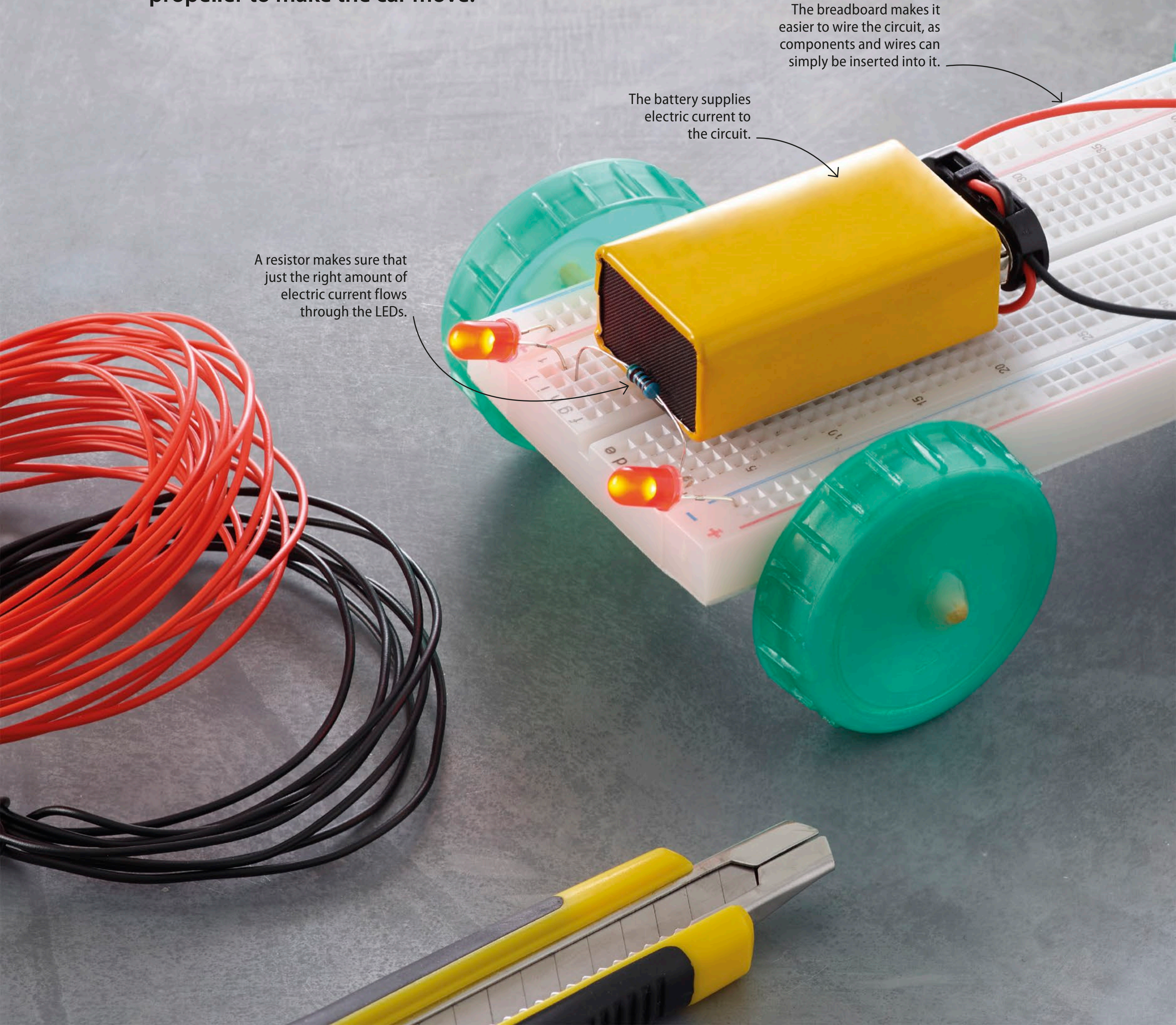
Real-world inventions

Bumper cars

Inside a bumper car is an electric motor that powers the wheels and electric lights for headlamps. The floor and the ceiling of the ride are connected to an electrical power supply. A metal pole touches the ceiling, and a metal contact beneath the car touches the floor. Electric current flows through the motor and the lights, as long as you have the foot pedal pressed down.

Breadboard car

This speedy car is powered by nothing more than a simple household battery. All you'll need to do is connect a few wires and basic components on a breadboard—which also acts as the car's frame. The car has bright LEDs as its headlamps and a motor that turns a propeller to make the car move.



The electric current flowing through the circuit and into the motor causes the fan to turn.

How to make a
Breadboard car

You'll need to follow these steps carefully to make sure you wire the LEDs and the motor correctly. The motor is powered by a 9-volt battery: if it becomes hot, switch off the car for a few minutes to let it cool down. For more information on how breadboards work, see pp.34–35.

Time
35 mins

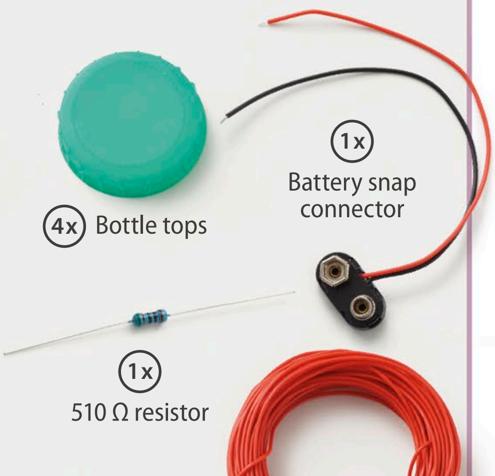
Be aware
Requires hot glue gun and soldering iron use.

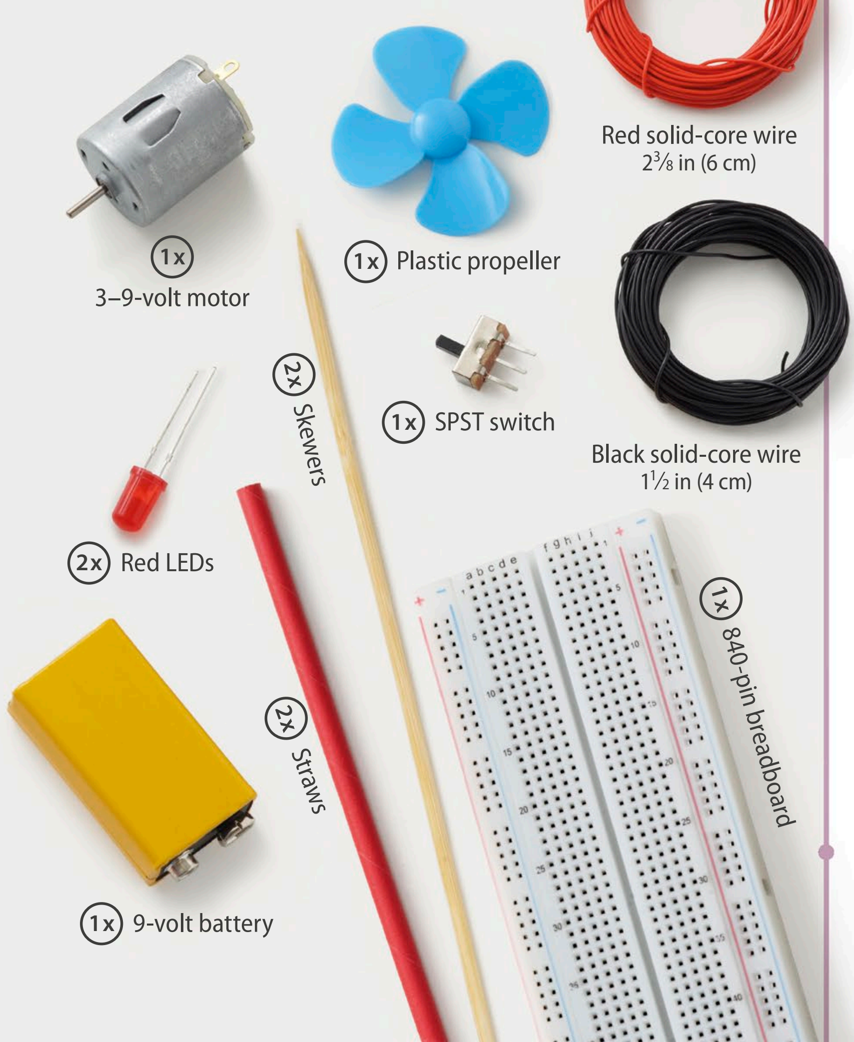
Difficulty
Medium

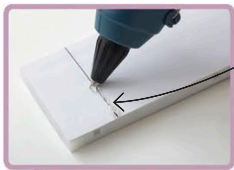
What you need

From the toolbox:

- Ruler
- Scissors
- Hot glue gun
- Wire cutters
- Double-sided foam tape
- Wire strippers
- Pliers
- Soldering iron and solder





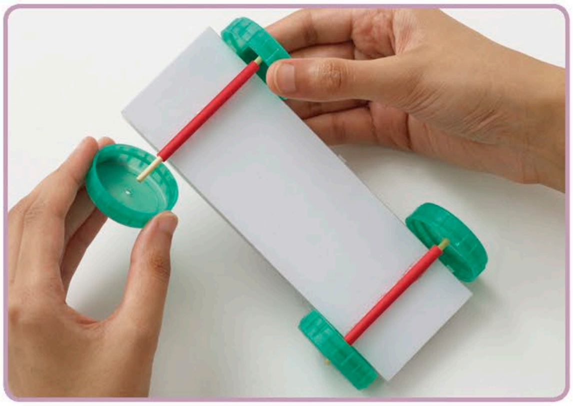


Apply glue along each line where a straw will go.

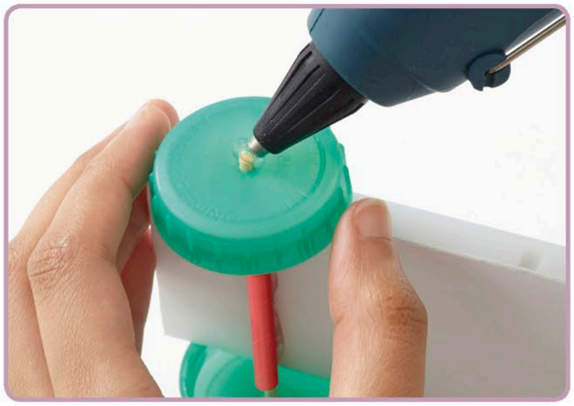
Using a glue gun see p.22

1 Mark two lines on the bottom of your breadboard that are at equal distances from the ends. Cut two pieces from the straws, each slightly wider than the breadboard. Use hot glue to stick the straws down.

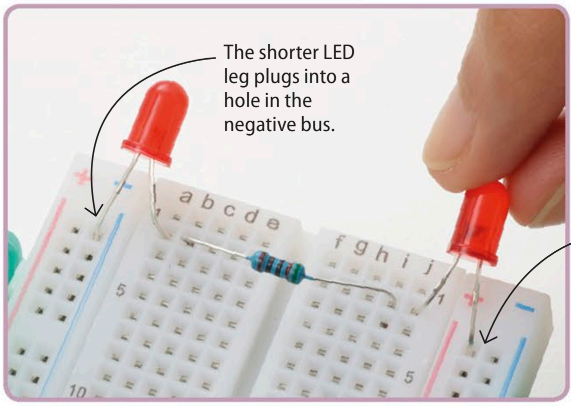
2 Use the sharp end of a skewer to poke a hole through the center of each of the bottle tops. Be careful not to hurt yourself with the sharp point.



3 Trim two skewers so that they are about 1⅛ in (3 cm) longer than the straws. Slide the skewers through the straws and push one bottle top onto each side of each skewer, as shown.

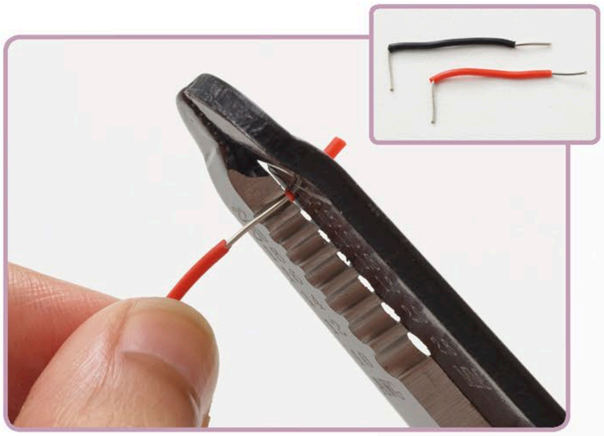


4 Put a small amount of glue on the ends of the skewers to hold the wheels in place. Make sure the wheels are at right angles to the skewer.



5 Plug in the LEDs and resistor as shown. It doesn't matter which way the resistor goes. Carefully bend the LED legs forward at right angles to look like headlights.

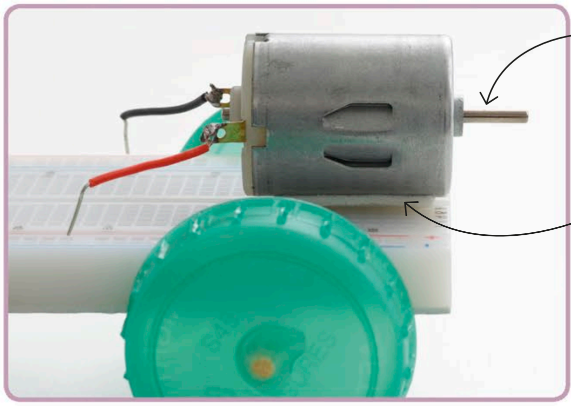
6 Cut a piece of double-sided foam tape the same size as your battery. Use it to secure the battery to the board, directly behind the resistor.



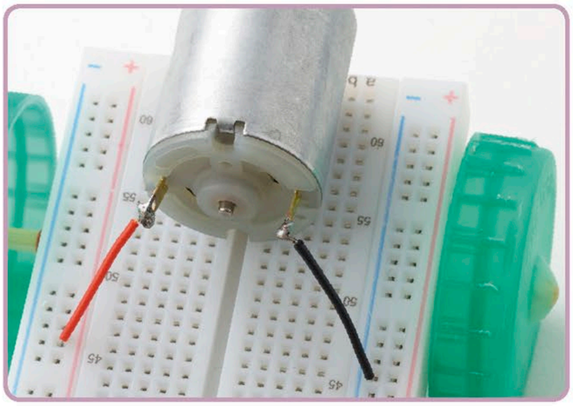
7 Cut a piece of black wire and a piece of red wire about 1½ in (4 cm) in length. Strip ⅜ in (1 cm) off the ends of each wire, and bend down the stripped end at one side of each wire.

8 Solder the unbent end of the wires to the terminals on your motor.

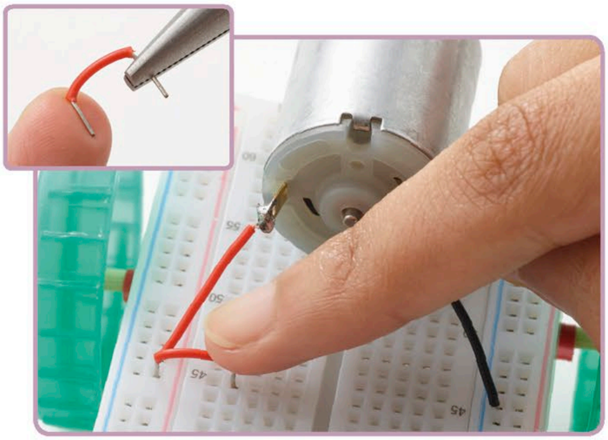
Soldering
see pp.25–26



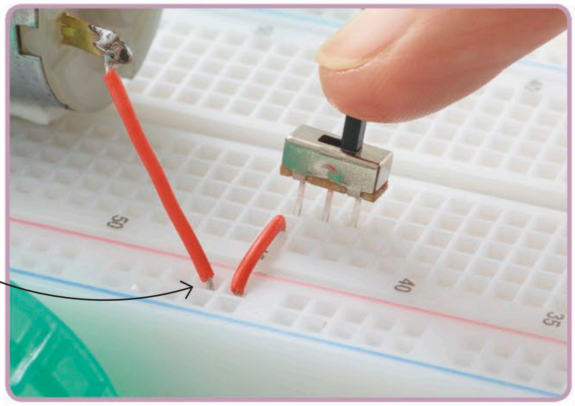
9 Cut a small piece of the double-sided foam tape and use it to secure the motor to the other end of the breadboard, with the motor's shaft pointing off the end of the breadboard.



10 Plug the red wire into a hole in the closest positive bus and the black wire from your motor into a hole in the closest negative bus.

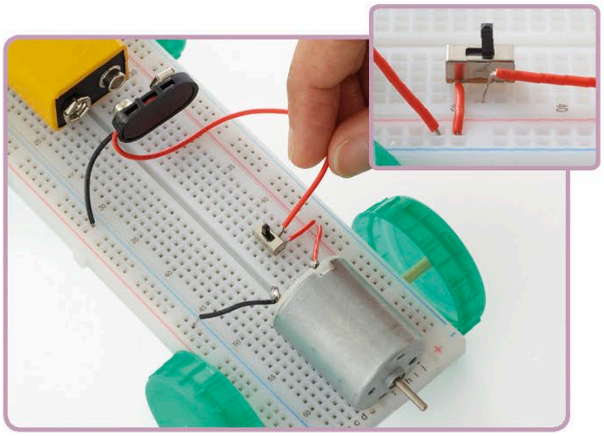


11 Cut a short piece of red wire about ¾ in (2 cm) long. Strip a little insulation off the ends, and bend the bared wire with your pliers. Push the ends into the breadboard as shown.

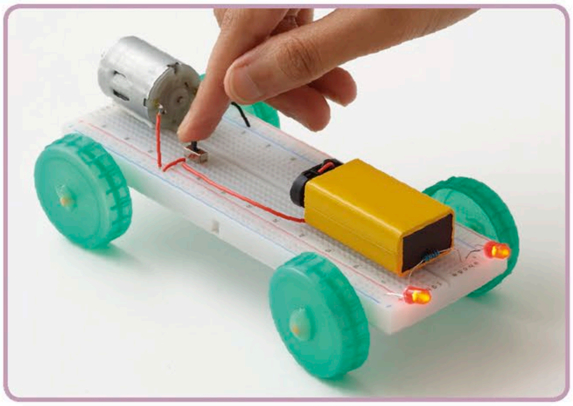


12 Plug the SPST switch into the breadboard as shown. The first prong of the switch should be in the same row as the small red wire.

13 Connect the battery snap connector to the battery. Use the wire cutters to trim the wires of the snap connector. Strip about ¼ in (½ cm) off the ends of the wires and twist the bared ends.

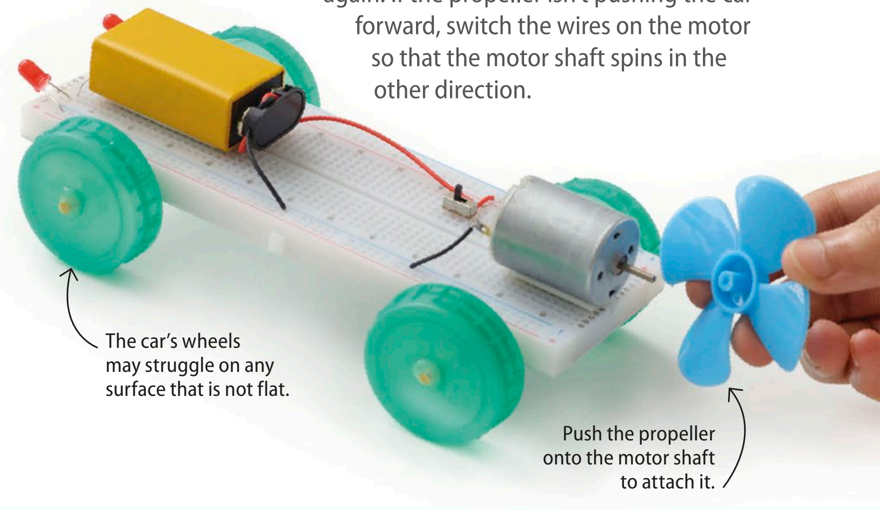


14 Push the end of the negative (black) wire into a hole in the negative bus and the end of the positive (red) wire into a hole next to the middle pin of the switch, as shown.



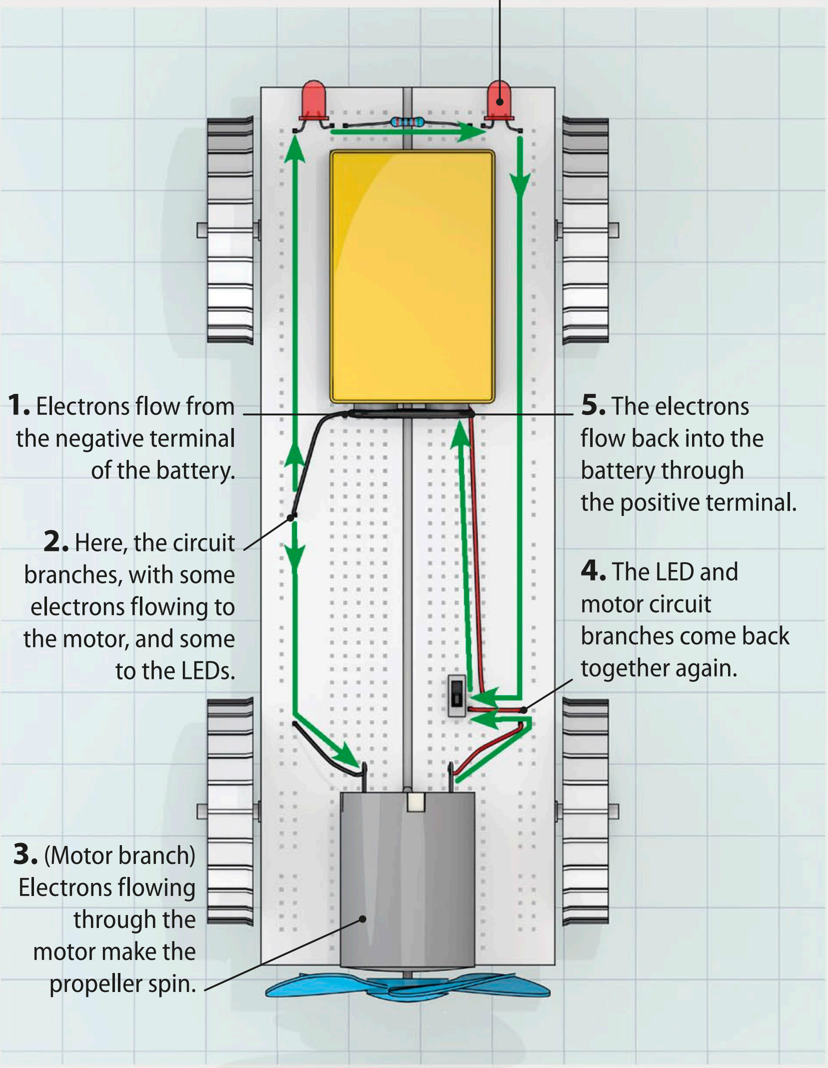
15 Flip the switch to check that your circuit is working. If it is, the two LEDs will light up, and the motor will whirr. If not, go back and check the previous steps carefully.

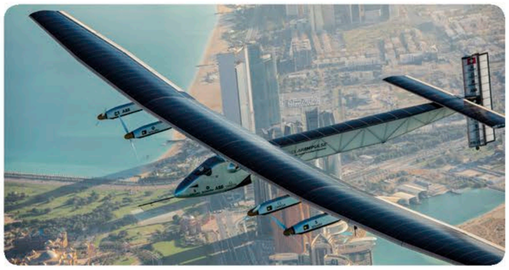
16 Attach the propeller. Now your car is ready to go when you flip the switch again. If the propeller isn't pushing the car forward, switch the wires on the motor so that the motor shaft spins in the other direction.



How it works

When you flip the switch, you are completing the circuit. Electric current flows through the motor (which makes the motor's shaft spin) and through the LEDs (which light up). As the motor spins, it turns the propeller. The propeller blades push on the air as they move—and that makes the car move forward. The car will pick up speed, so you'll have to be ready to catch it!



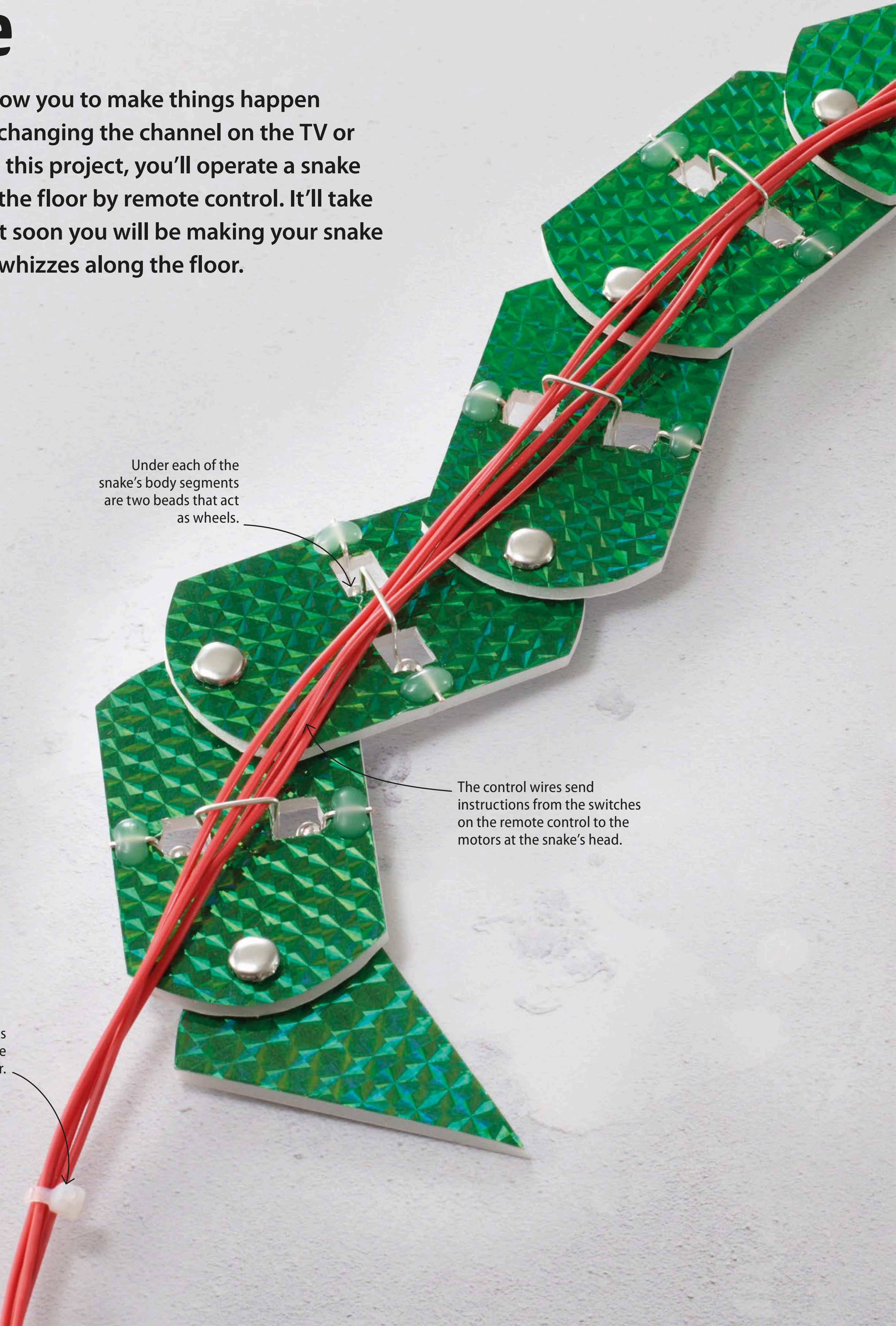


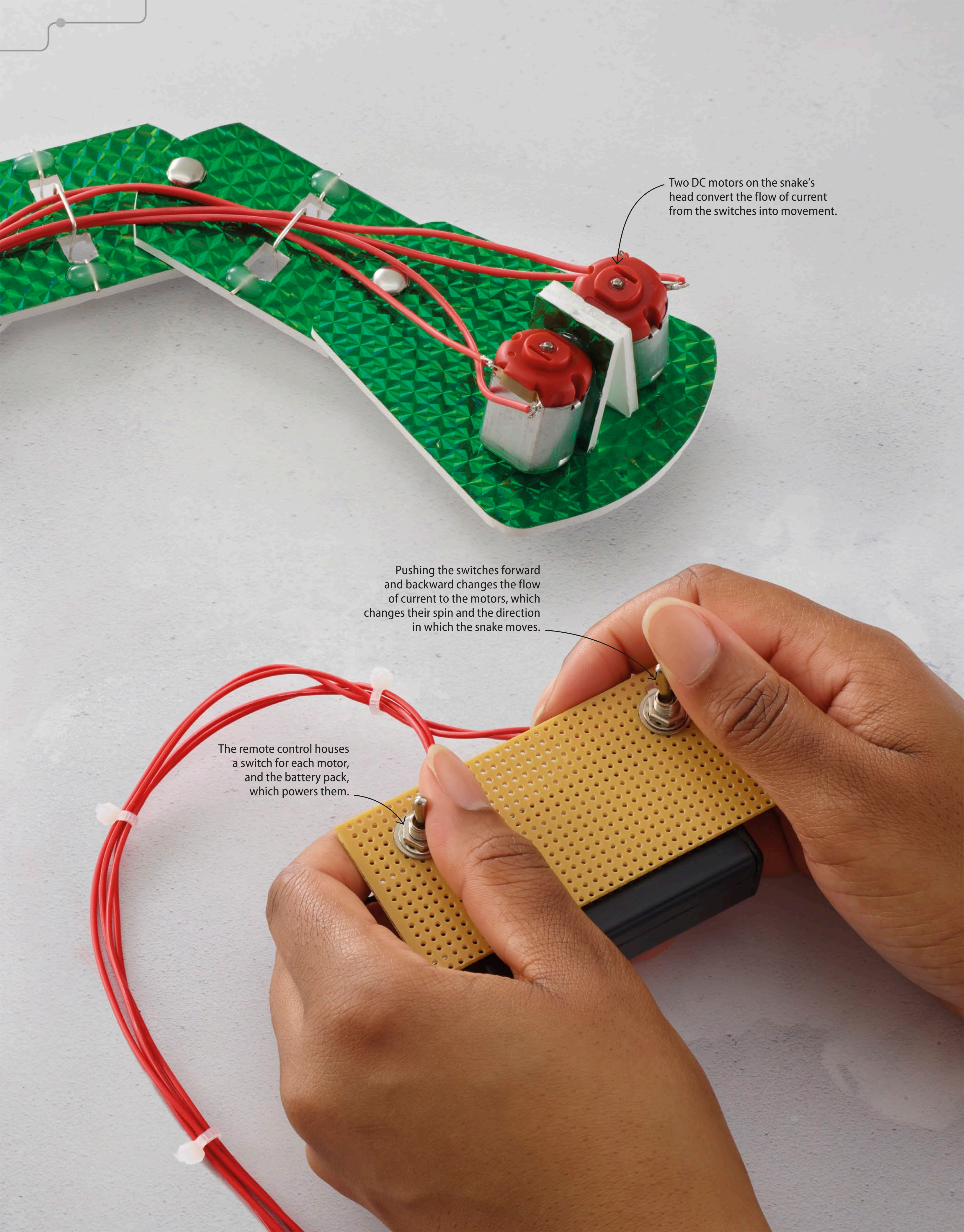
Real-world inventions
Solar Impulse 2

The Solar Impulse 2 is an airplane that uses electricity in a similar way to your breadboard car. It has four powerful electric motors that turn propellers. The electricity to turn the motors is provided by solar panels across the wings, which generate power whenever sunlight hits them. The energy from the solar panels is stored in batteries, so the plane can even fly at night.

Remote-controlled snake

Remote controls allow you to make things happen at a distance—like changing the channel on the TV or steering a drone. In this project, you'll operate a snake that slithers across the floor by remote control. It'll take a bit of practice, but soon you will be making your snake twist and turn as it whizzes along the floor.




Two DC motors on the snake's head convert the flow of current from the switches into movement.
Pushing the switches forward and backward changes the flow of current to the motors, which changes their spin and the direction in which the snake moves.
The remote control houses a switch for each motor, and the battery pack, which powers them.

How to make a

Remote-controlled snake

The key to this project are DPDT switches, which allow current to flow in either direction or turn it off completely. When you join the snake's body segments, make sure they can swivel—otherwise the snake will not slither! You can stick decorative paper onto one side of the foam board to give your snake some color.

Time
1 hour

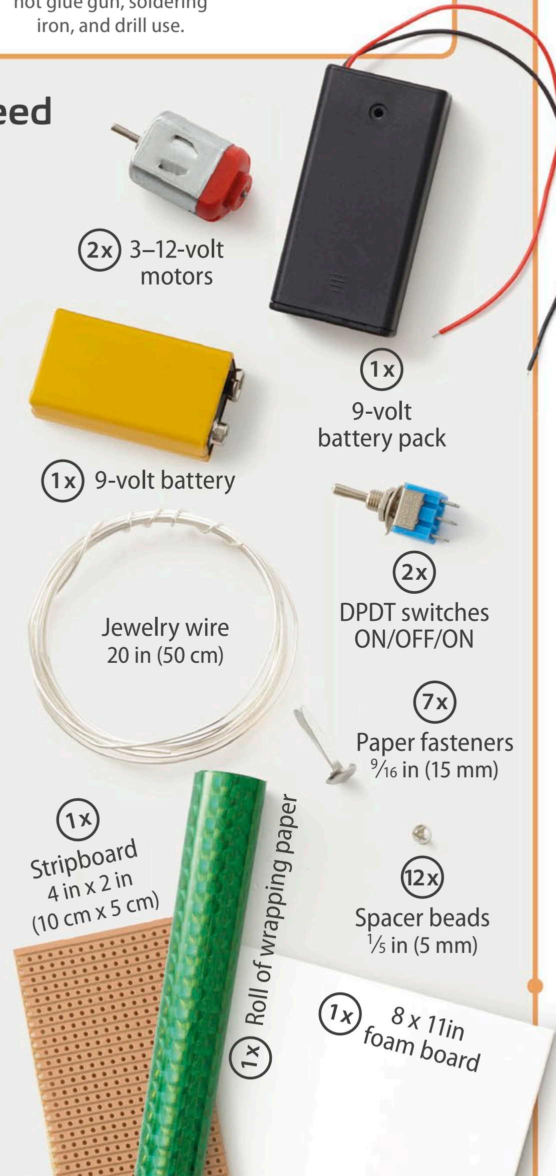
Be aware
Requires utility knife, hot glue gun, soldering iron, and drill use.

Difficulty
Hard

What you need

From the toolbox:

- Utility knife
- Cutting mat
- Bradawl
- Ruler
- Wire cutters
- Pliers
- Hot glue gun
- Wire strippers
- Soldering iron and solder
- Scrap wood and clamps
- Drill
- ¼ in (6 mm) drill bit
- Double-sided foam tape



2x 3–12-volt motors

1x 9-volt battery pack

1x 9-volt battery

2x DPDT switches ON/OFF/ON

Jewelry wire 20 in (50 cm)

7x Paper fasteners $^9/_{16}$ in (15 mm)

1x Stripboard 4 in x 2 in (10 cm x 5 cm)

1x Roll of wrapping paper

12x Spacer beads ⅕ in (5 mm)

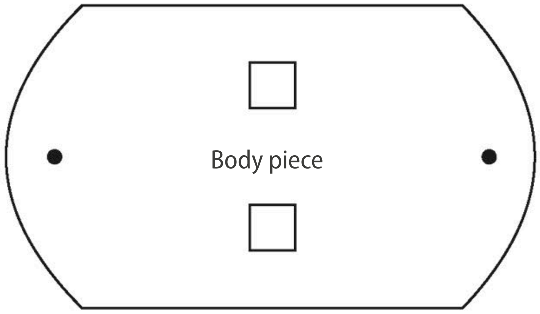
1x 8 x 11in foam board

Black stranded wire 3 in (8 cm)

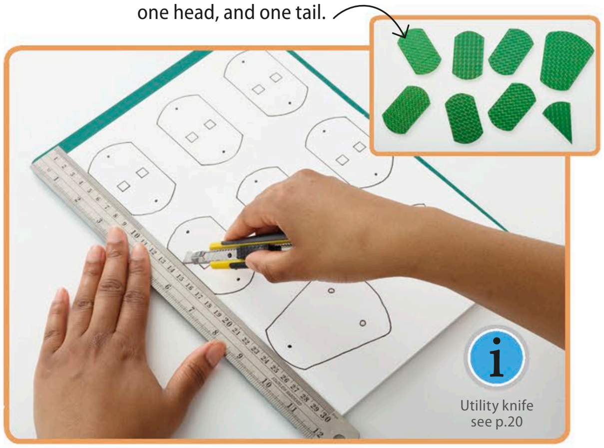
Red stranded wire 20 ft (6 m 16 cm)

Templates

Trace the three shapes here, and use that as a template to cut out the shapes below.

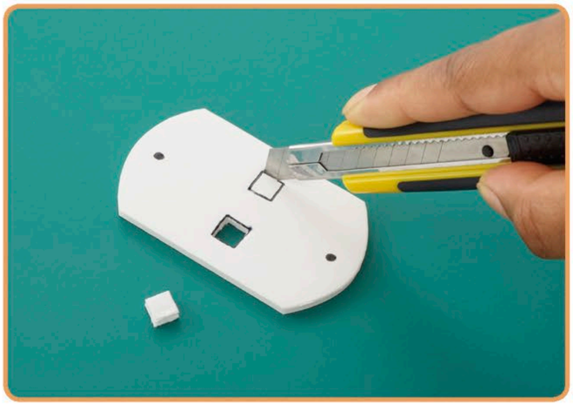


You will need six body pieces, one head, and one tail.

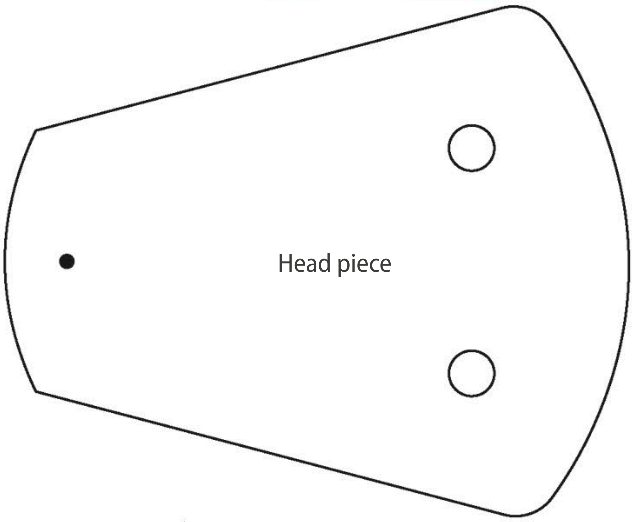


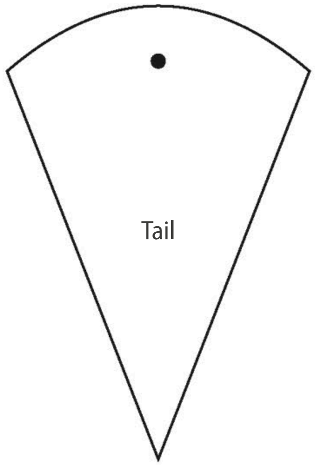
Utility knife see p.20

1 Stick your wrapping paper onto the foam board. Flip it over, and use the tracing paper to transfer the shapes above onto the foam board. Then use the utility knife to cut out the pieces.

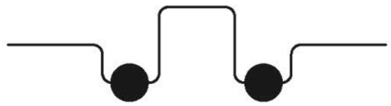


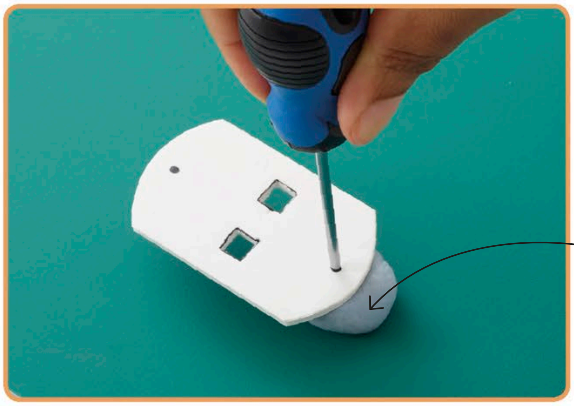
2 Using the utility knife, carefully cut out the squares in the body segments, and the two circles in the head piece.





When you get to steps 4–6, refer to the shape below to bend your jewelry wire accurately to make the axles for the snake's wheels.

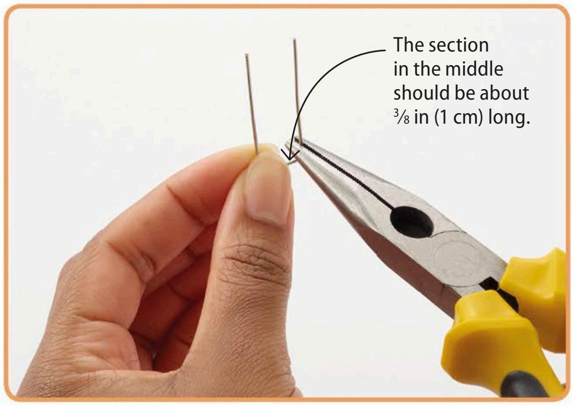




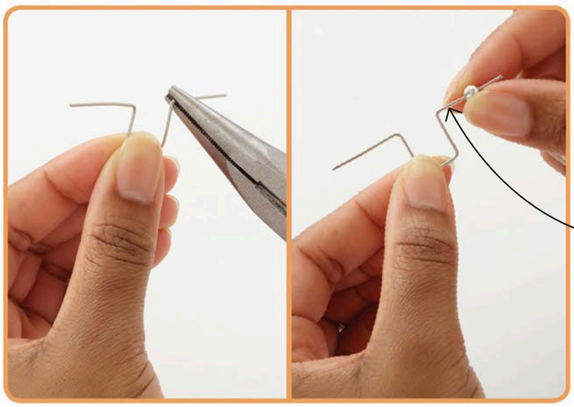
Using a bradawl see p.24

Using adhesive putty underneath the foam board will result in a cleaner hole, and will protect the surface.

3 Use the bradawl to poke holes through all the remaining markings on the six body segments and the head and tail.



4 Next, you will make the wheel axles for the snake. Cut an 3 1/8 in (8 cm) piece of jewelry wire. Following the template above, use pliers to make two right-angle bends, so that the piece has a "U" shape.

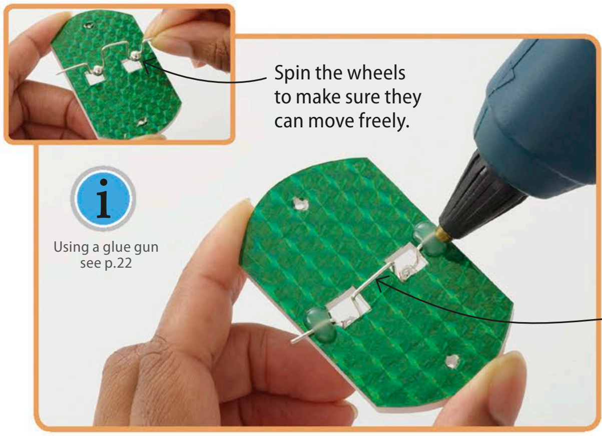


Make sure the jewelry wire on each side of the "U" bend is level with the other.

5 Make two more right-angled bends in the wire, each about 3/8 in (1 cm) away from either side of the existing bends. Now thread a bead onto the wire.

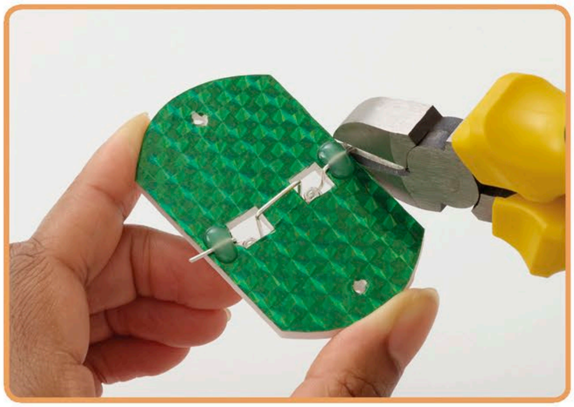
The beads will be the wheels for the body segments.

6 Put two more right-angled bends on the end of the wire so the bead cannot slip off. Repeat on the other side. Then, repeat steps 4–6 five more times, so you end up with six pieces of bent jewelry wire.



The middle part of the axle should stand above the top of the foam board.

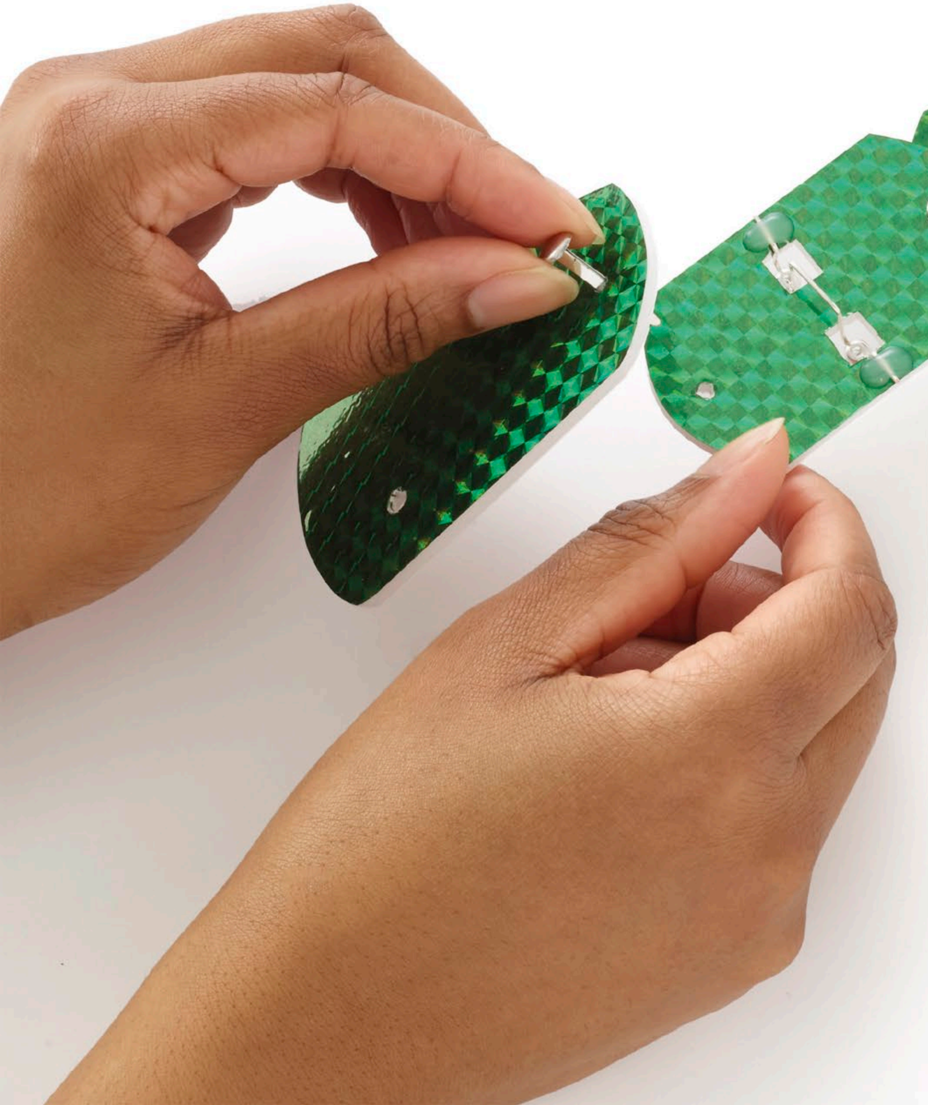
7 Push one axle through the two square holes in each body segment, so that the wheels end up underneath the segment. Use hot glue to secure the ends of the wire to the body segments.



8 Trim the ends of the jewelry wires so they are flush with the sides of the body pieces.

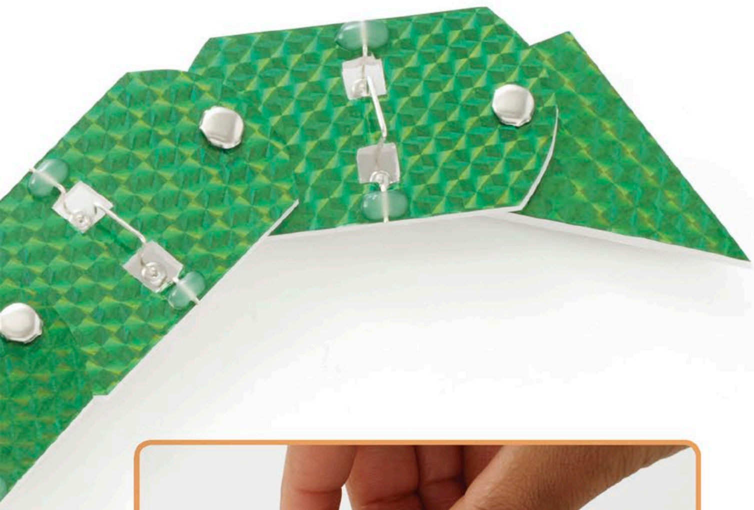
9 Use paper fasteners to connect the segments together through the holes at the end of each segment. Push the fasteners through from the top, and bend the legs outward to secure them.

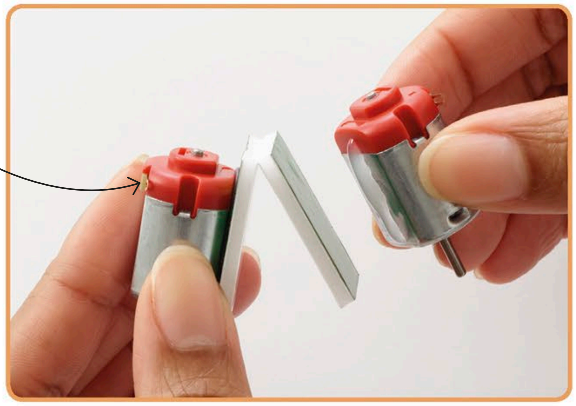
Put the fasteners on a little loose, to allow the segments to move.



Don't cut all the way through the foam board.

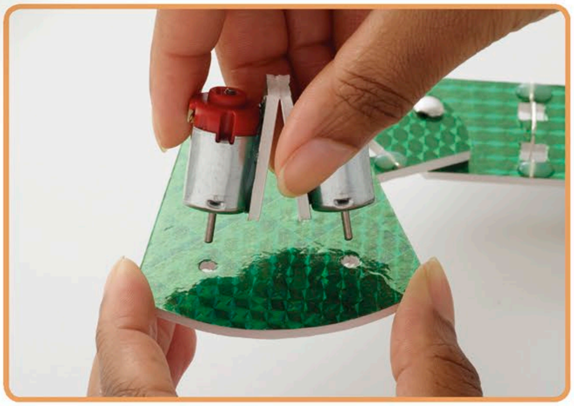
10 Cut out a piece of foam board about ¾ in (2 cm) by 2⅜ in (6 cm). Lightly score it across the center, and fold it to form a "V" shape.



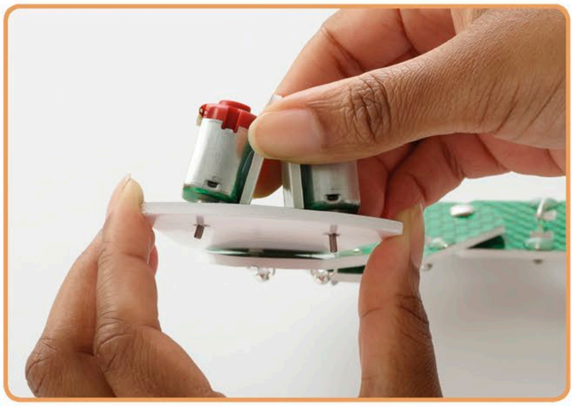


Make sure the motors' terminals face outward.

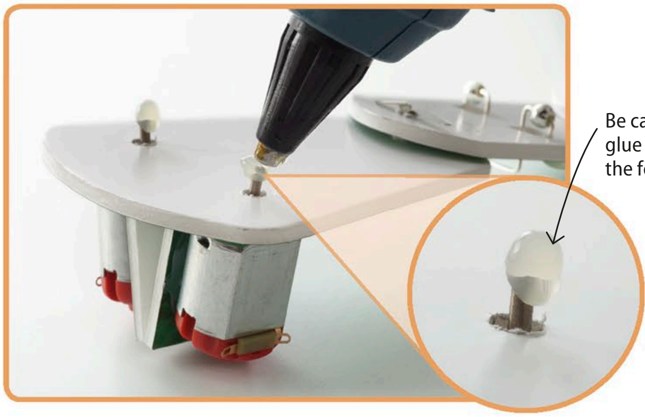
11 Use hot glue to attach the motors to either side of the "V" platform. Their shafts should face away from the scored edge, and the motors' bodies should align with the bottom edge of the platform.



12 Stand the motors on the snake's head, with the motors' shafts poking through the holes.



13 Glue the bottom of the platform to the top of the snake's head, making sure that the motor shafts are not touching the sides of the holes.



Be careful not to glue the shafts to the foam board.

14 Once the glue on the platform is dry, turn the snake over and put blobs of hot glue onto the ends of the motors' shafts.

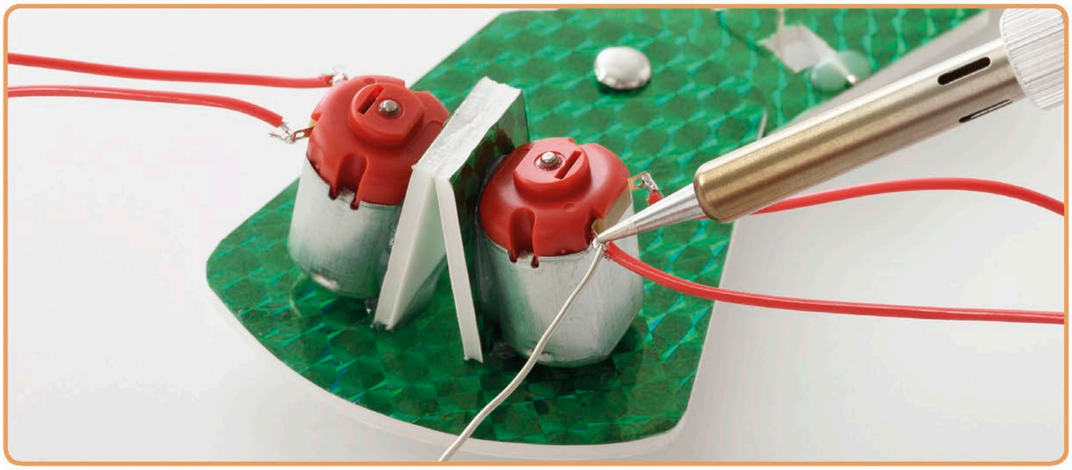
Preparing wires see p.24

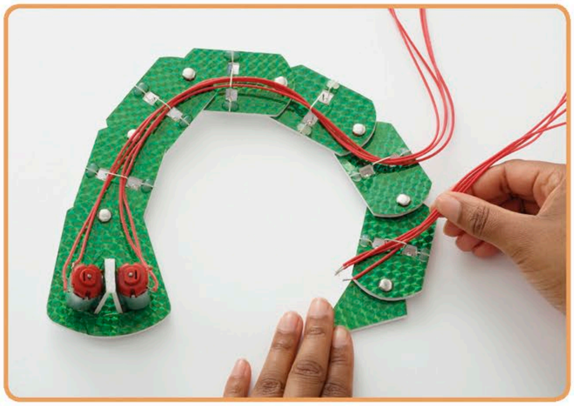
The longer these wires are, the farther away you can control the snake from.

15 Cut four pieces of red stranded wire, each 5 ft (1½ m) long. Strip the ends of all four wires.

16 Solder one end of each wire to each of the four motor terminals.

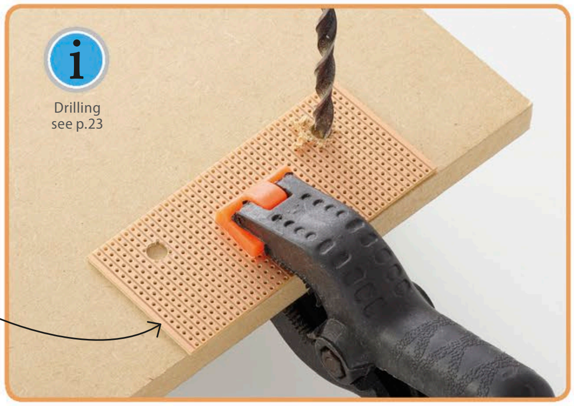
Soldering
see pp.25–26



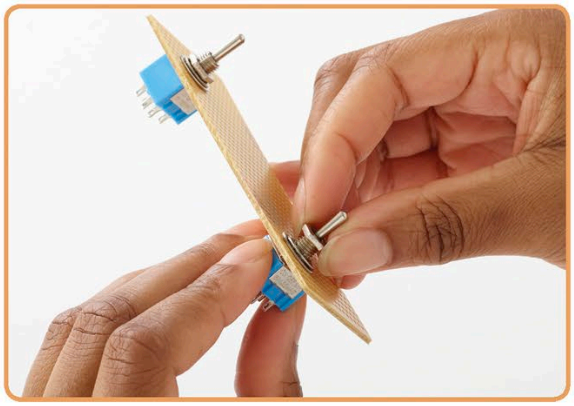


17 Thread all four long red wires through the middle of the axles where they project above the body segments.

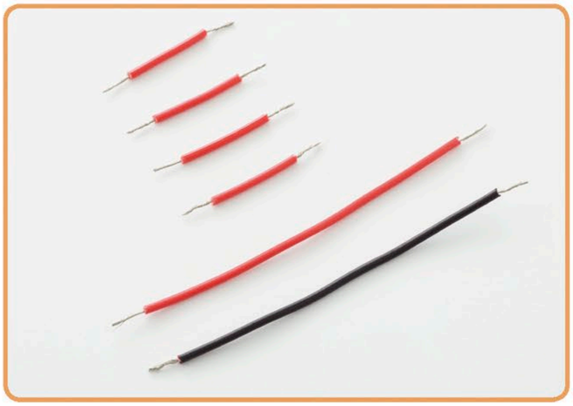
Make sure there is at least 1⅛ in (3 cm) of clear stripboard below the holes for the battery pack to fit onto.



18 Drill two ¼ in (6 mm) holes in the stripboard, each about ¾ in (2 cm) from the end and ⅜ in (1 cm) from the side. These holes will allow you to secure the DPDT switches.

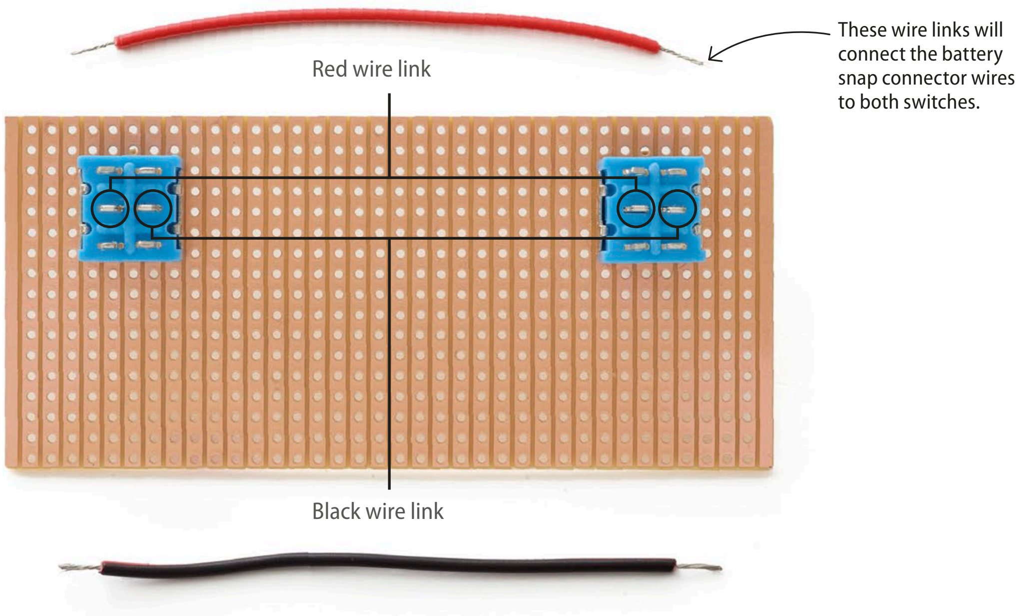


19 Place the DPDT switches into the holes in the stripboard, and screw on the washers and nuts from the other side.

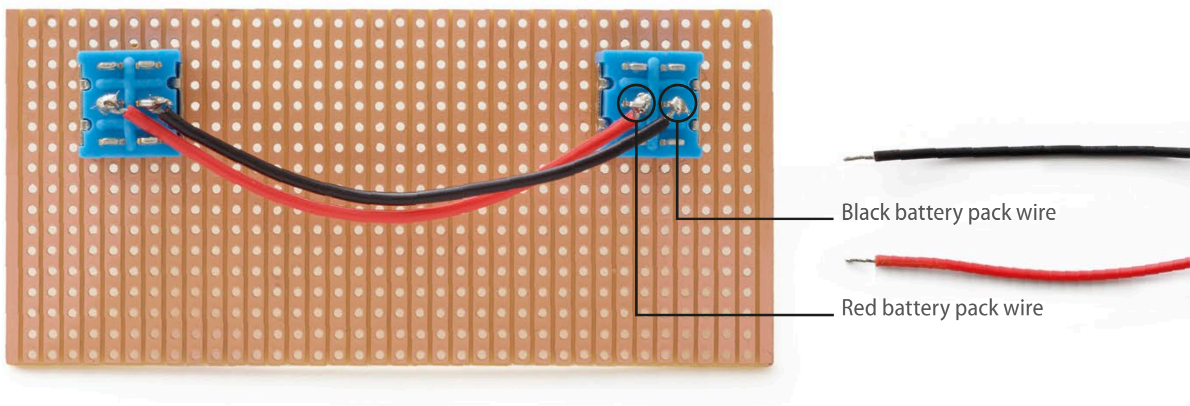


20 Next, cut four pieces of red stranded wire, each ¾ in (2 cm) long, and one black and one red wire each 3⅛ in (8 cm) long. Strip both ends of each wire.

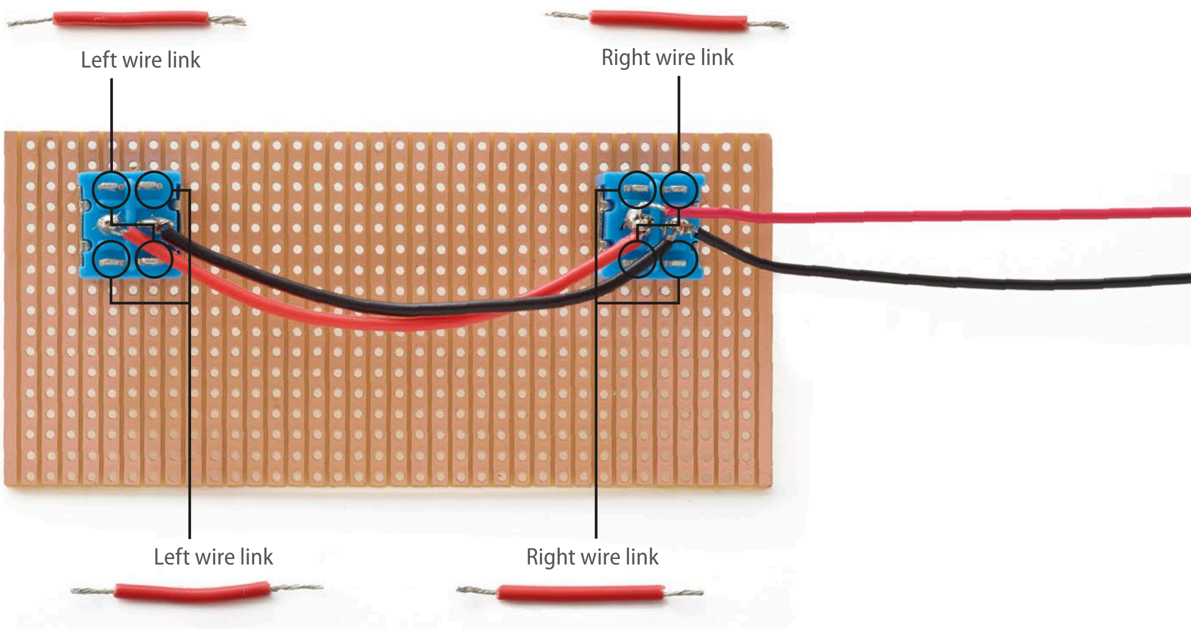
21 Take the long red and black wires, and, following the key to the right, solder them to the middle connections on the DPDT switches. Use adhesive putty to hold the board in place on your work surface while you solder.



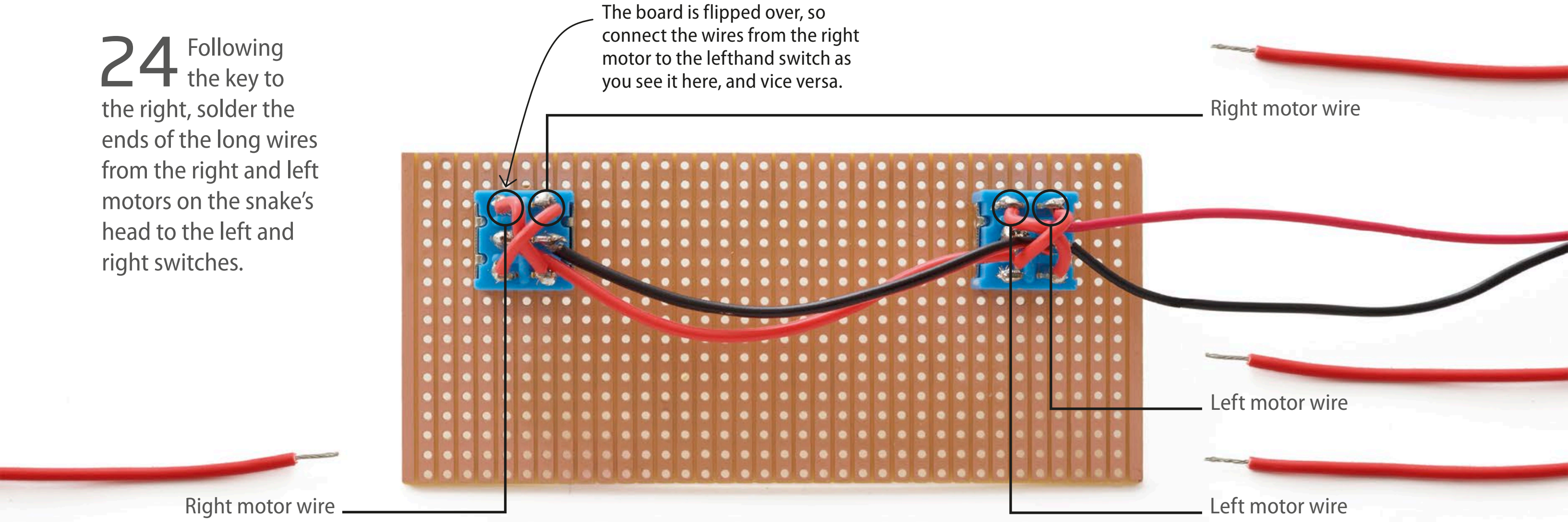
22 Strip the ends of the wires from the battery pack, and, following the key to the right, solder them to the righthand switch. You may need to trim the wires to size if they are too long.

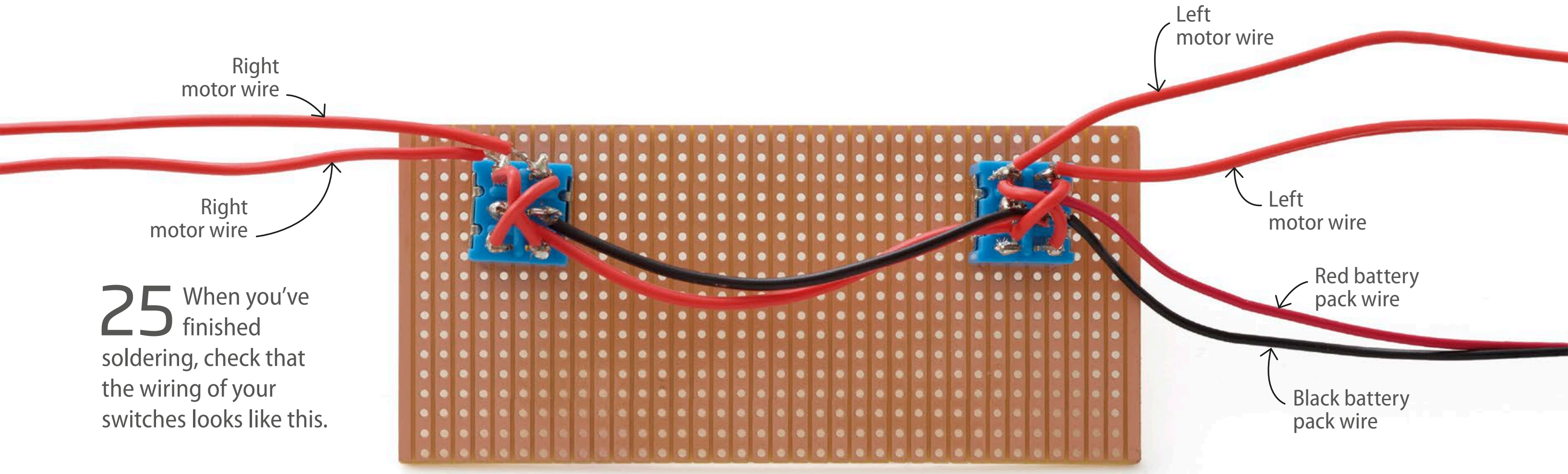


23 Next, following the key to the right, solder the four short red wire links to the switch terminals.

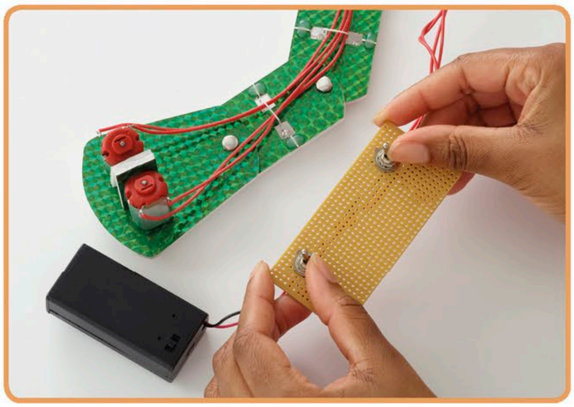


24 Following the key to the right, solder the ends of the long wires from the right and left motors on the snake's head to the left and right switches.



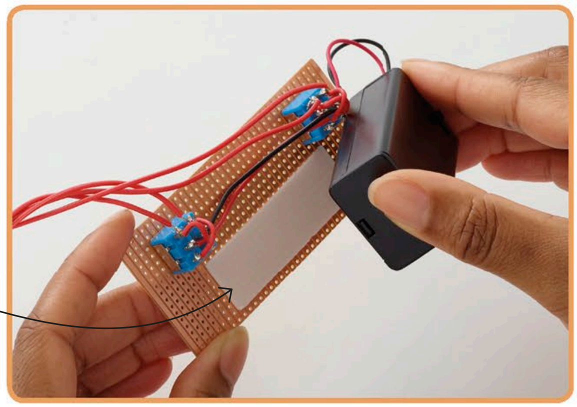


25 When you've finished soldering, check that the wiring of your switches looks like this.



26 Place the 9v battery into the battery pack and push and pull the switches. If the motors don't spin, go back and check all of your connections.

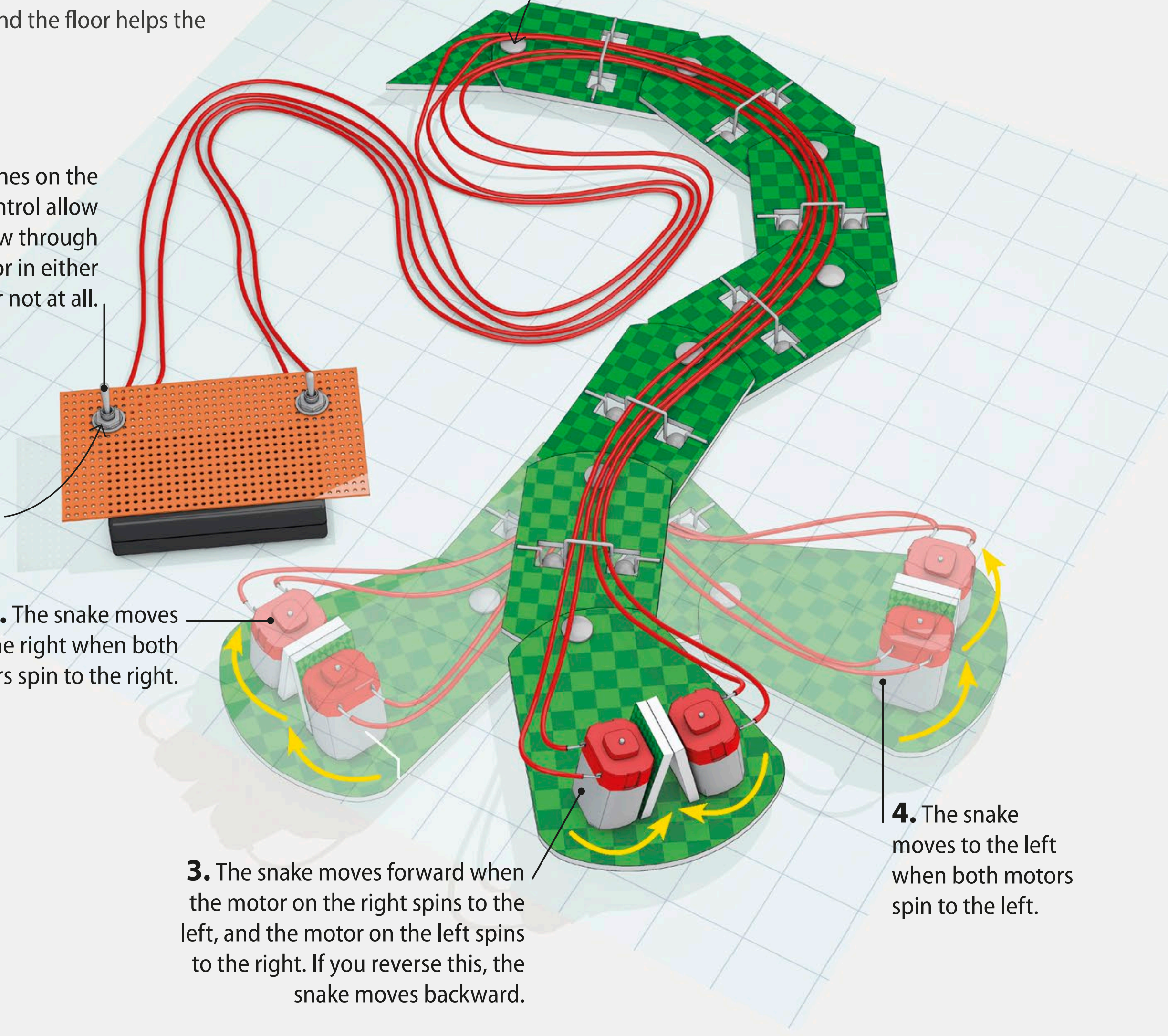
Place the battery pack away from the soldered connections.



27 Attach the battery pack to the underside of the stripboard using double-sided foam tape. Now flip both switches both ways, and watch the snake slither across the floor!

How it works

The motors' shafts can turn in either direction, depending on the direction of the current flowing through them. The blobs of glue on the motor shafts grip the floor, and when they spin, the friction between them and the floor helps the snake to move.



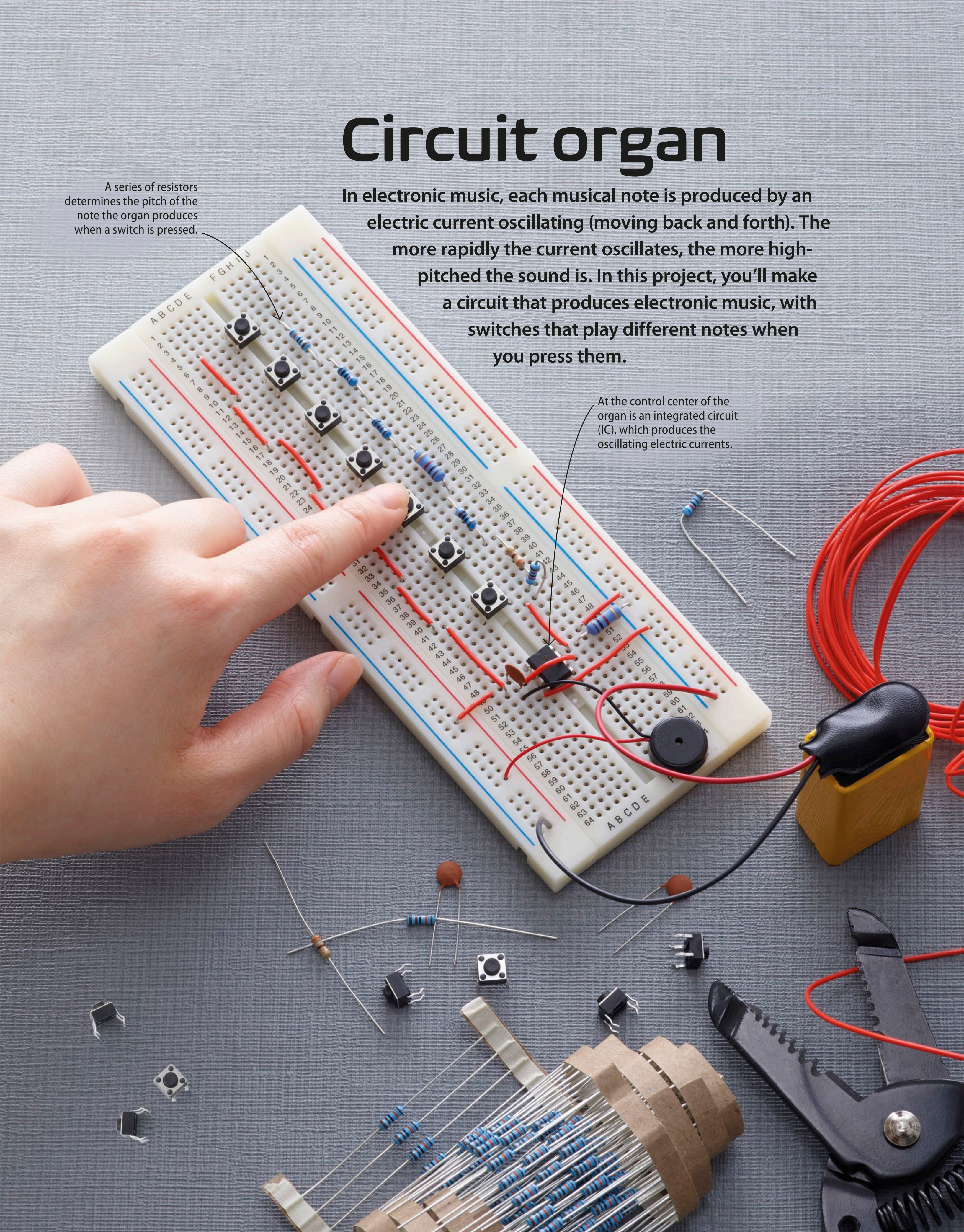
Real-world inventions

Wireless remote control

Most remotely controlled devices, like this drone, are not connected to their control by long wires. Instead, the control transmits coded radio signals that are received by the device. Different signals activate different motors or lights on the device. The batteries that power the device must be inside the device itself, rather than in the controller.

Circuit organ

In electronic music, each musical note is produced by an electric current oscillating (moving back and forth). The more rapidly the current oscillates, the more high-pitched the sound is. In this project, you'll make a circuit that produces electronic music, with switches that play different notes when you press them.



How to make a

Circuit organ

All the components of the organ are inserted into a breadboard. If the wires of your battery pack and sounder are stranded, you will need to tin them with the soldering iron before you begin.

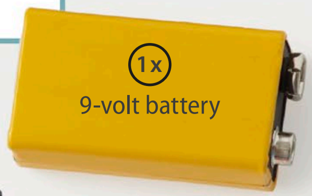
Time
25 mins

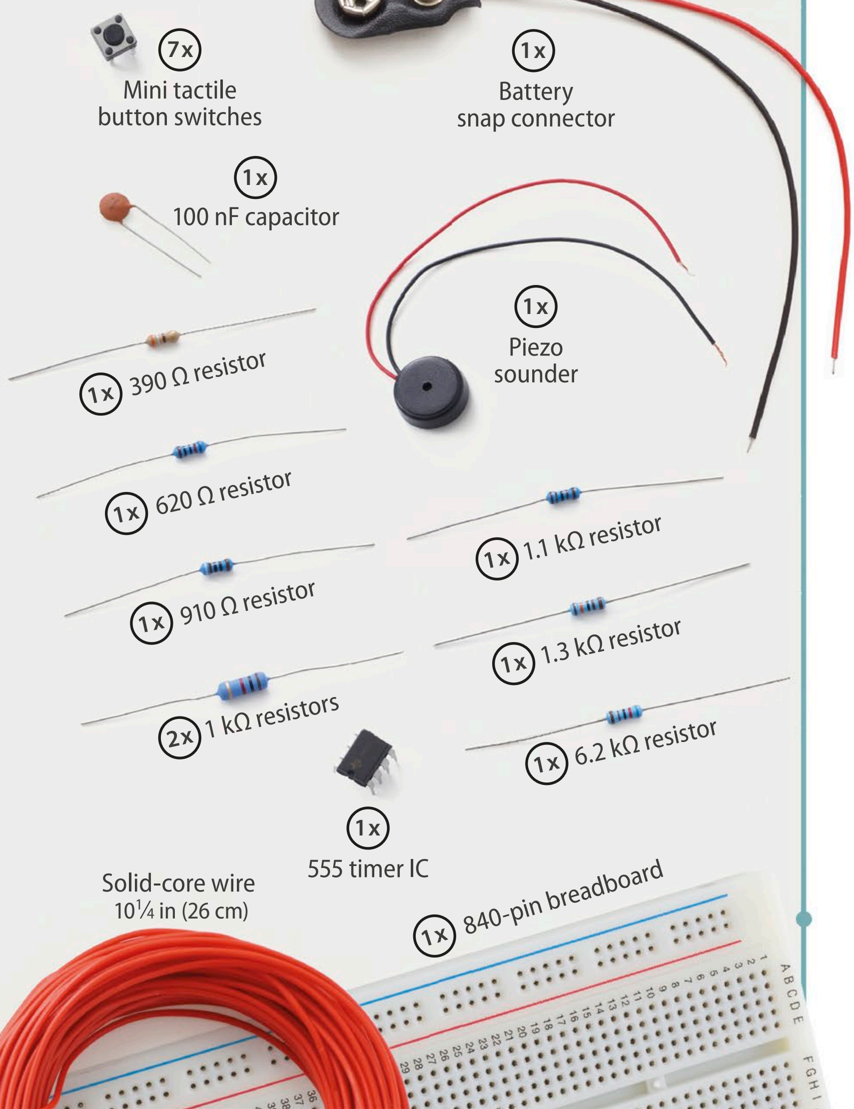
Difficulty
Easy

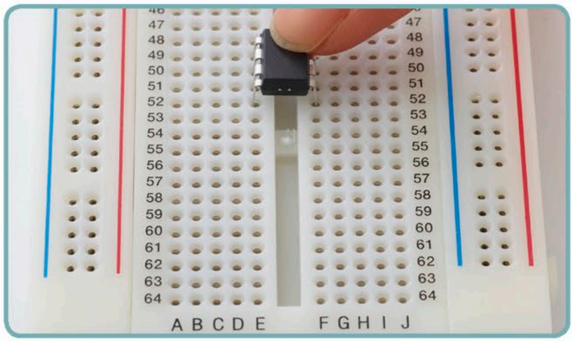
What you need

From the toolbox

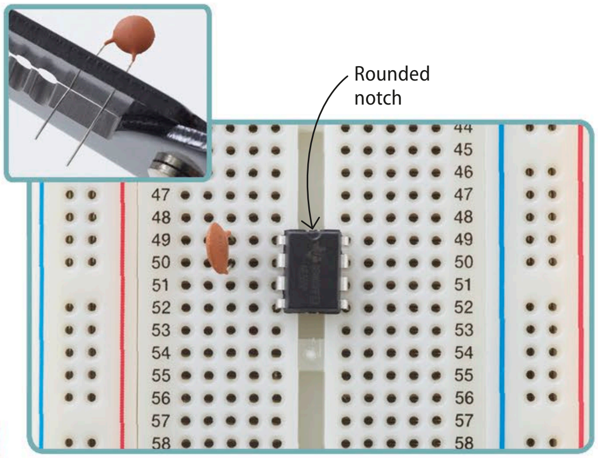
- Wire cutters



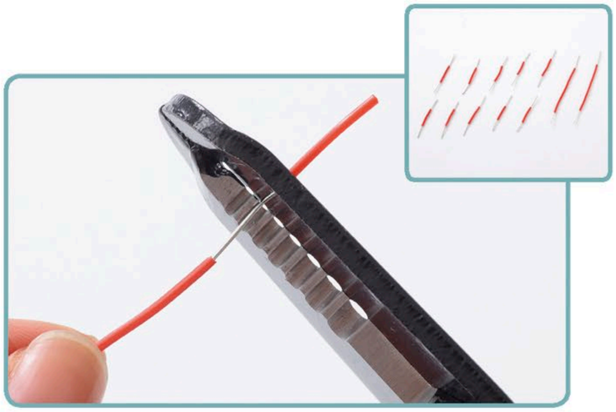




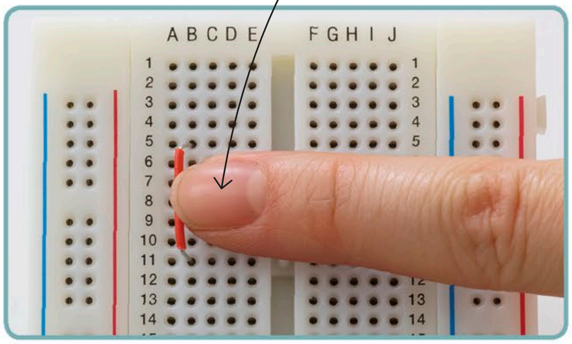
1 Push the 555 timer IC into the board with its rounded notch facing away from you, and with its corner legs in the holes for E49, F49, E52, and F52.



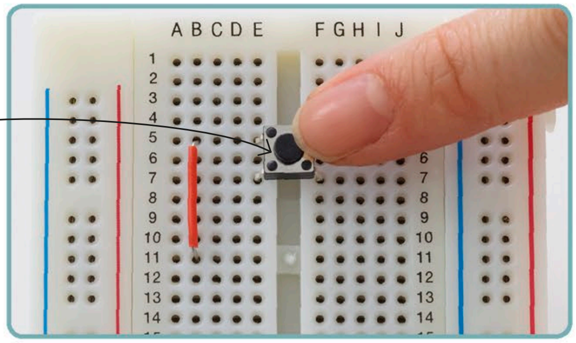
2 Trim the legs of the capacitor, so that it won't stand too high on the board. Push the legs into holes C49 and C50—it doesn't matter which way they go in.



3 Cut 10 pieces of the solid-core wire, each about ¾ in (2 cm) long, and two pieces 1⅛ in (3 cm) long. Strip ¼ in (6 mm) off all of the ends, and bend the stripped parts down at right angles.



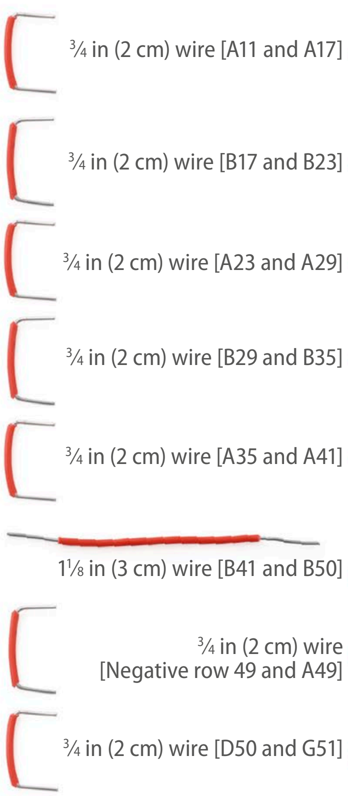
4 Insert one of the short wires into holes B5 and B11 of the breadboard.

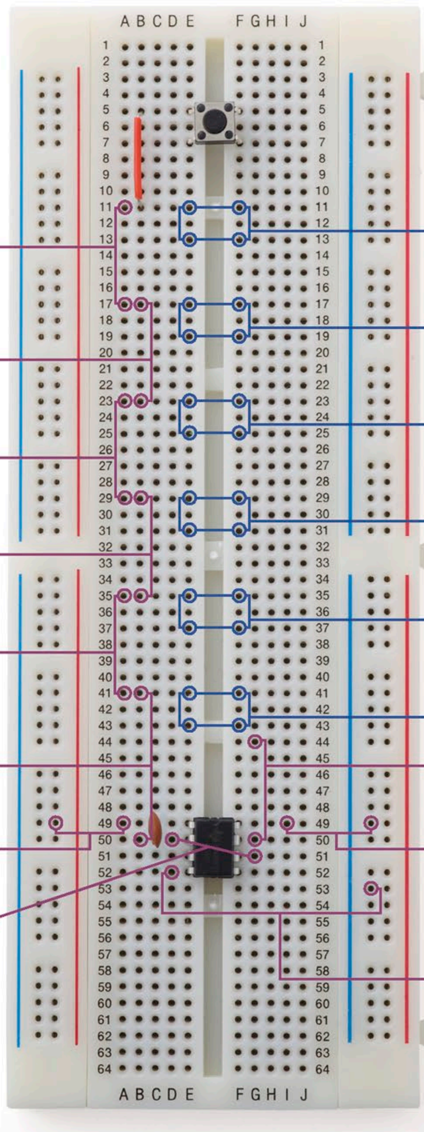


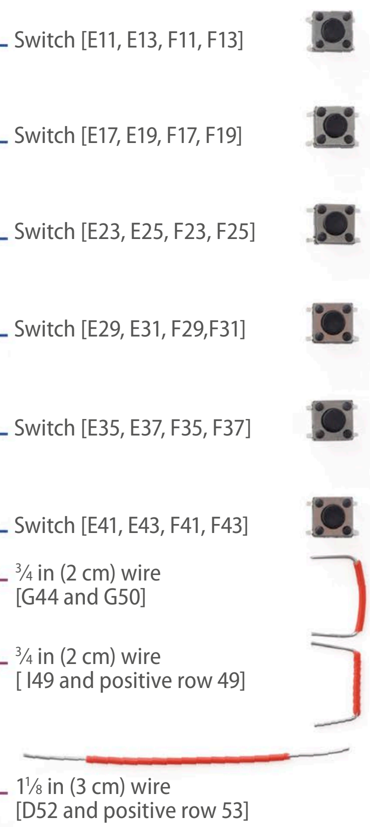
5 Push one of the button switches into the breadboard with its legs in holes E5, E7, F5, and F7.

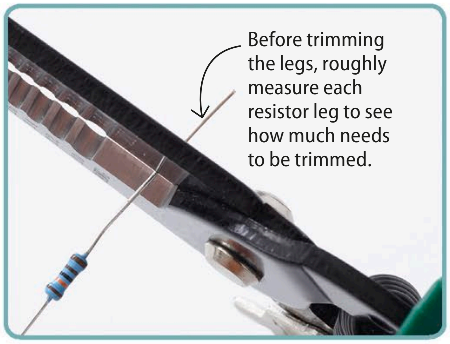
6 Using the breadboard map to the right, insert the stripped and bent ends of the wires into their positions on the board.

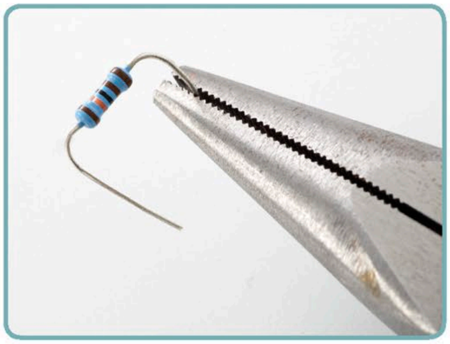
7 Place the other button switches into the breadboard where shown. Make sure that each one is exactly three holes away from the one before.

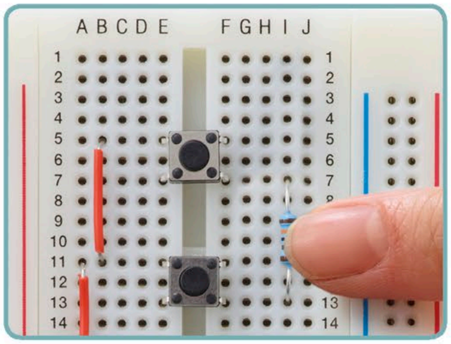










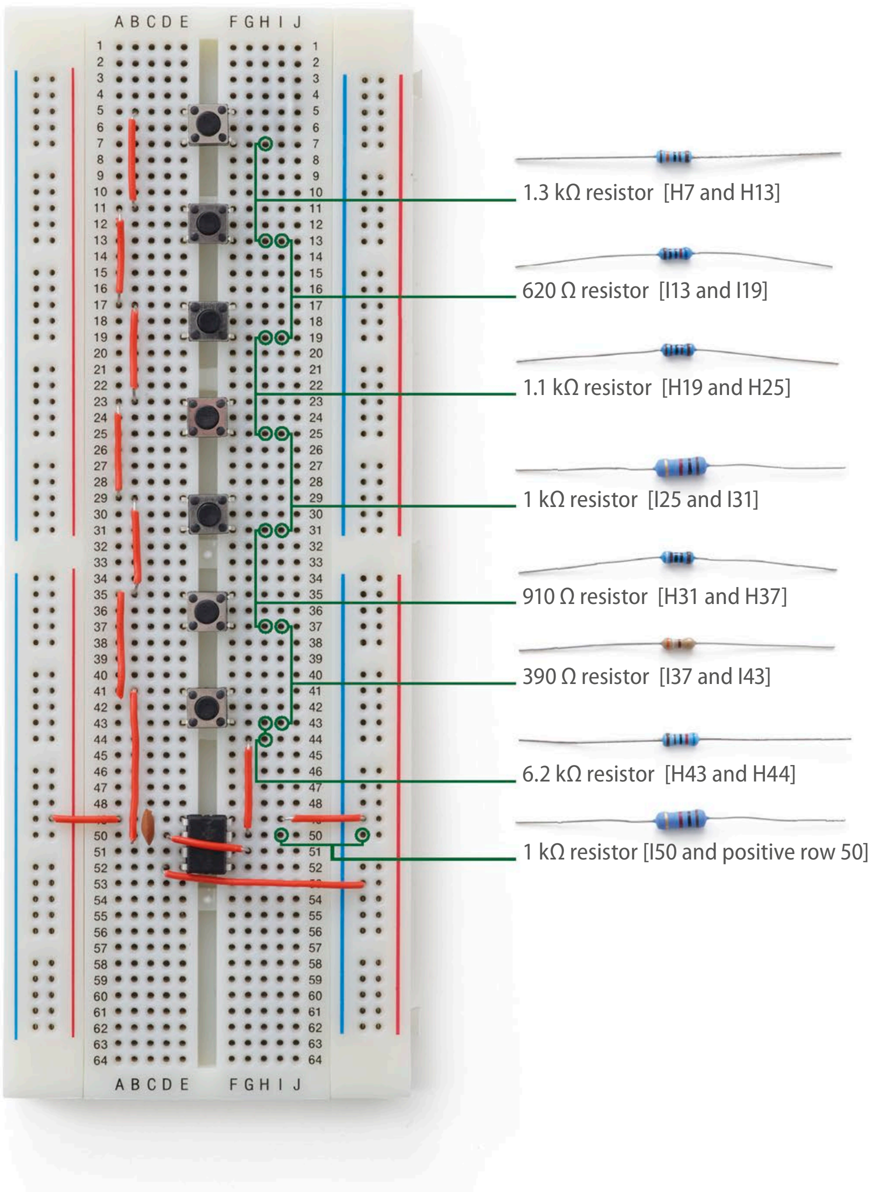


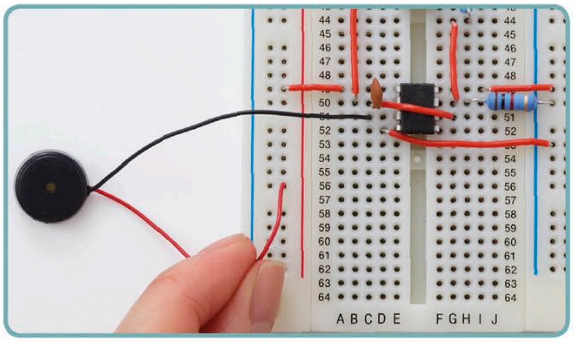
8 Next, you'll be pushing the resistors into the exact positions on the breadboard. You'll need to trim the legs to the correct length, but it's best to do this one-by-one, as you go along.

9 Remember to bend the ends of the resistors' legs at right angles, to make them easier to insert into the board, as you did with the lengths of solid-core wire.

10 Insert the 1.3 kΩ resistor into holes I1 and I7.

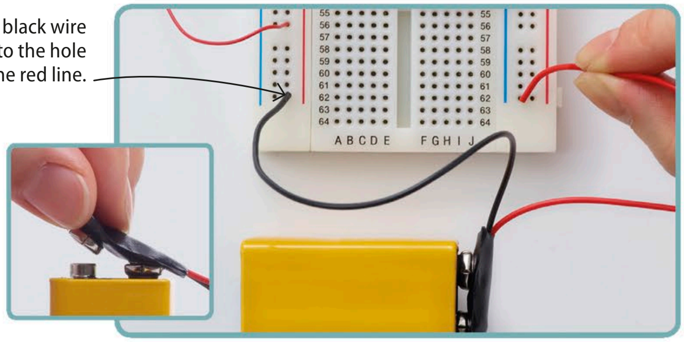
11 Using the breadboard map to the right, insert the trimmed and bent legs of the resistors into their positions on the board. It doesn't matter which way the resistors go.





12 Push the black wire of the piezo sounder into C51 and the red wire into the negative side of row 56.

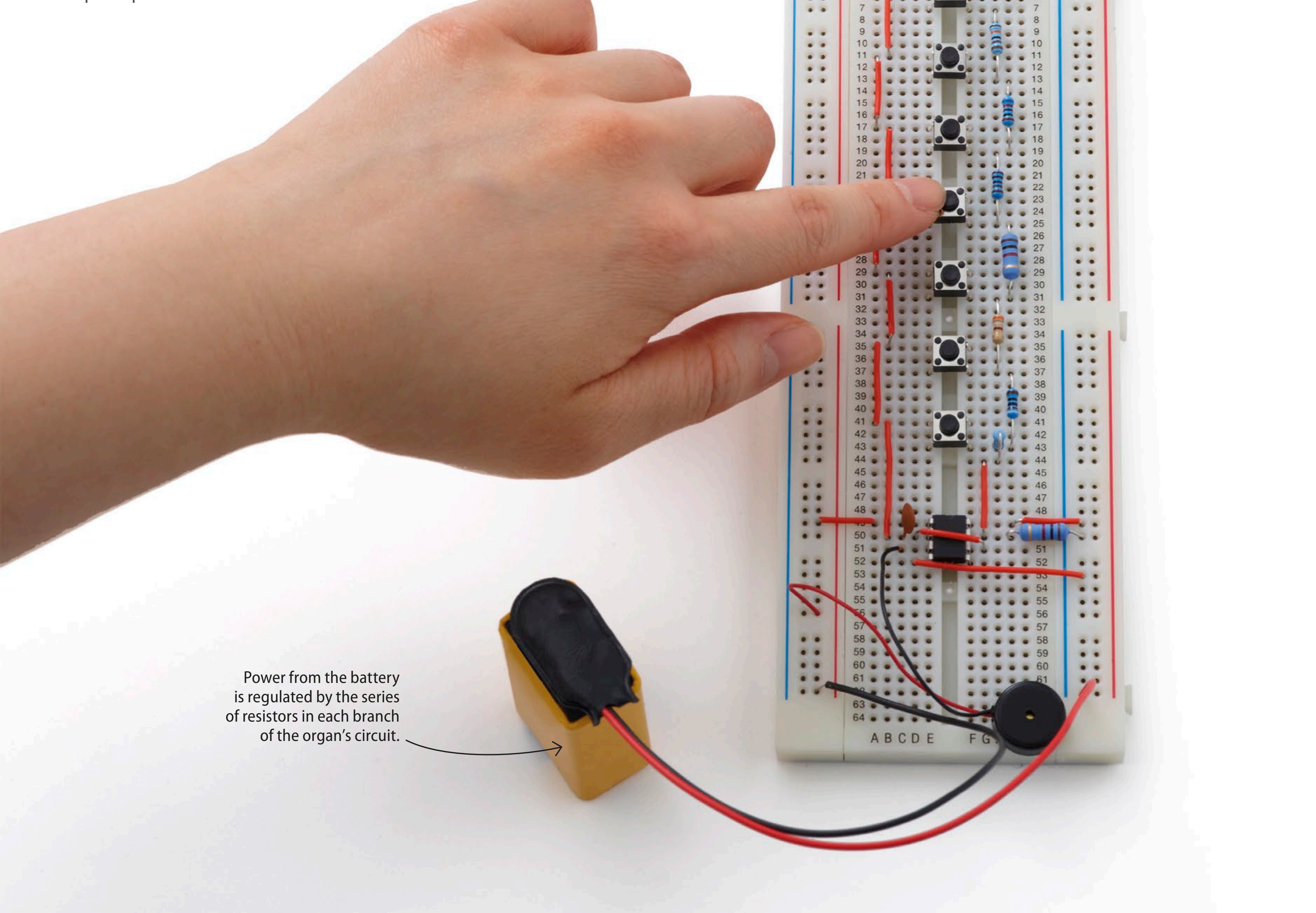
The black wire goes into the hole closest to the red line.



13 Snap the battery connector onto the battery, and push its black wire into negative row 62 on the left side, and the red wire into positive row 62 on the right side, as shown.

14 Your organ is now complete. Pressing the button switches will cause the sounder to make a sound. Each switch you press produces a different musical note.

Each switch completes a circuit, causing a note to sound.

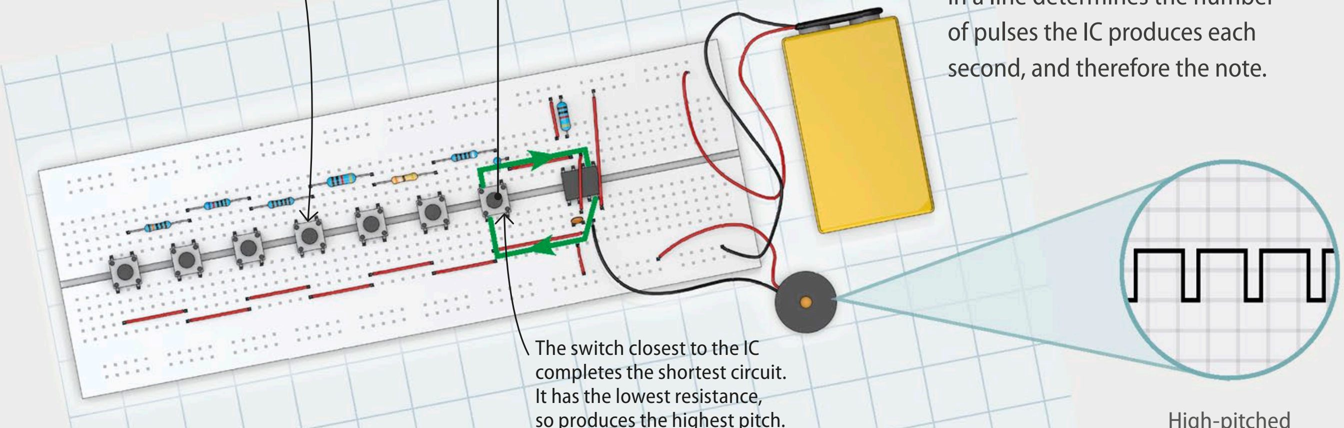


Power from the battery is regulated by the series of resistors in each branch of the organ's circuit.

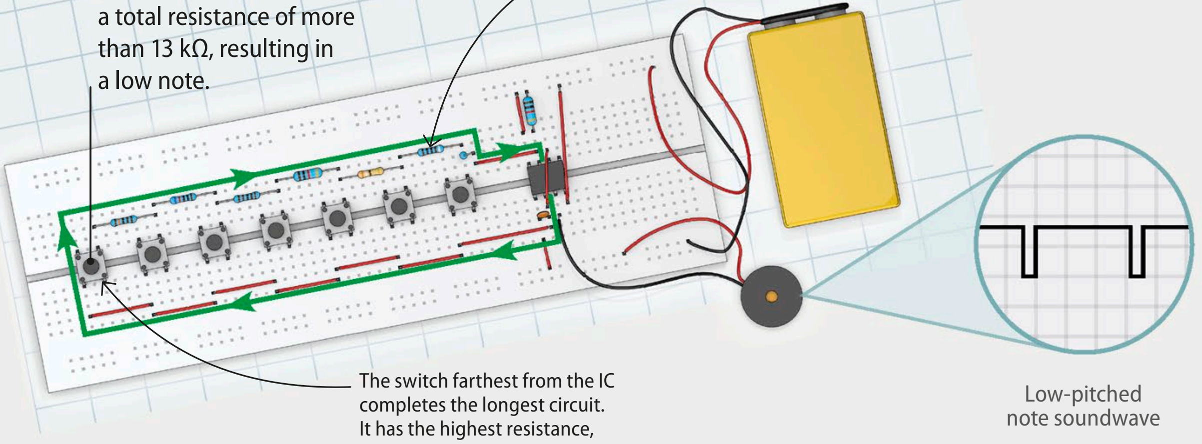
1. The lower the resistance, the higher the pitch. When you press the switch closest to the IC, you complete a circuit that includes only the 6.2 kΩ resistor, resulting in a high note.

How it works

The integrated circuit (IC) produces a series of electric pulses, which cause the piezo sounder to produce the notes that you can hear. The more pulses per second, the more high-pitched the note. The total resistance of the resistors in a line determines the number of pulses the IC produces each second, and therefore the note.



2. When you press the switch at the other end of the breadboard, you connect a circuit that has a total resistance of more than 13 kΩ, resulting in a low note.



Real-world inventions

Piano

Like your circuit organ, a piano produces different musical notes, from high- to low-pitched. A piano produces sound when strings are made to vibrate by hammers that strike them when you hit a key. The shorter, thinner strings make higher-pitched notes than the longer, thicker strings.

Bottle boat

Make some waves with this shipshape, propeller-powered boat! This boat uses batteries to drive two electric motors, which each spin a propeller. A propeller is a type of fan that turns rotational (spinning) motion into thrust, which allows your boat to go forward. Float your boat in the water, turn it on, and watch it go!

Flipping the switch allows electric current to flow through the boat's twin motors.

The boat's motors turn two screw propellers, which drive the boat through the water.


Two AA batteries provide the power for the boat.
The boat's hull (body) is made from a plastic bottle.

How to make a
Bottle boat

The tricky part of this project is making a platform at the stern (back) of the boat for the motors to sit on—and making sure the boat is watertight. The hard plastic tube can be bought at a craft store. Make sure that its diameter is more than that of the pen's ink tube.

Time
60 mins

Be aware
Requires utility knife, bradawl, hot glue gun, and soldering iron use.

Difficulty
Medium

What you need

From the toolbox

- Utility knife
- Bradawl
- Cutting mat
- Hot glue gun
- Ruler
- Wire cutters
- Wire strippers
- Soldering iron and solder
- Third-hand tool
- Double-sided foam tape


Utility knife see p.20

1 Use the utility knife to cut a large rectangle out of the middle of one side of the bottle. Be careful not to cut too far down on the sides.

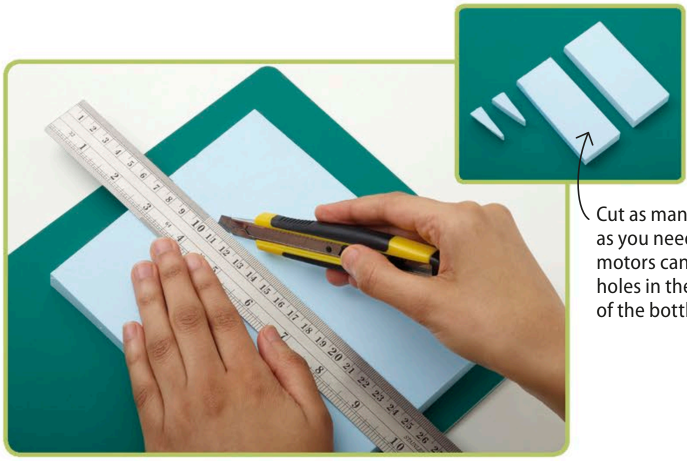
2 Near the base of the bottle, cut out a rectangle that is slightly smaller than the SPST switch and is in line with the middle of the larger hole.


Using a bradawl see p.24

3 Use the bradawl to make two holes about halfway up the bottom of the bottle, on either side of the center. Make the holes slightly larger than the diameter of the hard plastic tube.

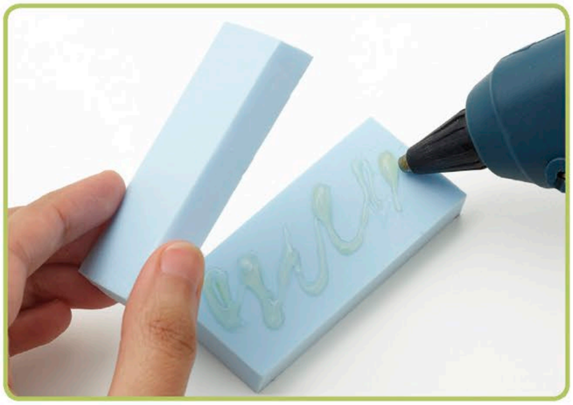
4 Use the utility knife to cut two equal lengths of the hard plastic tube, about 3⁄8 in (1 cm) shorter than the metal propeller shafts.

5 Push the plastic tubes into the holes in the bottom of the bottle, and hot-glue them into place. Make sure the tubes are both positioned downward at an angle of about 30°.

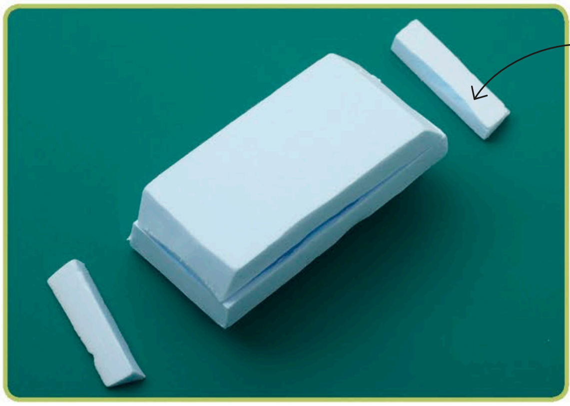


Cut as many rectangles as you need so that the motors can reach the holes in the bottom of the bottle.

6 Next, you need to create a platform for the motors from the polystyrene. Cut rectangles of polystyrene that are as wide as the bottle, and as long as the motors, and two ramps to angle the motors.



7 Glue the rectangles together. Don't put the nozzle of the glue gun close to the surface for too long, as it could melt the polystyrene.

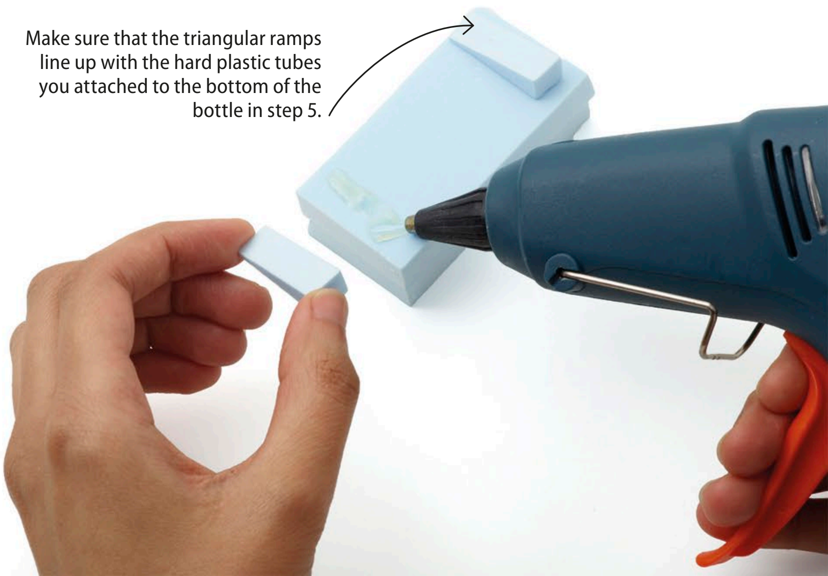


Discard the pieces you don't need.

8 You may need to trim the polystyrene to fit snugly inside the bottle.

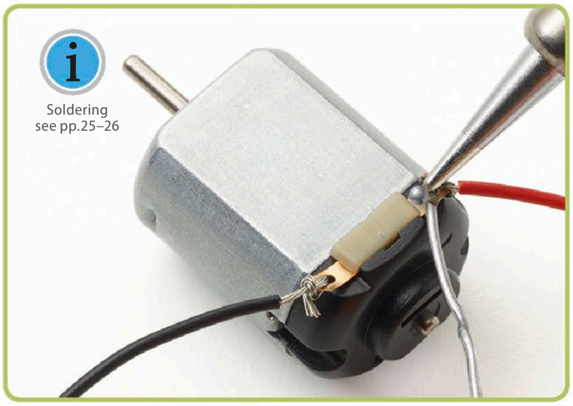
9 Now glue the two triangular ramps on either side of the top of the glued polystyrene rectangles.

Make sure that the triangular ramps line up with the hard plastic tubes you attached to the bottom of the bottle in step 5.

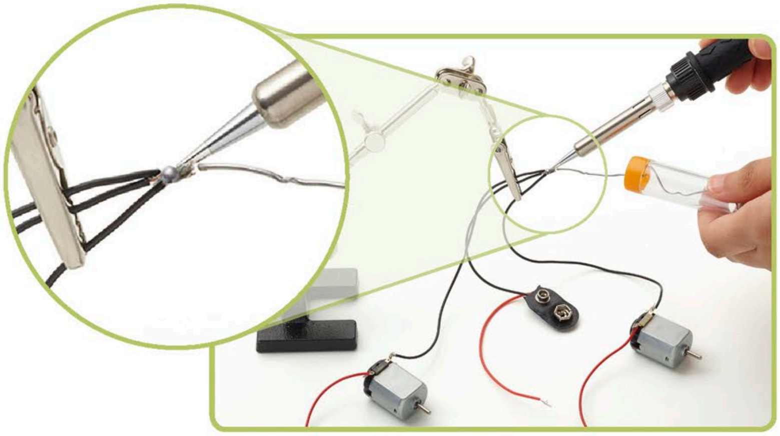


10 Apply hot glue to the underside of the polystyrene platform and secure it in place at the base of the bottle.

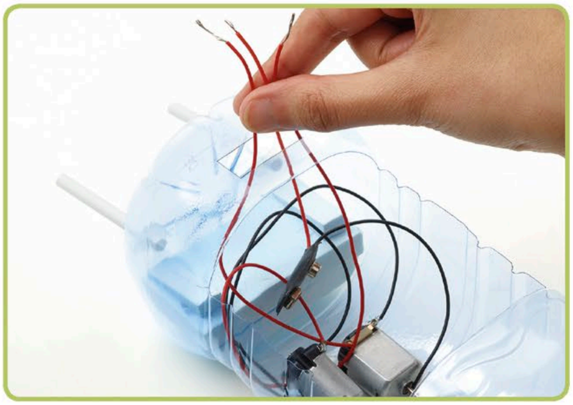
11 Cut, strip, and tin two red wires and two black wires approximately 4 in (10 cm) long. Strip and tin the wires on the battery snap connector, too.



12 Solder one black wire to one of the terminals of each of the DC motors. Then take the two red wires and solder them to the other terminal on each motor.

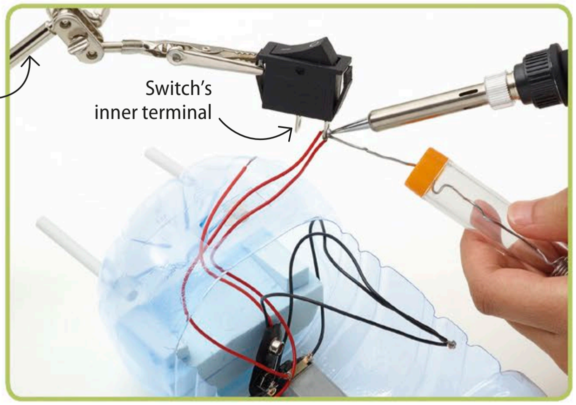


13 Solder the black wires from the motors and the black wire from the battery snap connector together to create a three-way junction.

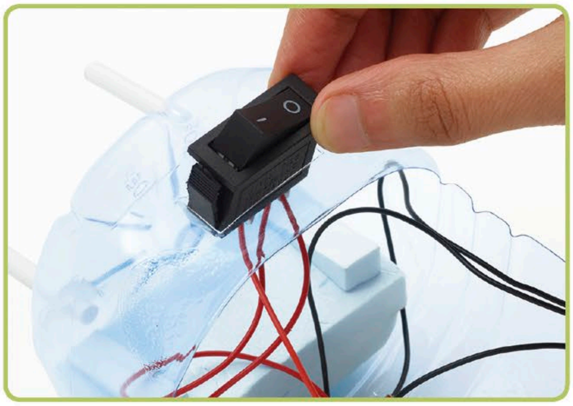


14 Place the motors, wires, and battery snap connector into the hull of the boat. Feed the red wires through the smaller rectangle that you cut in step 2 for the SPST switch.

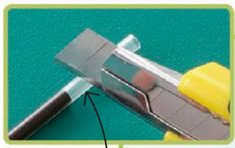
Use the third-hand tool to hold the switch steady as you solder.



15 Solder the red wires from the motors to the outer SPST switch terminal, creating a two-way junction. Then solder the red wire from the battery snap connector to the inner switch terminal.



16 Slot the SPST switch into the hole, making sure that it sits snugly and won't fall out. Ensure that the wires don't get caught between the switch and the switch's slot.



17 Now, take the shafts out of the ballpoint pens. Cut $\frac{3}{8}$ in (1 cm) off the ends of the shafts, to create plastic sleeves. Use a little hot glue to secure a sleeve onto each motor shaft.

18 Use a small strip of double-sided foam tape to stick each motor down onto one of the polystyrene ramps.

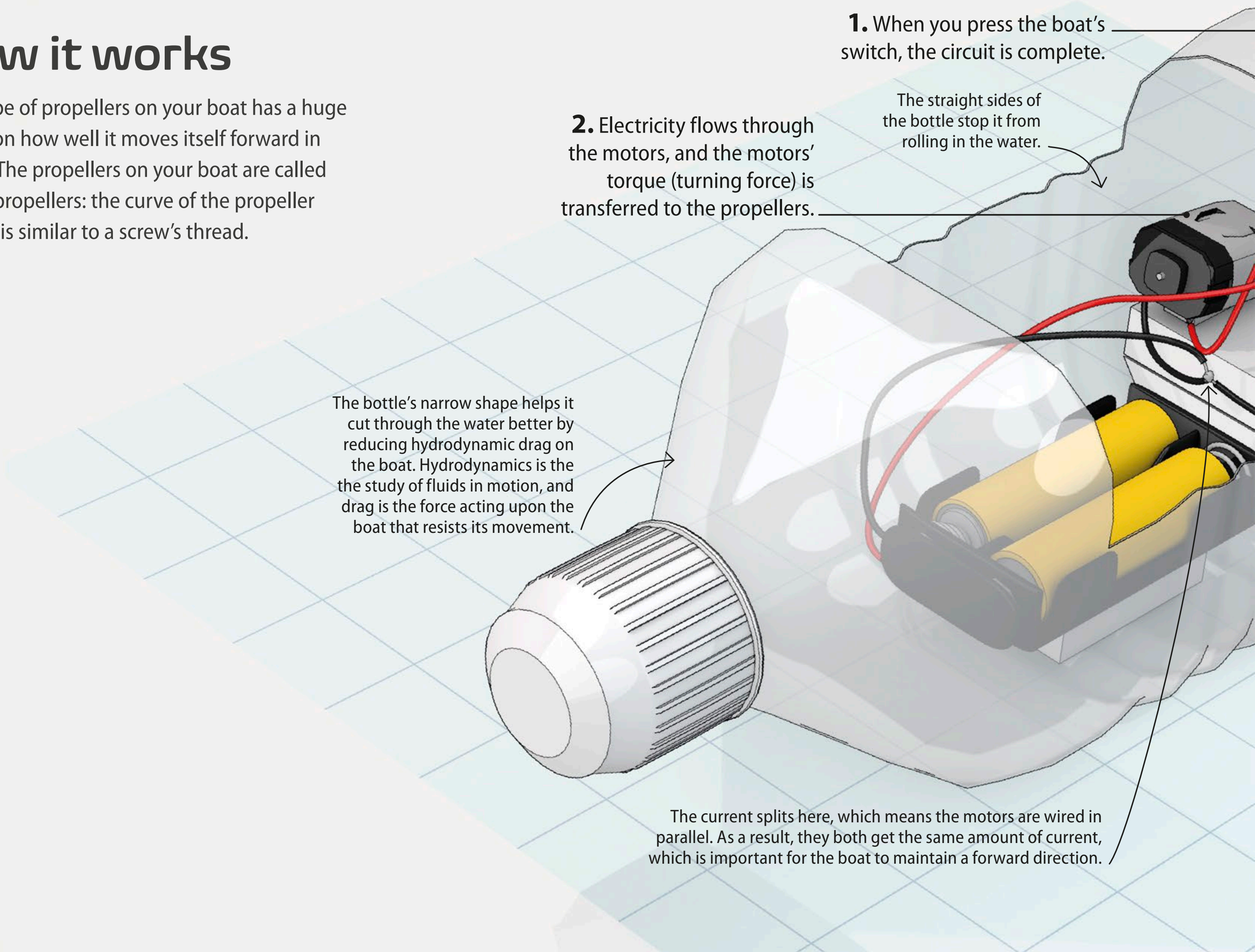
19 Push the model boat propellers onto the two metal shafts. Pass the shafts through the plastic tubes and push them firmly into the open end of each of the plastic sleeves.

20 Cut out a rectangular piece of polystyrene large enough for your battery pack to sit on. Use the battery pack as a guide.

21 Use hot glue to stick the battery holder to the polystyrene, then connect the battery snap connector to the battery pack.

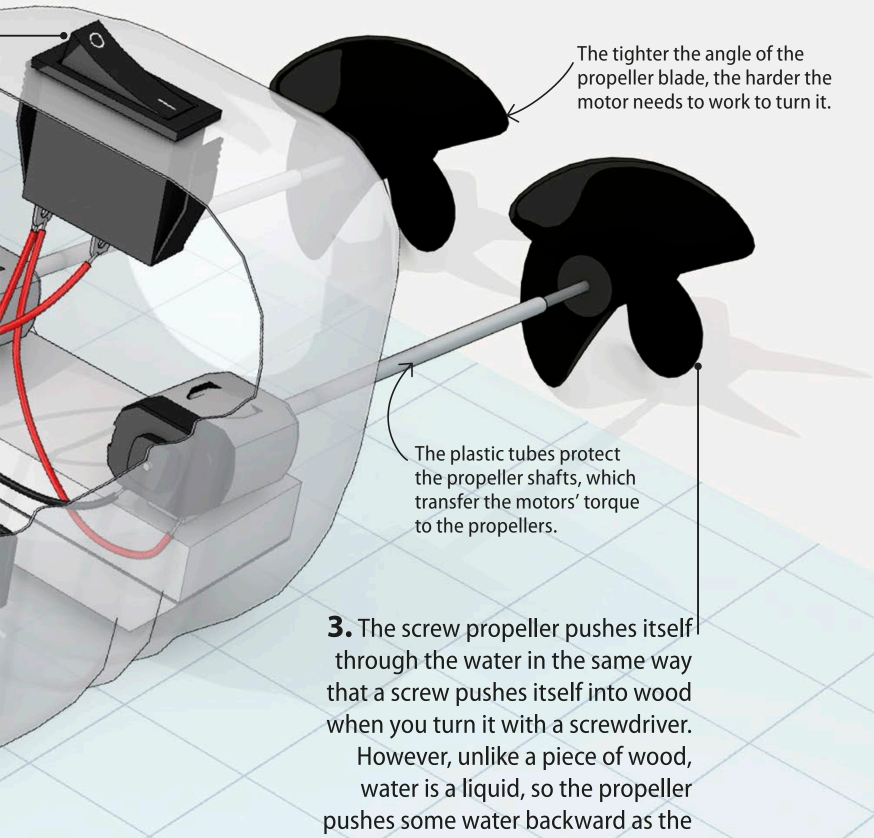
How it works

The type of propellers on your boat has a huge effect on how well it moves itself forward in water. The propellers on your boat are called screw propellers: the curve of the propeller blades is similar to a screw's thread.



Putting the battery in the center between the two sides increases the boat's stability.

22 Use hot glue to stick the other side of the battery pack's polystyrene rectangle to the bottom of the boat. Your bottle boat is ready: turn the boat on, and place it in the water to watch it go!



The tighter the angle of the propeller blade, the harder the motor needs to work to turn it.

The plastic tubes protect the propeller shafts, which transfer the motors' torque to the propellers.

3. The screw propeller pushes itself through the water in the same way that a screw pushes itself into wood when you turn it with a screwdriver. However, unlike a piece of wood, water is a liquid, so the propeller pushes some water backward as the boat moves forward.

Real-world inventions

Emma Maersk propeller

The largest propeller ever made was for the *Emma Maersk*, a Danish-owned container ship, in 2006. Its propeller measures nearly 32 ft (10 m) in diameter—the height of three adult elephants! It's made of bronze and has a mass of more than 125 tonnes.

Pipe stereo

Portable stereo speakers can be quite expensive to buy, but you can assemble your own for a fraction of the cost. In this project, the audio signal from a smartphone is passed through a circuit called an amplifier, which makes the signal powerful enough to be heard through two speakers.

A smartphone's computer produces an audio signal when it plays music or videos.

The body of this stereo unit is made of sections of plastic pipe from a hardware store.

Each speaker has a paper cone
that vibrates to produce sound.

How to make a
Pipe stereo

At the heart of this build is a ready-made electronic circuit called an amplifier. The one you'll use runs on five volts supplied by a USB cable, which you need to plug into a USB socket (such as on a computer, or the type used to charge a smartphone). There is a lot of cutting, stripping, and soldering, so take your time.

Time
60 mins

Be aware
Requires hacksaw, soldering iron, hot glue gun, and household power use.

Difficulty
Hard

What you need

From the toolbox:

- Marker
- Ruler
- Tape
- Scrap wood
- Hacksaw
- Sandpaper
- Wire cutters
- Wire strippers
- Third-hand tool
- Soldering iron and solder
- Multimeter
- 5⁄16 in (8 mm) drill bit
- Drill
- Hot glue gun

1x Stereo minijack-to-minijack cable
19¾ in (50 cm)

1x PAM8403 5V amplifier module board

2x 90° PVC pipe elbows
1½ in (40 mm)

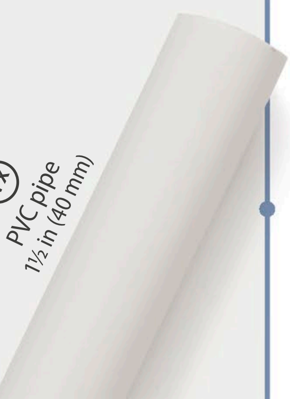
Red stranded wire
19¾ in (50 cm)

Black stranded wire
19¾ in (50 cm)

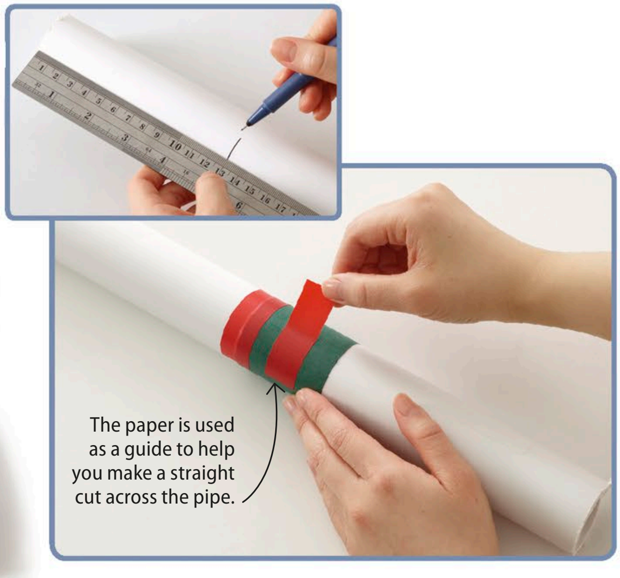
1x USB-A to USB-B cable
19¾ in (50 cm)

2x Speakers 4 Ω 3 W

1x Paper
6 in x 1½ in
(15 cm x 4 cm)



1x PVC pipe
1½ in (40 mm)



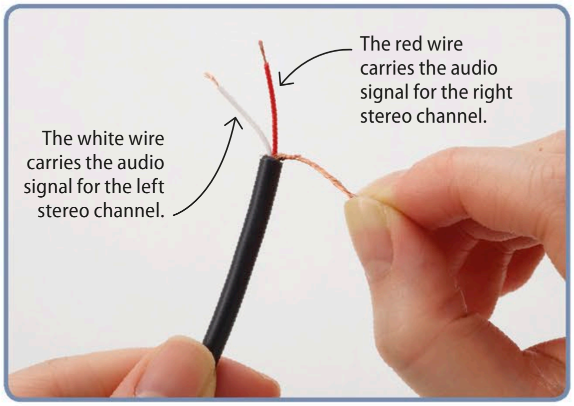
1 Make a mark 51⁄8 in (13 cm) in from one end of the PVC pipe. Wrap a piece of paper around the pipe so that one edge of the paper lies at the mark. Tape down the paper.

Hacksaw see p.21

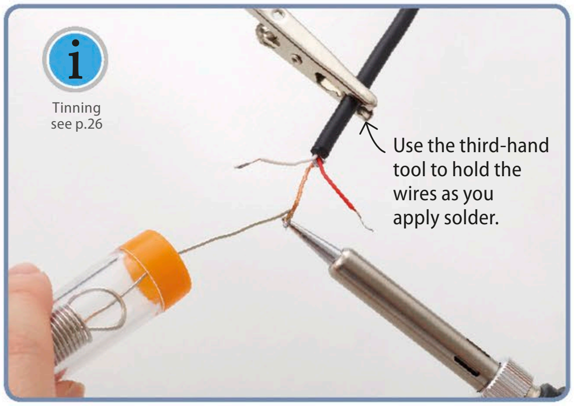
2 With the length of pipe over the edge of a table or workbench, saw through the PVC pipe, using the edge of the paper as a guide. Sand the pipe's edges with sandpaper to make them smooth.


Preparing wires see p.24

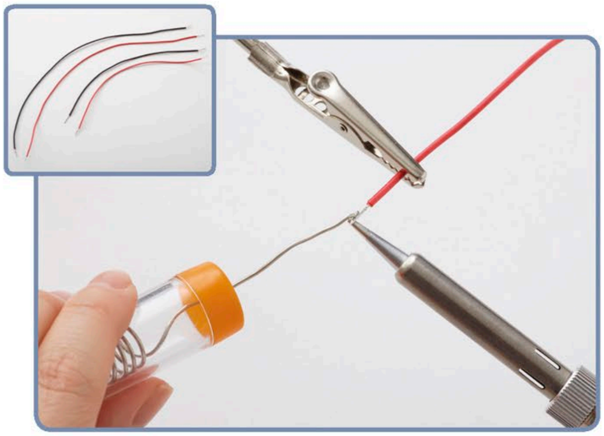
3 Cut and discard one minijack from the minijack-to-minijack cable. Strip away about 1 in (2½ cm) of the outer insulation, being careful not to cut through the internal wires.



4 Separate the red and white internal wires, and strip about ⅜ in (1 cm) of insulation from the ends. Twist the strands of the all-copper wire together.


Tinning see p.26

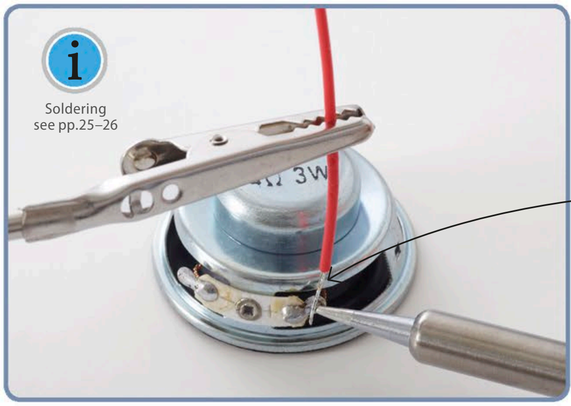
5 Tin the twisted ends of each of the three wires with solder. This will make it easier to solder them later. The copper wire is the "ground" wire—just tin the tip of this wire.



6 From the red and black stranded wire, cut pieces of wire about 12 in (30 cm) long. Next, cut some more pieces of about 8 in (20 cm) long. Strip about ⅜ in (1 cm) of insulation off the ends, and tin one end of each wire.

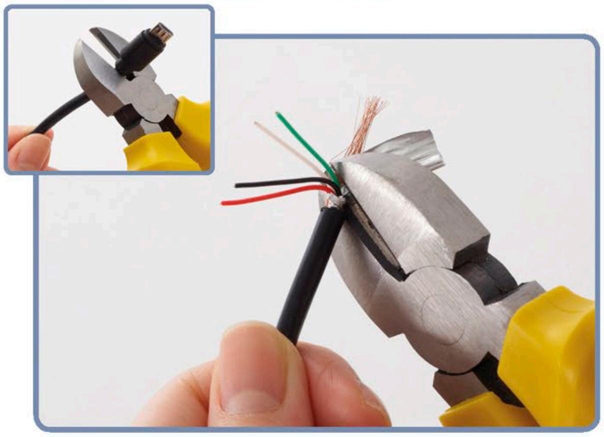
7 Tin the terminals of both speakers. This will make it easier to connect wires to them later.

Be careful when using a soldering iron.

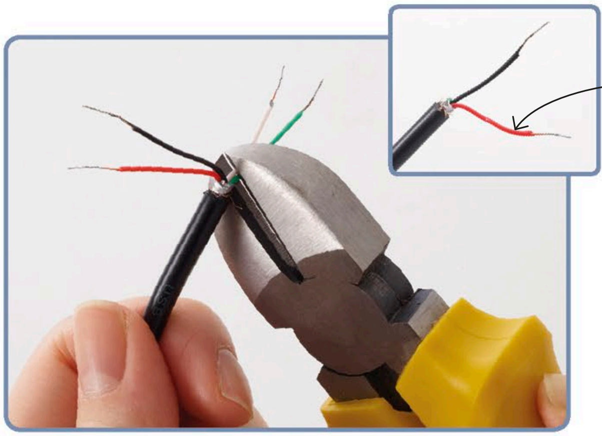

Soldering
see pp.25–26

Solder the wires across the terminals, so they reach toward the back of the speaker.

8 Solder the tinned ends of the shorter wires to the terminals of one speaker—red to the positive (marked "+") and black to the negative (marked "–"). Repeat with the longer wires on the other speaker.



9 Cut off the B-side of the USB lead, then strip the outer insulation from the end. Separate the wires inside, and cut away everything except the four colored wires.



The positive and negative leads are usually the red and black wires.

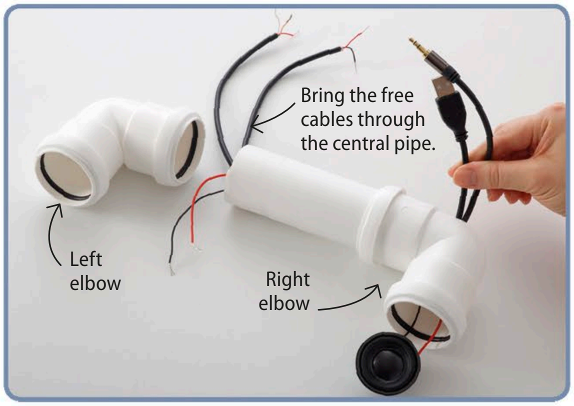
10 Plug the USB cable into a USB socket and test the four wires with a multimeter, to find out which are the positive and negative wires. Strip and tin their ends, and cut off the other two wires.

Using a multimeter
see pp.28–29

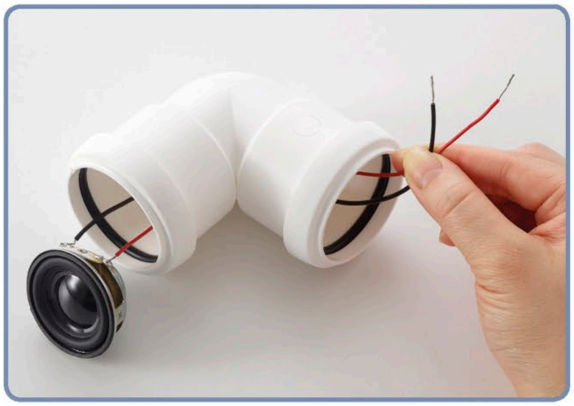

Drilling
see p.23

Use scrap wood when drilling to protect the surface.

11 Push the two elbow fittings onto the straight piece of pipe, and drill a hole about ⅓ in (8 mm) in diameter into the center of the back of each elbow fitting.

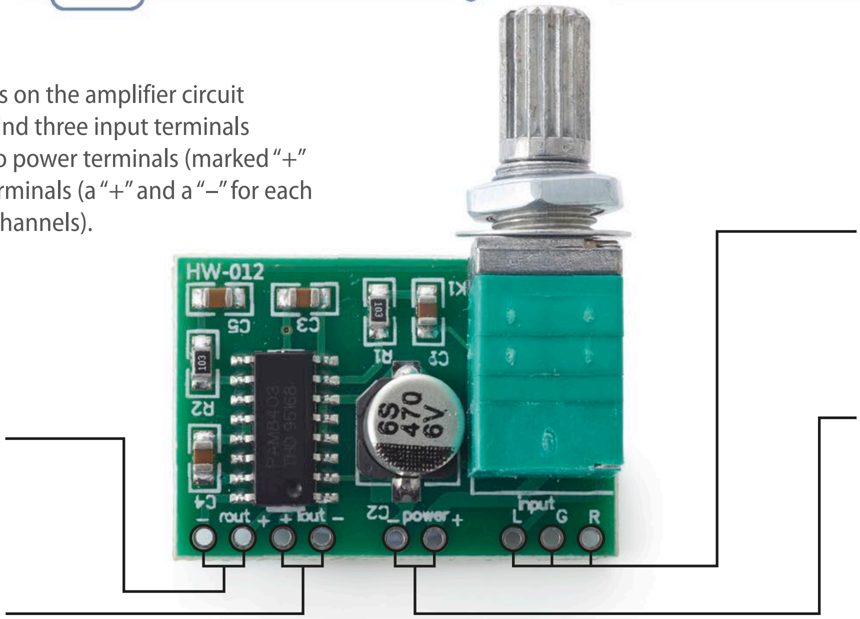


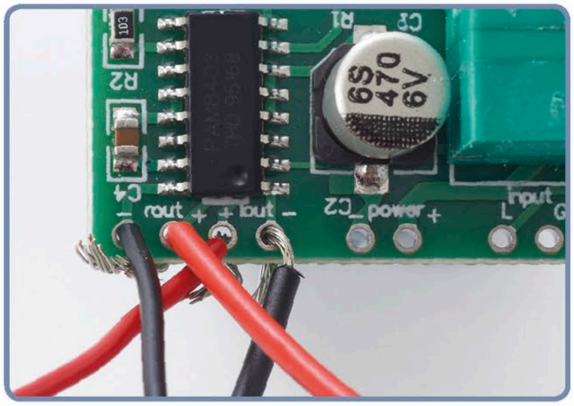
12 Remove the left elbow, and fit the speaker with the longer wires into the right elbow. Feed the trimmed ends of the USB and minijack cables through the hole in the right elbow.



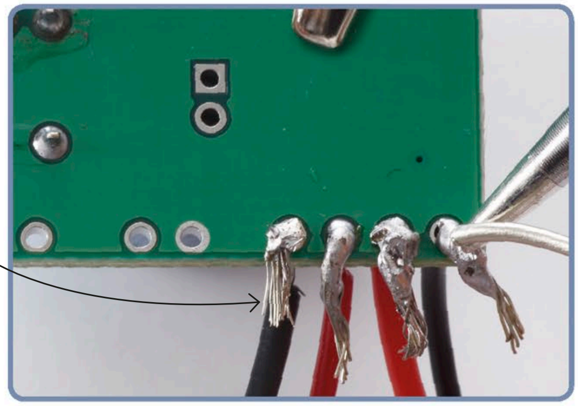
13 Fit the speaker with the shorter wires into the left elbow, and bring the red and black wires through the open end of the PVC elbow.

14 Locate the terminals on the amplifier circuit board. You should find three input terminals (labeled "L," "G," and "R"), two power terminals (marked "+" and "–"), and four output terminals (a "+" and a "–" for each of the right and left stereo channels).

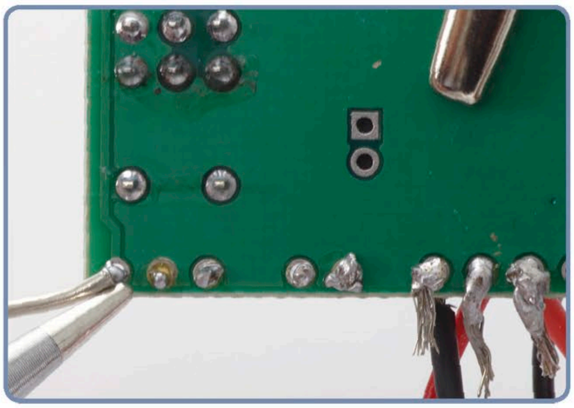




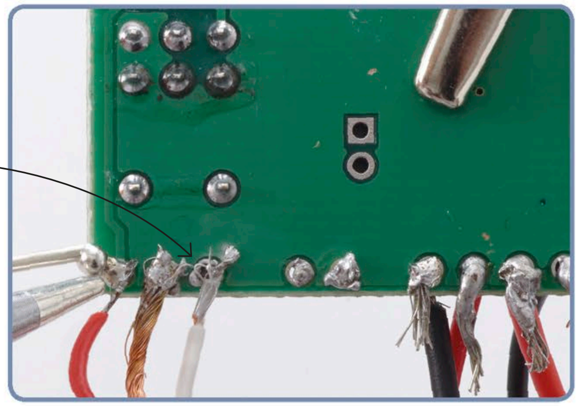
15 Feed the right speaker's red wire through the positive "Rout" terminal, and the black wire through the negative "Rout" terminal. Repeat for the left speaker, feeding the wires through the "Lout" terminals.



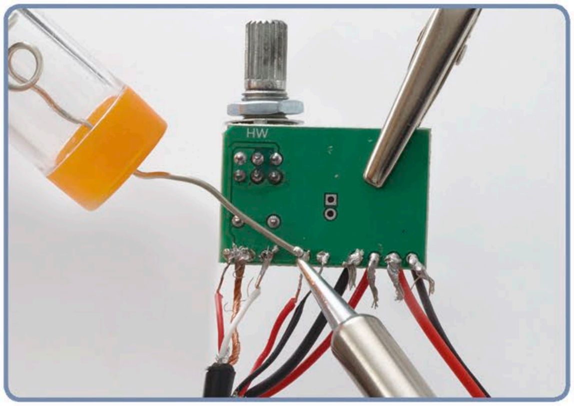
16 Turn over the circuit board and hold it in place with the third-hand tool. Solder the speaker wires you have just connected. Make sure the bare part of the wires that are next to each other do not touch.



17 Use solder to tin the input and power terminals underneath the amplifier circuit board.



18 Solder the red wire of the minijack cable to the right ("R") input terminal, the white wire to the left ("L") input terminal, and the twisted copper wire to the ground ("G") terminal.



19 Solder the ends of the wires in the USB cable to the power terminals. Attach the positive (red) wire to the positive terminal ("+") and the negative (black) wire to the negative terminal ("–").

20 To test the stereo, plug the USB cable into a power source, and plug the minijack into a smartphone playing music. Turn the amplifier volume knob. If you can't hear anything, check the connections.

21 Carefully attach the speakers to the elbow fittings with hot glue. In each case, make sure you don't get any glue on the speaker's paper cone.

22 Remove the nut from the volume knob on the circuit board, then push the knob through the hole in the left elbow fitting. Screw the nut back on to secure the circuit board in place. Push all of the pipes together, and play your music!

Cool sounds!

If you have completed the radio project in this book (see pp.84–89), you can plug the minijack from your pipe stereo into the headphone socket of the radio circuit. The sounds from the radio will play loud and clear through the pipe stereo.

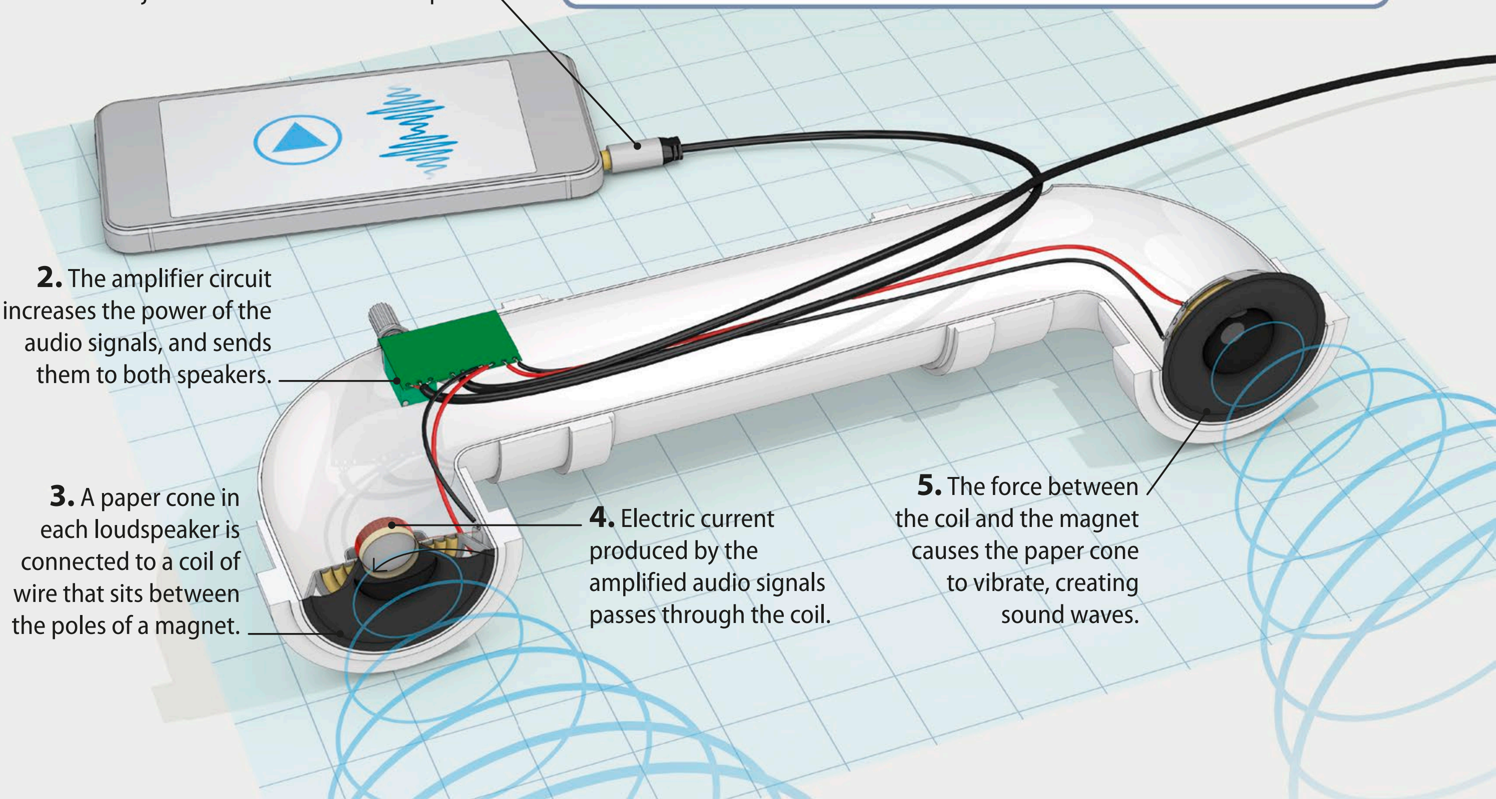
How it works

Audio signals produced at the headphone jack of a smartphone are not strong enough to be heard through loudspeakers. The amplifier circuit uses current supplied by the USB cable to boost the power of the audio signals.

Real-world inventions

Very loud speakers

Huge, powerful speakers are used at concerts to produce sound waves powerful enough for the whole audience to hear the music. These are so powerful that standing too close to them can damage your hearing!



Ferrous metal sensor

In this project, you'll build a sensor that can identify objects made of ferrous materials—materials that contain iron—even if they are hidden from view. It works in a similar way to metal detectors, as both inventions use a magnetic field produced by a coil of wire. Your sensor emits a high-pitched sound that changes pitch whenever the coil is close to a ferrous material.

How to make a

Ferrous metal sensor

Time
60 mins

Be aware
Requires hot glue gun, drill, and soldering iron use.

Difficulty
Hard

It's okay if you can't find any old CDs—try to find something sturdy with the same dimensions of $4\frac{3}{4}$ in (12 cm) in diameter. The electronic circuit is housed inside a hard plastic box. Boxes of this kind are popular with makers, as they protect components from damage.

What you need

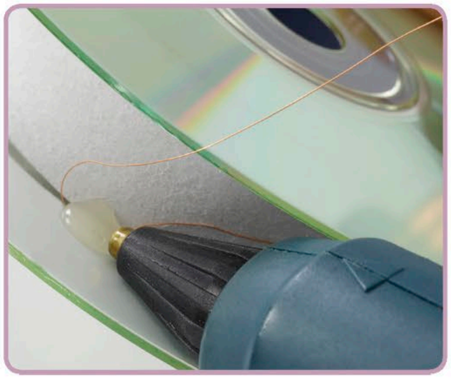
From the toolbox:

- Hot glue gun
- Ruler
- Wire cutters
- Sandpaper
- Double-sided foam tape
- Marker
- Scrap wood and clamps
- Drill
- $\frac{13}{64}$ in (5 mm) drill bit
- Wire strippers
- Soldering iron
- Solder
- Third-hand tool
- Screwdriver

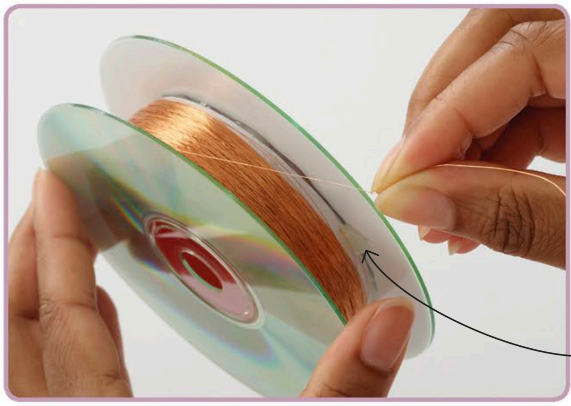

Using a glue gun see p.22

1 Use hot glue to attach the used tape roll to the center of one of the CDs.

2 Glue the second CD to the other side of the used tape roll.

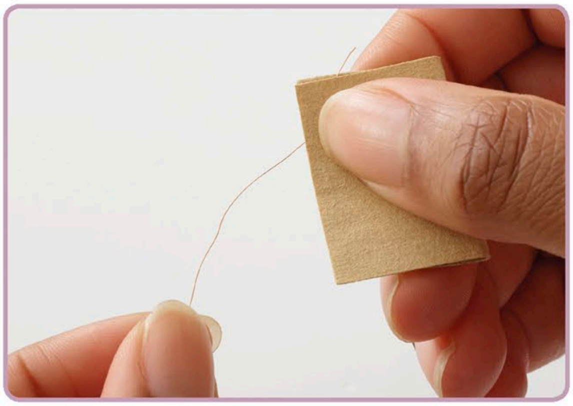


3 Use the hot glue gun to secure one end of the copper wire where the used tape roll and CD meet, leaving about 8 in (20 cm) free at the end.



4 Wind about 400 turns of the copper wire around the used tape roll. Then cut the wire, leaving about 8 in (20 cm) free at the end.

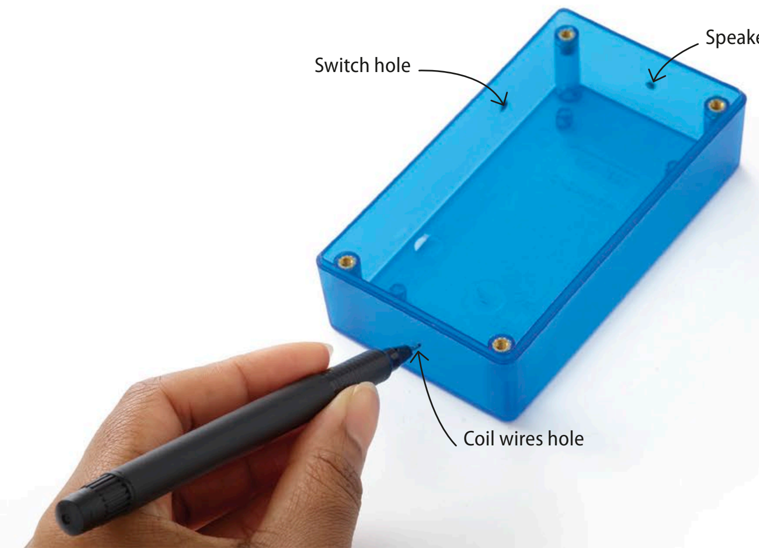
5 Leaving about 8 in (20 cm) free at the end, use hot glue to secure the copper wire beside the other end of the wire. You should now have two free lengths of wire of 8 in (20 cm).



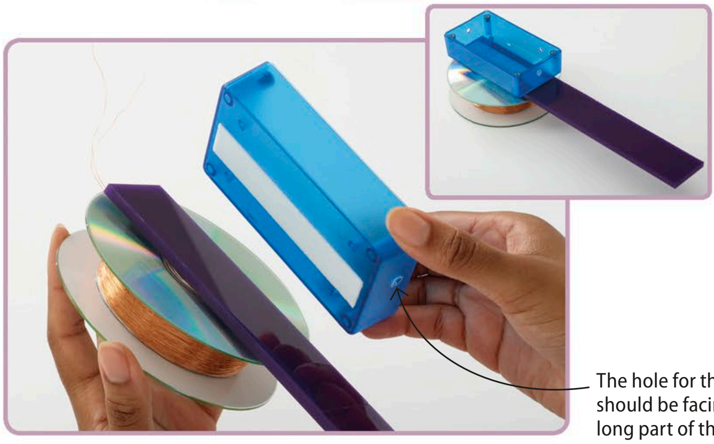
6 Scrape away about ¾ in (2 cm) of the coating from each end of the copper wire using sandpaper.

7 Now, attach your handle across the middle of one of the CDs with double-sided tape. Align the handle with the edge of the CD as best you can.

8 Open the plastic box—you may have to use a screwdriver to loosen the screws, or simply pull off a cover. Following the guide below, use a pen to mark where the switch, speaker wires, and wires from the coil will go.



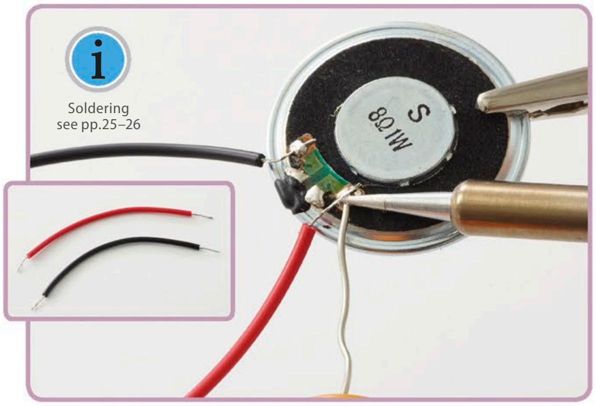
9 Select a drill bit suitable for plastic—ask an adult if you're not sure—and drill three 13/64 in (5 mm) holes through each of the markings on the plastic box.



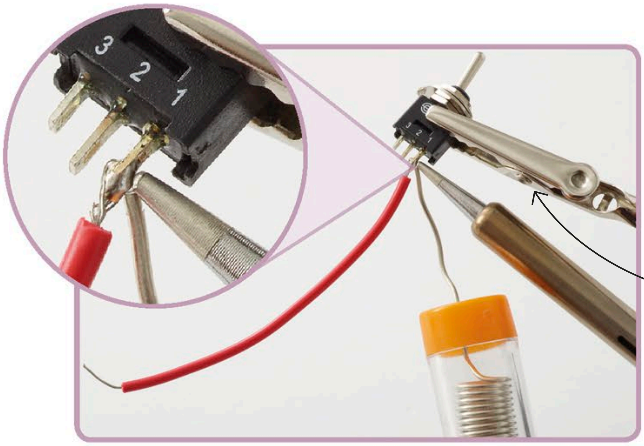
The hole for the speaker should be facing the long part of the handle.

10 Using double-sided foam tape, attach the plastic box to the handle. Align the bottom of the box with the edge of the handle.

Soldering see pp.25–26



11 Cut a black and a red wire, each 3⅛ in (8 cm) long. Strip the ends, and tin one end of each wire. Solder the black wire to the negative terminal of the speaker and the red wire to the positive terminal.

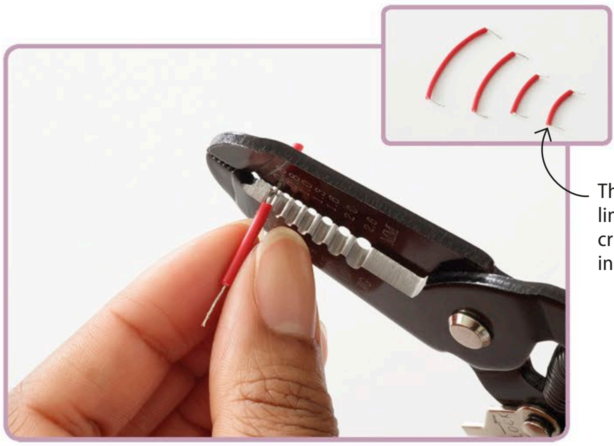


Use the third-hand tool to hold the switch while you solder.

12 Cut a red wire 3⅛ in (8 cm) long and strip the ends. Feed one end through one of the outer terminals of the switch, twist it, and then secure it with solder.

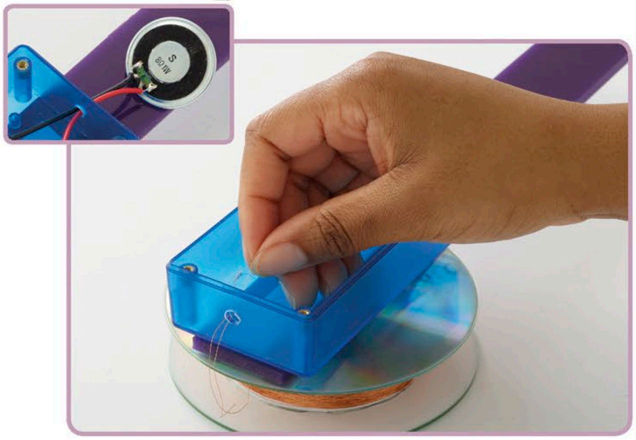
13 Strip the ends of the battery snap connector wires. Attach the red (positive) wire to the center terminal of the switch, and solder it in place. Leave the black (negative) wire free.

Hold the switch in the third-hand tool to keep it in place as you solder.

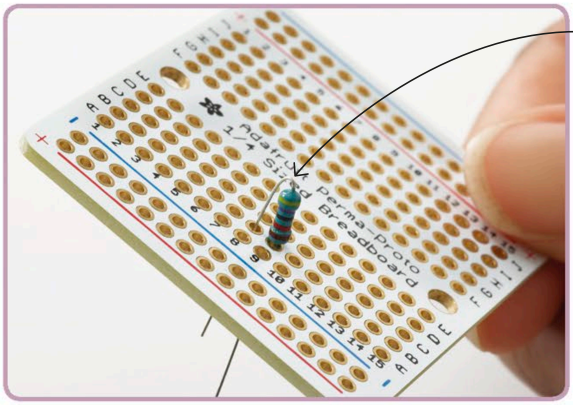


These short wire links will form crucial connections in the circuit.

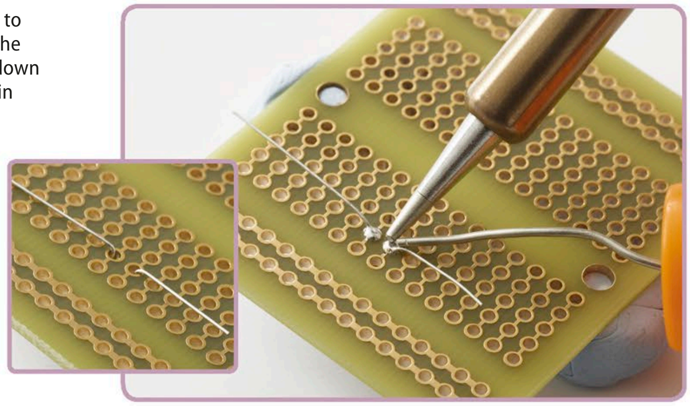
14 Cut four red wires: two 1⅛ in (3 cm) long, one 1½ in (4 cm) long, and one 2 in (5 cm) long. Strip and twist both ends of each wire, and bend the stripped ends at right angles.



15 Feed the speaker wires through the hole at the top of the plastic box. Then feed the free ends of the coil through the hole on the opposite side.

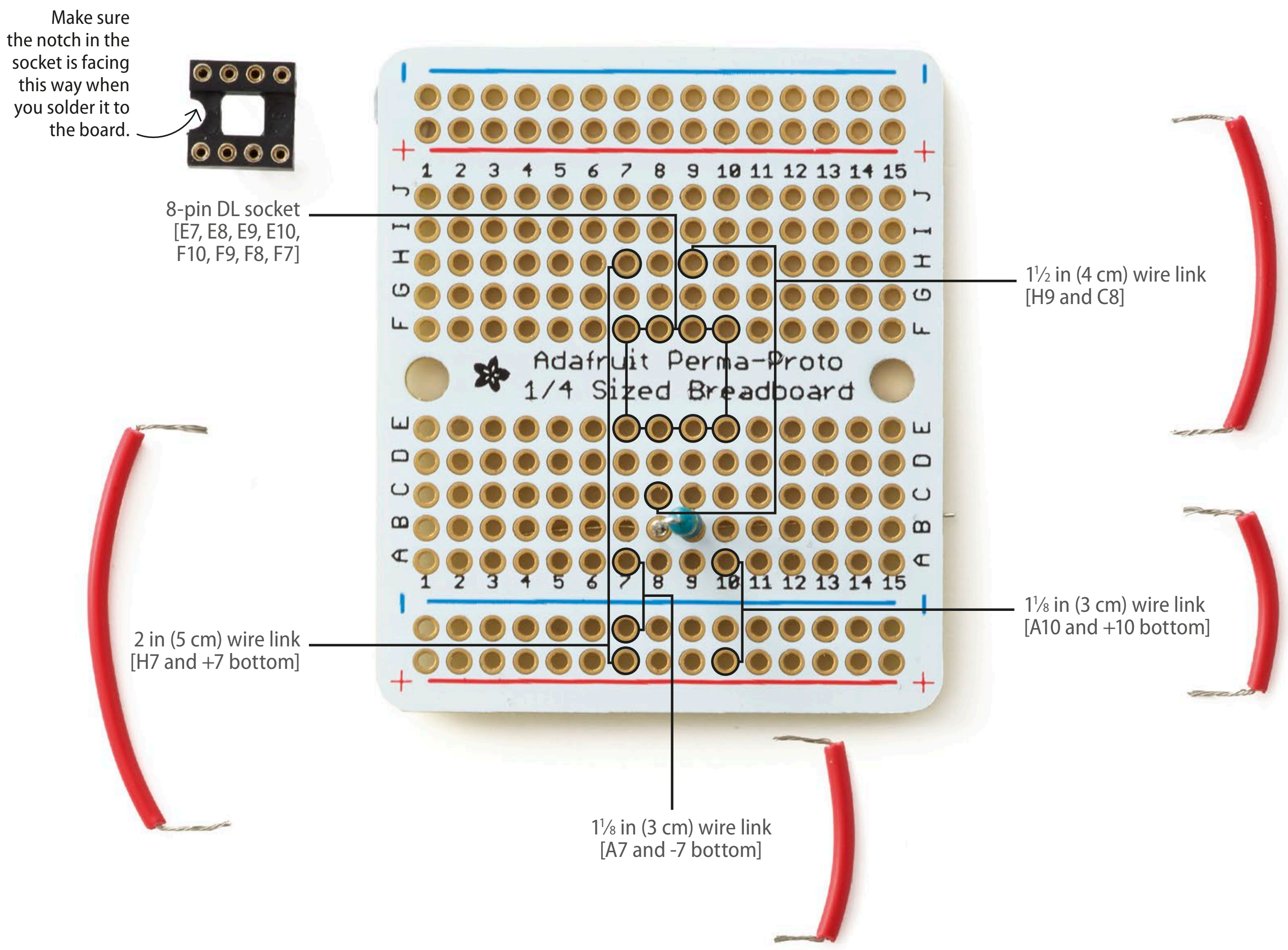


16 Push the legs of the 47 kΩ resistor through holes 8B and 9B on the breadboard, making sure the resistor sits on the top surface of the board.

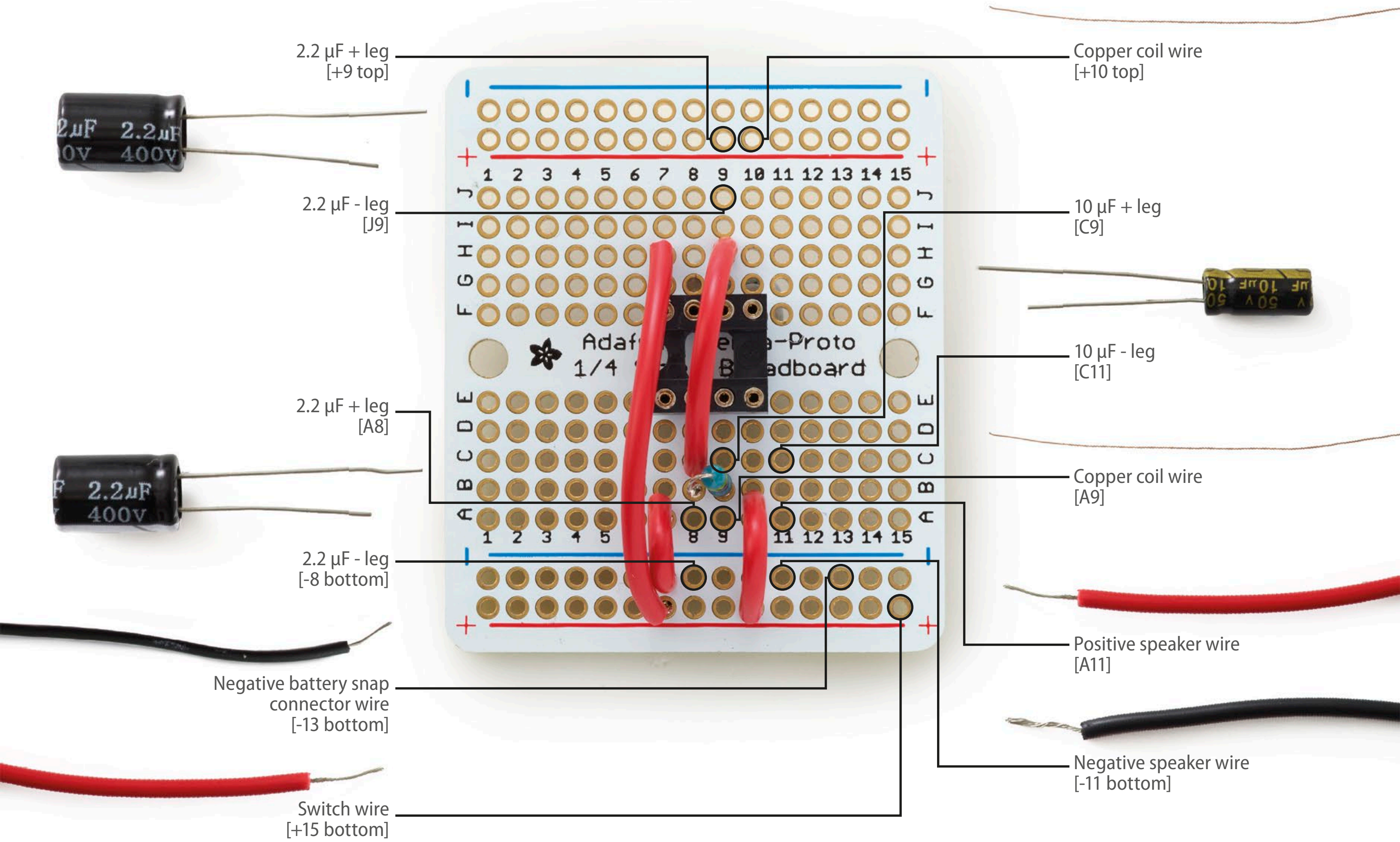


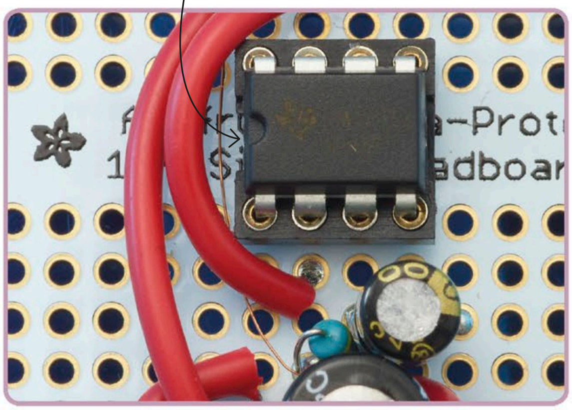
17 Turn over the board and bend the resistor legs flat to hold it in place. Use a small amount of solder to secure the resistor, then trim the resistor legs with wire cutters.

18 Following the breadboard map below, push the 8-pin socket and the wire links into the board from the top. Solder them in place underneath the board, and cut away the excess wire. You can use adhesive putty to hold the board in place on your work surface while you solder.

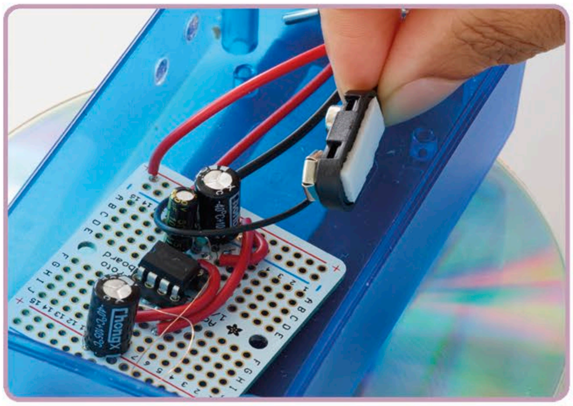


19 Connect the other components and wires, as shown on the breadboard map below. Again, solder the wires and legs underneath the board, and cut off any excess. It is important that you feed the wires from the coil and the speaker through their holes before you solder them.

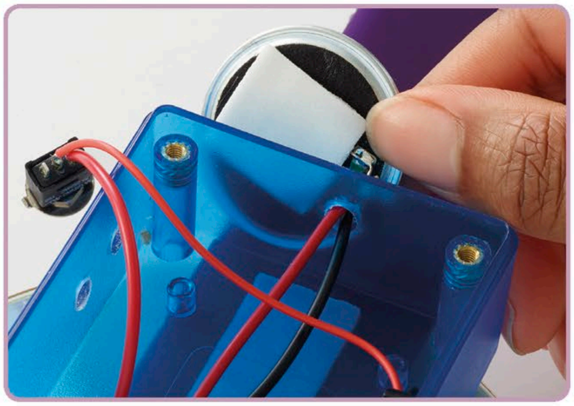




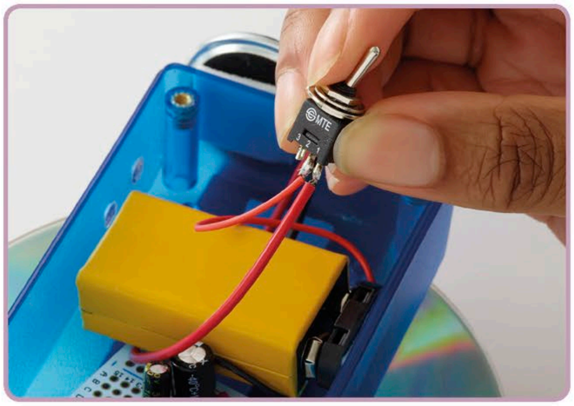
20 Plug the 555 IC timer into the 8-pin socket when you have finished soldering. The small notch on the 555 IC timer should align with the notch in the 8-pin DL socket.



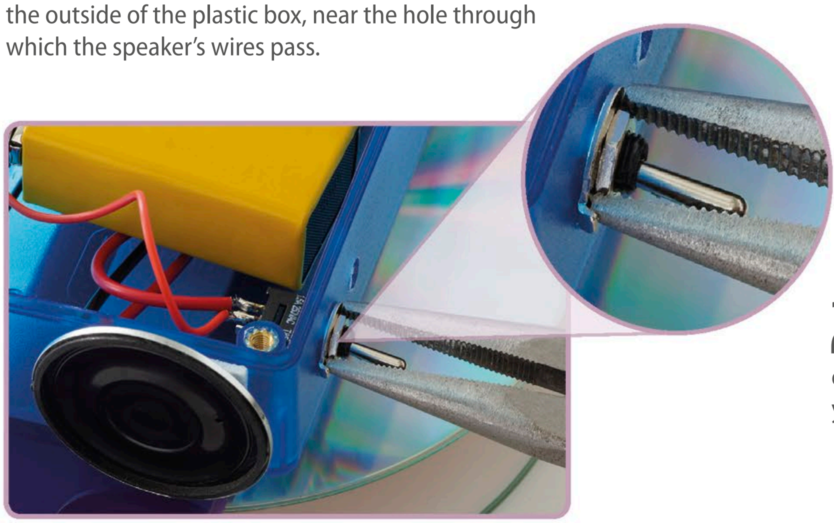
21 Stick a small piece of double-sided foam tape to the back of the battery snap connector, and stick it into the inside of the plastic box.



22 Use a small piece of double-sided foam tape to attach the back of the speaker to the outside of the plastic box, near the hole through which the speaker's wires pass.



23 Connect the battery to the battery snap connector, and flip the switch. You should hear a high-pitched sound. If there is no sound, flip the switch off and go back and check the connections.

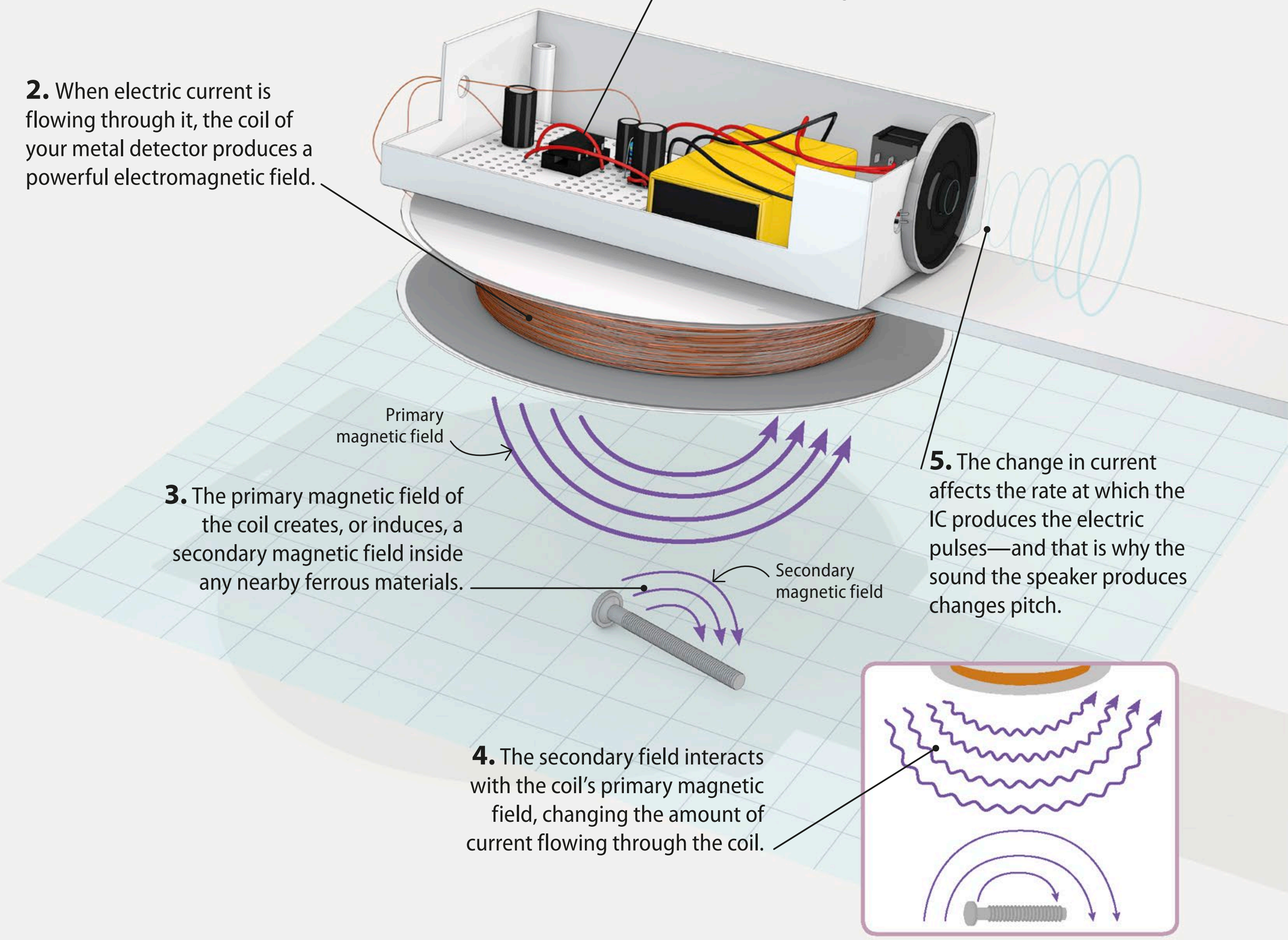


24 Unscrew the nut from the switch, and push the switch through the remaining hole in the plastic box from the inside out. Secure the nut on the other side with pliers.

25 Replace the lid of the enclosure. Make sure the switch is turned on. Your ferrous metal sensor is ready for you to find things to test!

How it works

When your ferrous metal sensor comes close to a material containing iron, it creates a magnetic field within that material. The interaction between magnetic fields in the sensor and the iron material causes a change of current in the ferrous metal sensor's coil.



1. The integrated circuit (IC) produces hundreds of electric pulses every second, which cause the speaker to produce the high-pitched sound.

2. When electric current is flowing through it, the coil of your metal detector produces a powerful electromagnetic field.

3. The primary magnetic field of the coil creates, or induces, a secondary magnetic field inside any nearby ferrous materials.

4. The secondary field interacts with the coil's primary magnetic field, changing the amount of current flowing through the coil.

5. The change in current affects the rate at which the IC produces the electric pulses—and that is why the sound the speaker produces changes pitch.

Real-world inventions

Metal detector

Treasure hunters use metal detectors to find old coins and other metallic artifacts buried underground. Their detectors have two coils. One produces a magnetic field that creates an electric current in any nearby metal. That current produces a magnetic field, which the second coil detects.

Automatic night-light

The gentle glow of a night-light in a hallway or in your bedroom can help you see a little better in the dark. The night-light you'll make in this project uses a component called a photoresistor. The photoresistor automatically turns on a strip of LED lights at nighttime, and turns them off again in the morning.


The circuit that controls the LED strip is hidden behind the decal.
The LED strip is wrapped around the night-light but hidden behind the decal, so that it casts a gentle glow on the wall.

How to make an

Automatic night-light

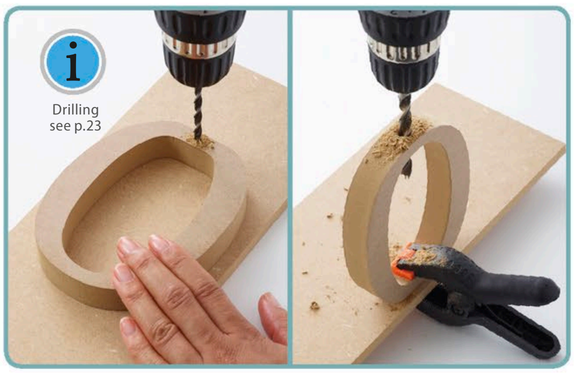
Time	Be aware	Difficulty
1 hour	Requires drill, hot glue gun, soldering iron, and house power use.	Hard

You will need a cuttable LED strip to build this night light. LED strips can come in two, three, or four colors—any will work for this project. To make your decal, print a picture of your favorite design and cut it to the same size as your plywood disk.

What you need

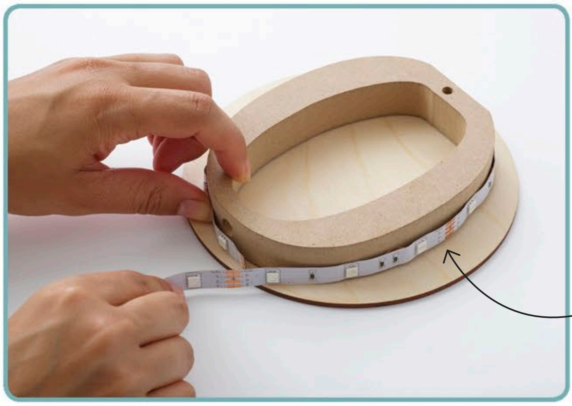
From the toolbox:

- Scrap wood and clamps
- Drill
- $^{13}/_{64}$ in (5 mm) drill bit
- $^{5}/_{16}$ in (8 mm) drill bit
- Hot glue gun
- Scissors
- Third-hand tool
- Soldering iron and solder
- Wire cutters
- Wire strippers
- Double-sided tape
- Adhesive putty



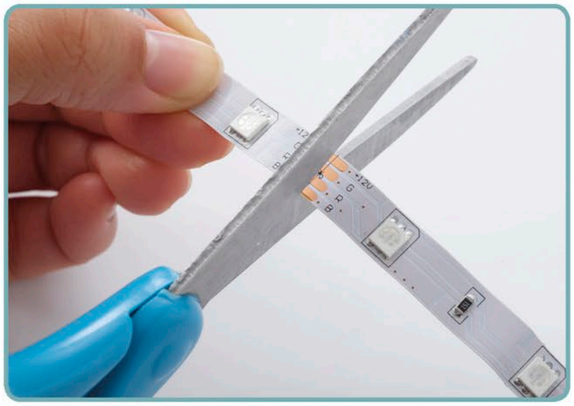
1 Carefully drill a $^{13}/_{64}$ in (5 mm) hole halfway through the wooden O. This hole is for hanging the night-light on a nail or a hook. Then drill an $^{5}/_{16}$ in (8 mm) hole through the opposite end.

2 Spread a little hot glue on one of the flat sides of the wooden O—the side that doesn't have the hole you drilled for the nail—then press the plywood disk down onto it. Make sure the wooden O is in the center of the plywood disk.

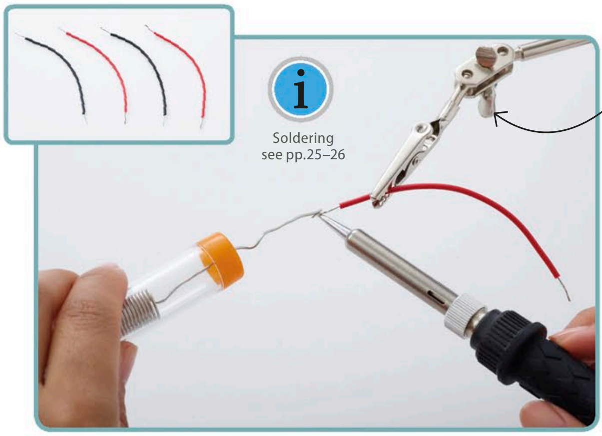


If the strip is so long it covers the hole, you'll be able to tidy it up with glue after step 25.

3 Beginning at the 5⁄16 in (8 mm) hole, wrap the LED strip all the way around the wooden O to measure the length that you'll need. This is just to measure it—don't glue it down just yet.



4 Cut the LED strip at the closest cut line nearest to the edge of the drilled hole. Only cut it at a cut line!

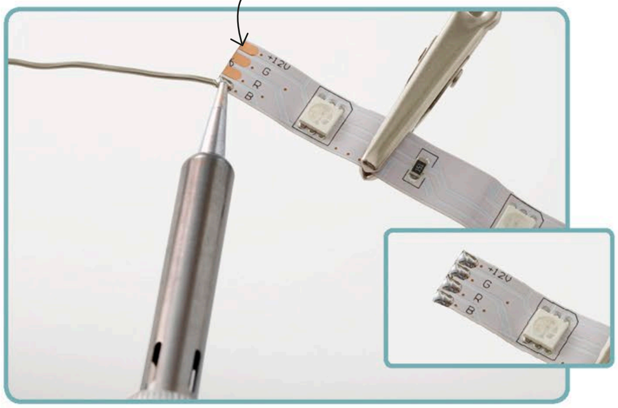


Soldering see pp.25–26

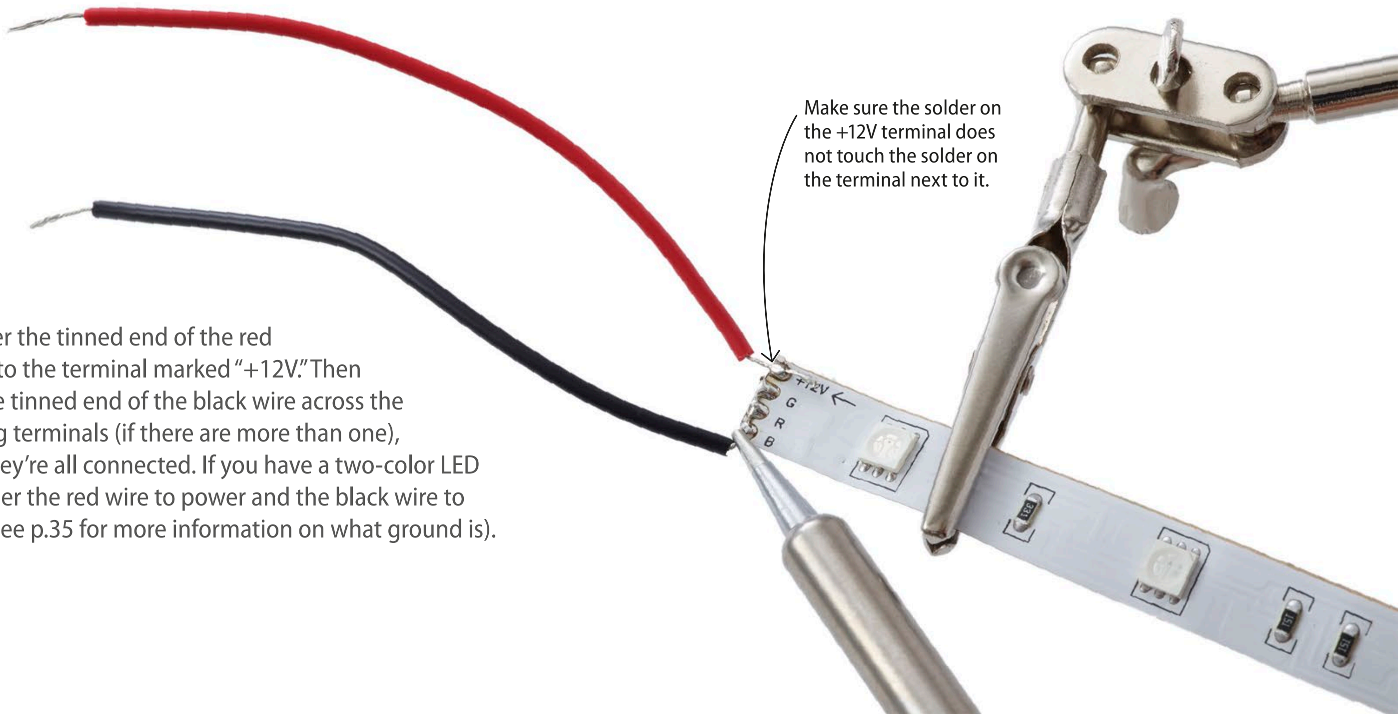
Use the third-hand tool to hold the wires steady as you apply solder.

5 Cut two black and two red wires each at 4 in (10 cm). Strip both ends of each wire, and tin one end of each wire. Set aside one black and one red wire until step 14.

LED strip terminals



6 Apply a small blob of solder to each of the terminals on one end of the LED strip (yours may have two, three, or four). Make sure the blobs of solder do not touch.



Make sure the solder on the +12V terminal does not touch the solder on the terminal next to it.

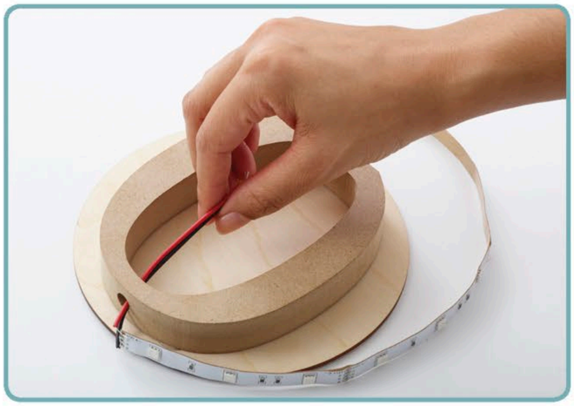
7 Solder the tinned end of the red wire to the terminal marked "+12V." Then solder the tinned end of the black wire across the remaining terminals (if there are more than one), so that they're all connected. If you have a two-color LED strip, solder the red wire to power and the black wire to ground (see p.35 for more information on what ground is).

8 Making sure it is not plugged in, cut the jack off the end of the 12v AC/DC cable. Strip $1\frac{1}{8}$ in (3 cm) of the outer insulation, then strip the ends of the internal wires.

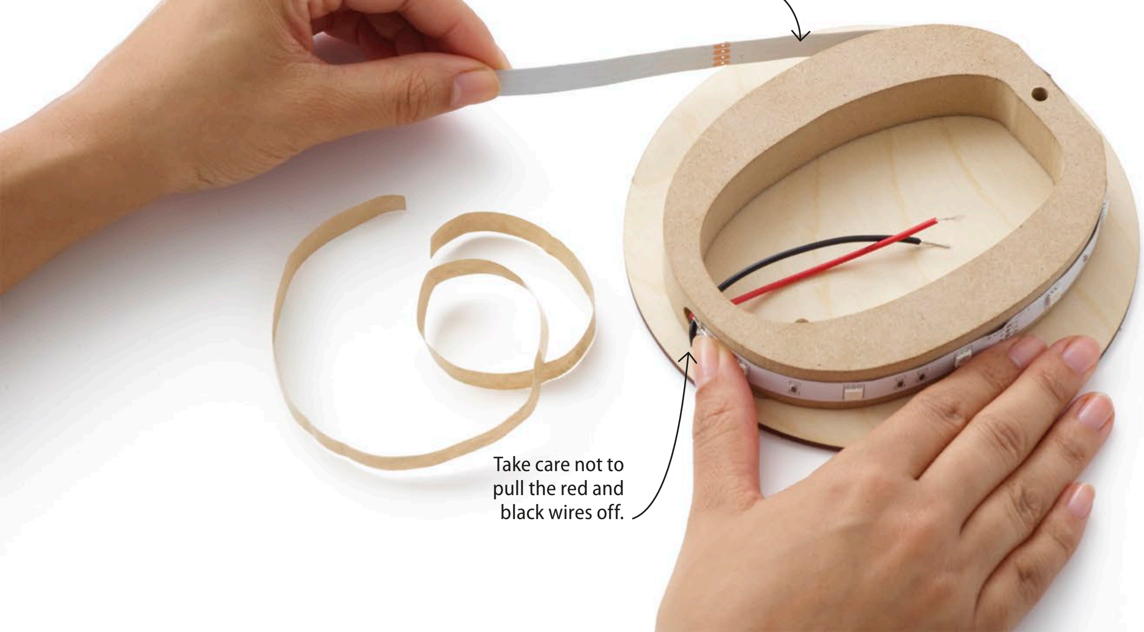
9 Stick the decal onto the plywood disk using double-sided tape or glue. Neatly trim or fold over the edges if the decal is slightly larger than the disk.

Use scrap wood to reduce the chance of damaging your furniture.

10 Drill a $\frac{13}{64}$ in (5 mm) hole through the plywood disk, off-center but within the wooden O. Drill right through the decal. Try to choose a place that won't show too much on the decal design.



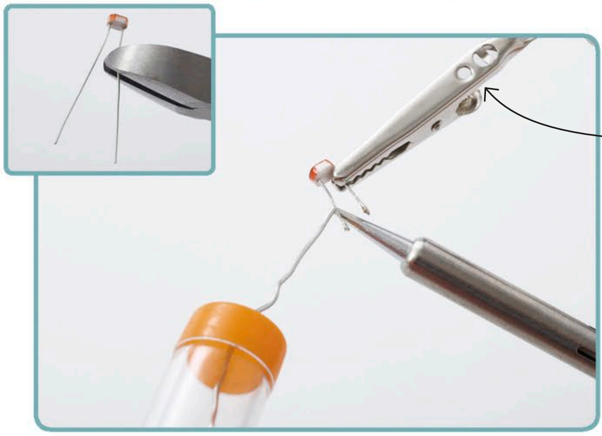
11 Feed the red and black wires connected to the LED strip into the wooden O through the hole in the bottom.



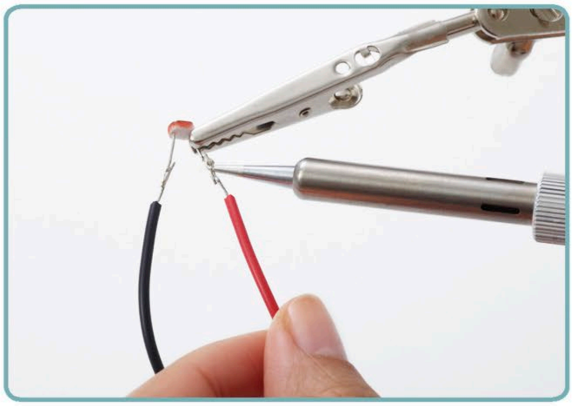
If your LED strip doesn't have adhesive backing, use hot glue or double-sided tape.

Take care not to pull the red and black wires off.

12 Remove the adhesive backing from the LED strip, and stick it to the outer edge of the wooden O. Make sure the red and black wires are near the edge of the hole.



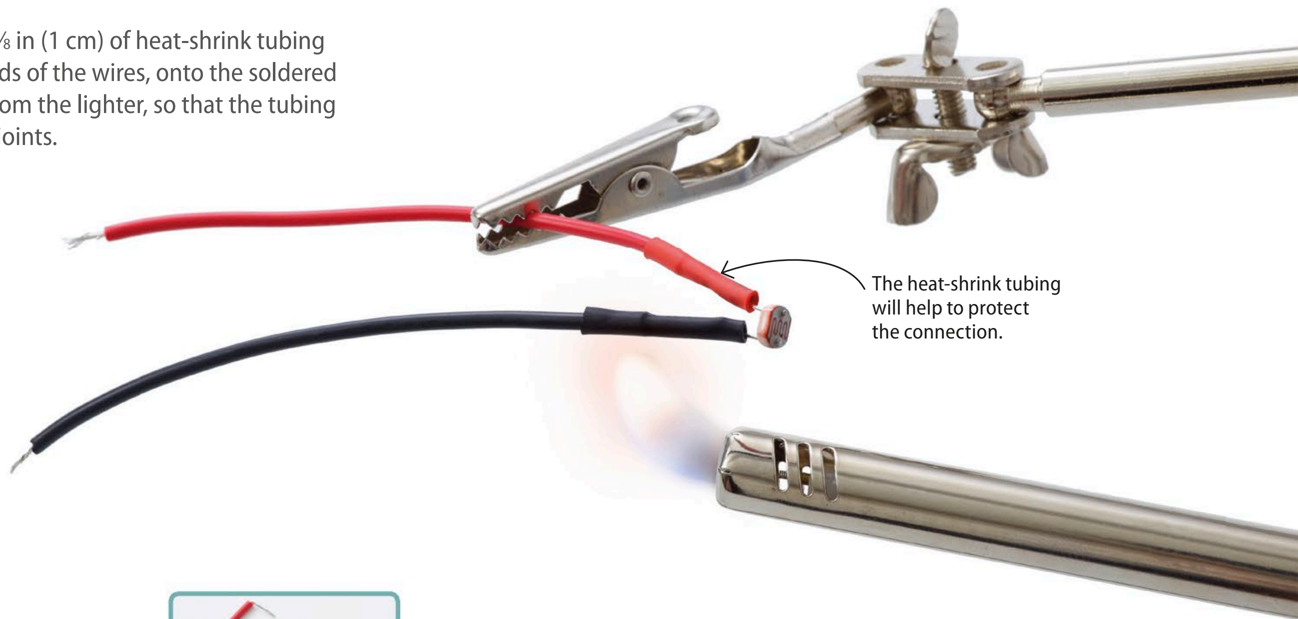
13 Use wire cutters to trim the legs of the photoresistor to a length of about ⅜ in (1 cm). Next, tin both legs with a little solder.



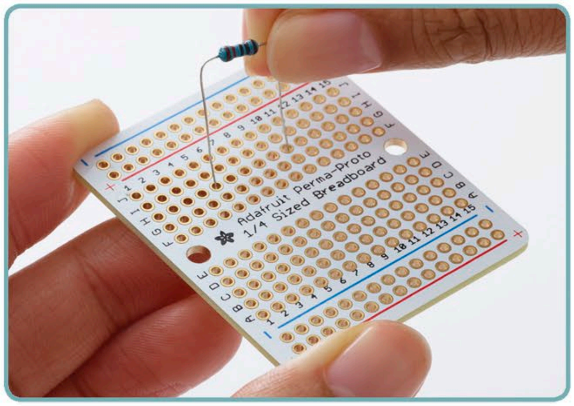
14 Solder the tinned ends of the red and black wires you prepared in step 5 to the legs of the photoresistor. It doesn't matter which one goes where.

15 Slip about ⅜ in (1 cm) of heat-shrink tubing over the ends of the wires, onto the soldered joints. Apply heat from the lighter, so that the tubing shrinks around the joints.

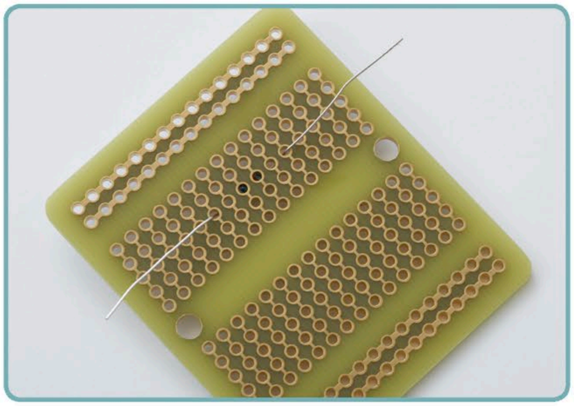
Always be careful when using an open flame.



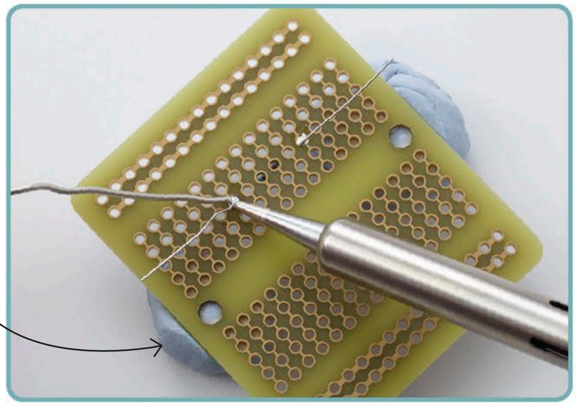
16 Cut three short wires—one ¾ in (2 cm) long and two 1½ in (4 cm) long. Strip each end of all three wires, using pliers to hold them if necessary, and then bend the ends down 90°.



17 Fold down the legs of the 10 kΩ resistor, and push them through terminals H5 and H10 of the breadboard.

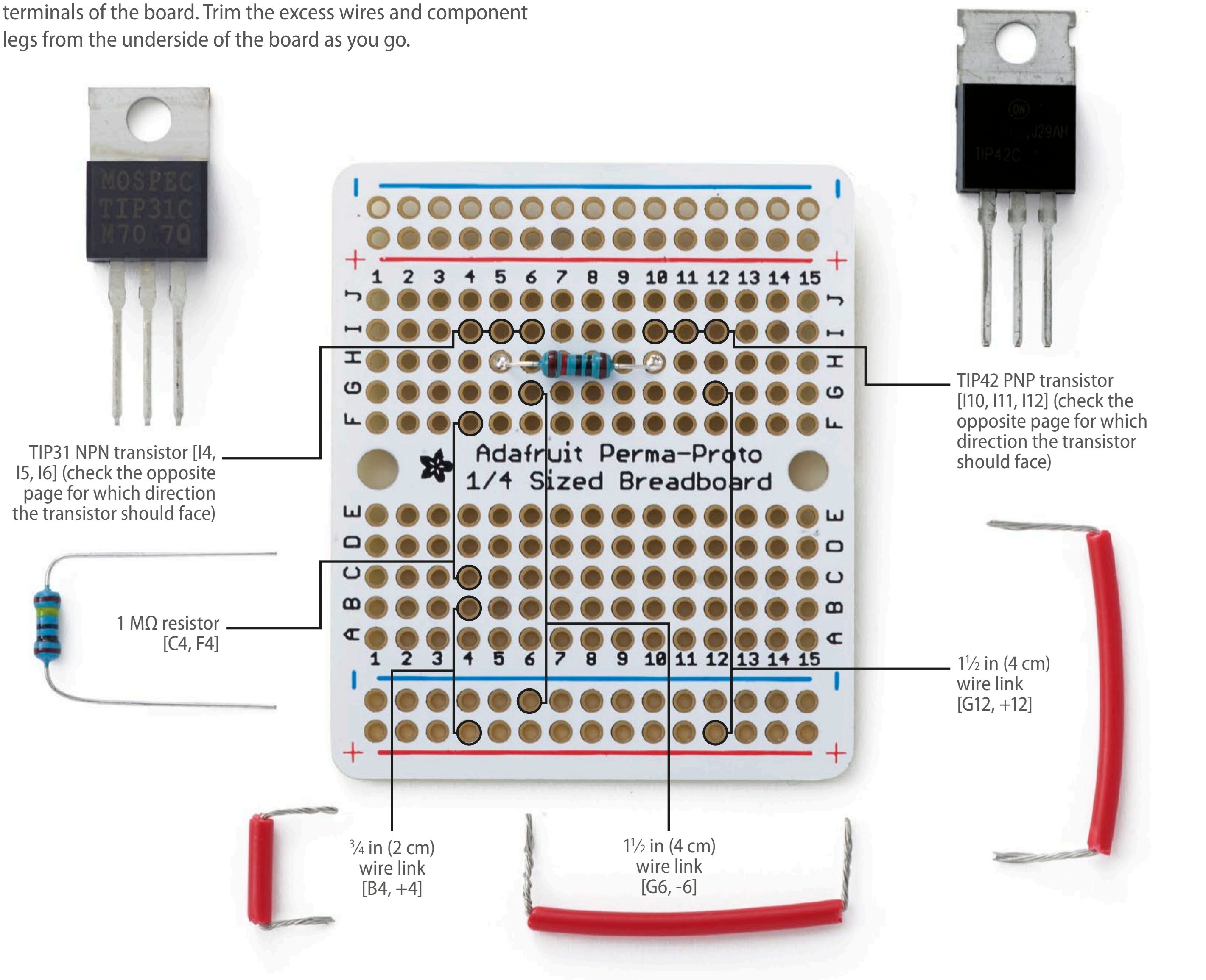


18 Turn over the breadboard, and bend the resistor's legs outward to hold the resistor in place, ready for soldering.

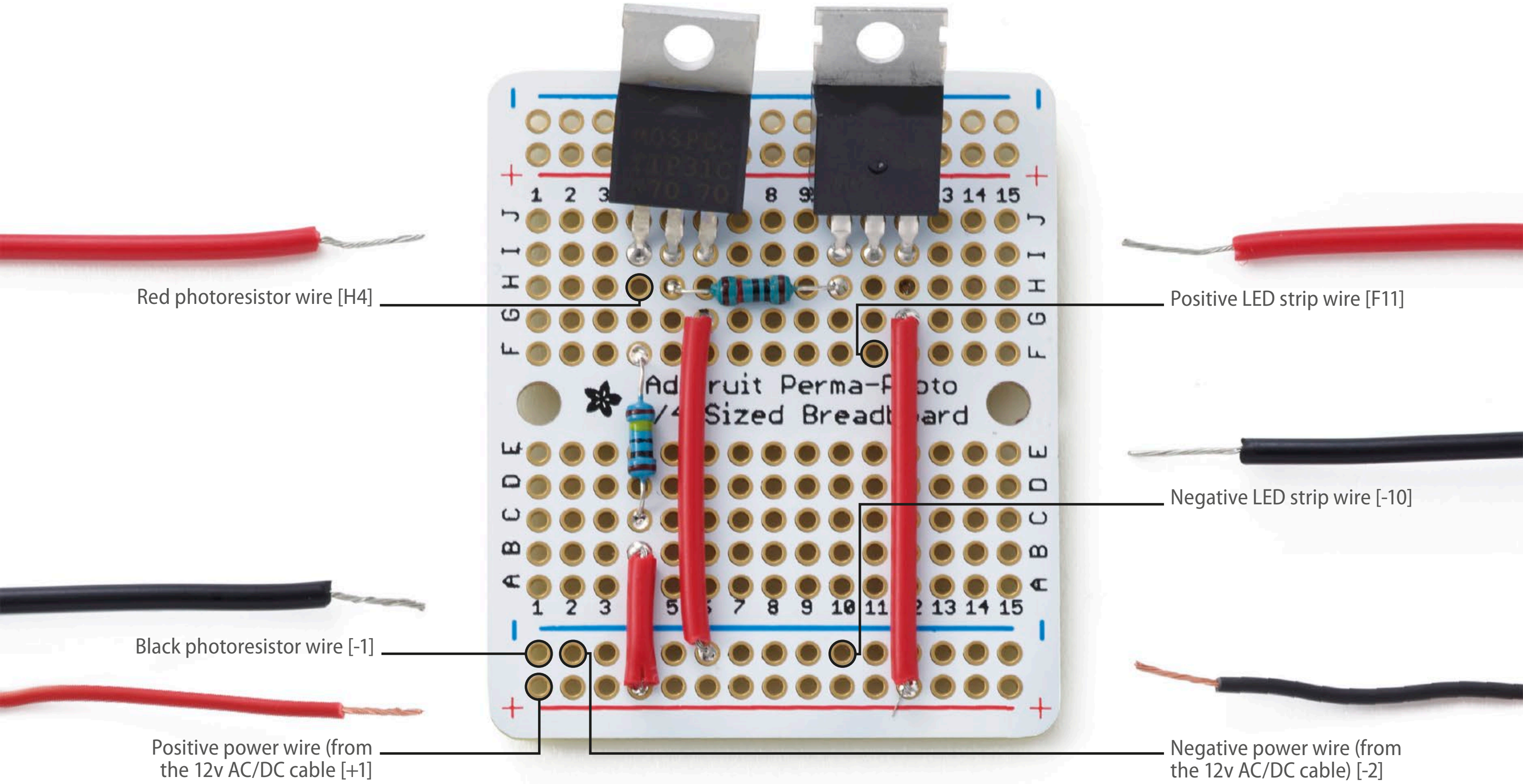


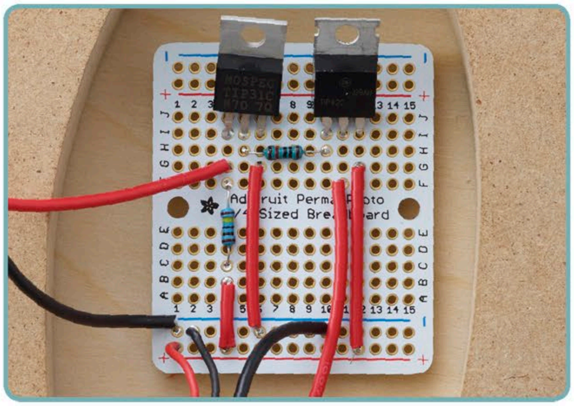
19 Apply a small amount of solder around the resistor legs to secure them to the breadboard. To avoid short circuits, make sure no solder leaks onto the adjacent holes.

20 Following the breadboard map below, solder the second resistor, wire links, and transistors into the terminals of the board. Trim the excess wires and component legs from the underside of the board as you go.

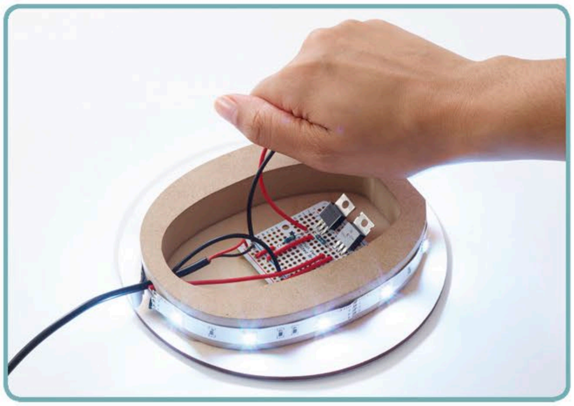


21 Next, take the wooden O and place the breadboard inside it. Feed the end of the power cord through the hole in the wooden O, so that it lies alongside the wires from the LED strip. Following the breadboard map below, solder the photoresistor wires, LED strip wires, and power wires onto the board.

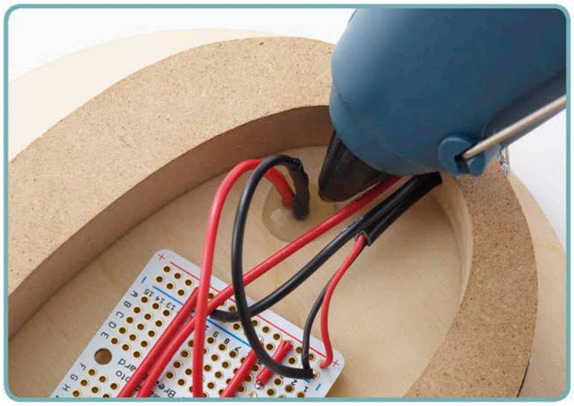


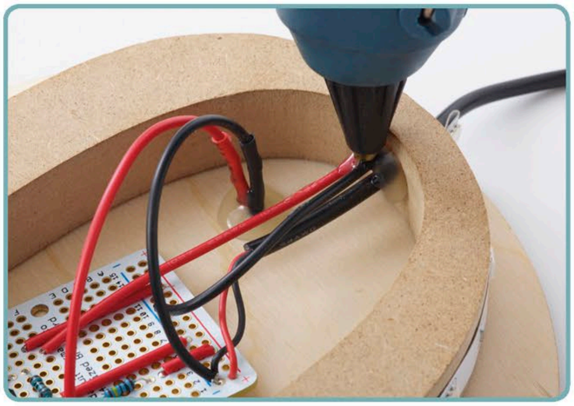


22 Once all of your components are soldered, your board should look like this. Plug the power adapter into a wall socket—the LED strip should not turn on.



23 Now cover the photoresistor with your hand, so that very little light is falling on it. The LED strip should light up—if it doesn't, go back and make sure all of the connections are correct.

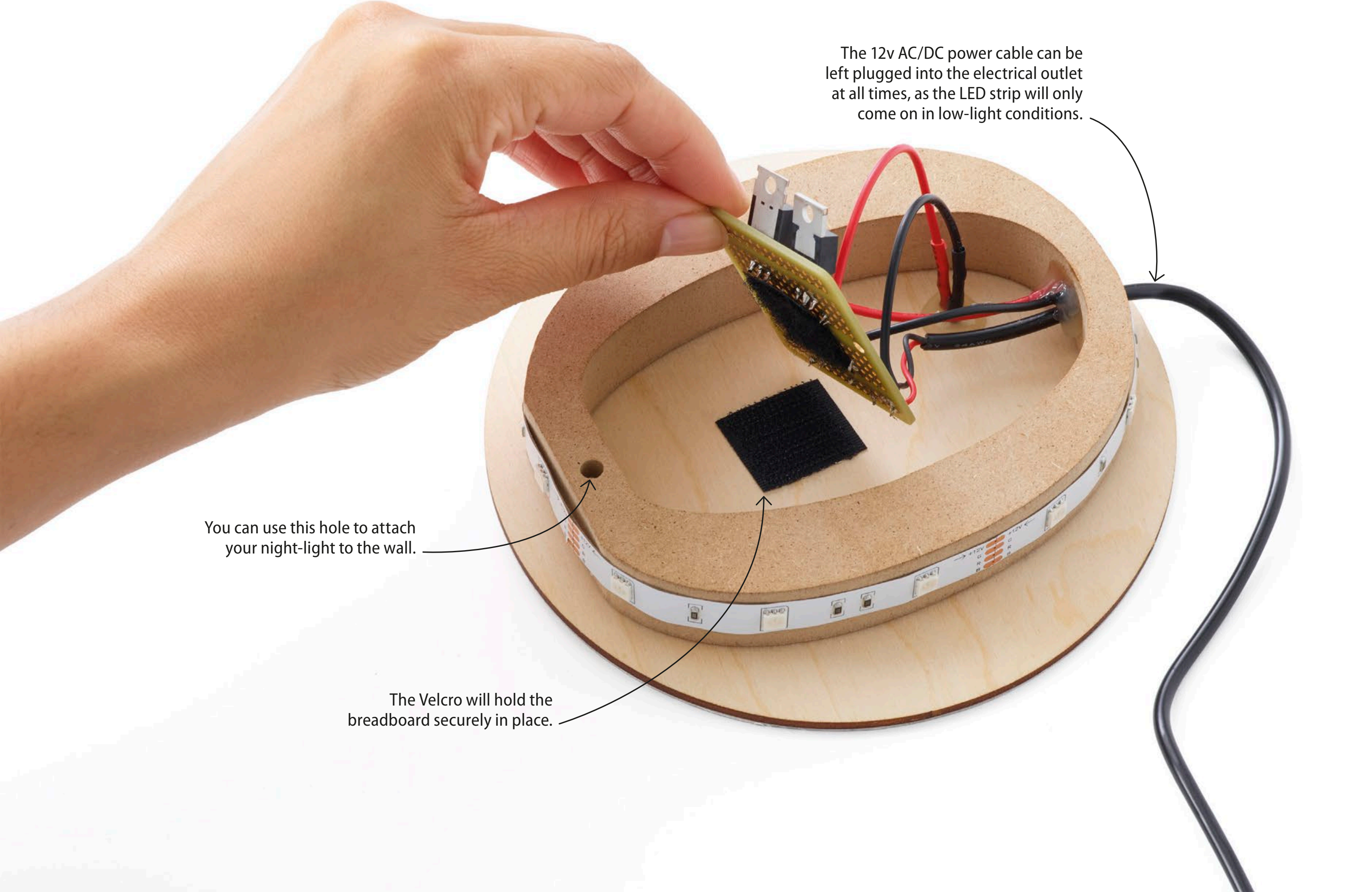




24 With the decal lying against the table, carefully push the photoresistor through the hole in the plywood disk, so that its flat surface is flush with the table. Now secure it in place with hot glue.

25 Apply hot glue to the hole in the end of the wooden O to secure the power cable and the wires from the LED in place.

26 Use a piece of Velcro to secure the circuit onto the plywood disk inside the wooden O. Ask a friend to help you attach your night-light to the wall, then plug in the power adapter and wait until it gets dark!



The 12v AC/DC power cable can be left plugged into the electrical outlet at all times, as the LED strip will only come on in low-light conditions.

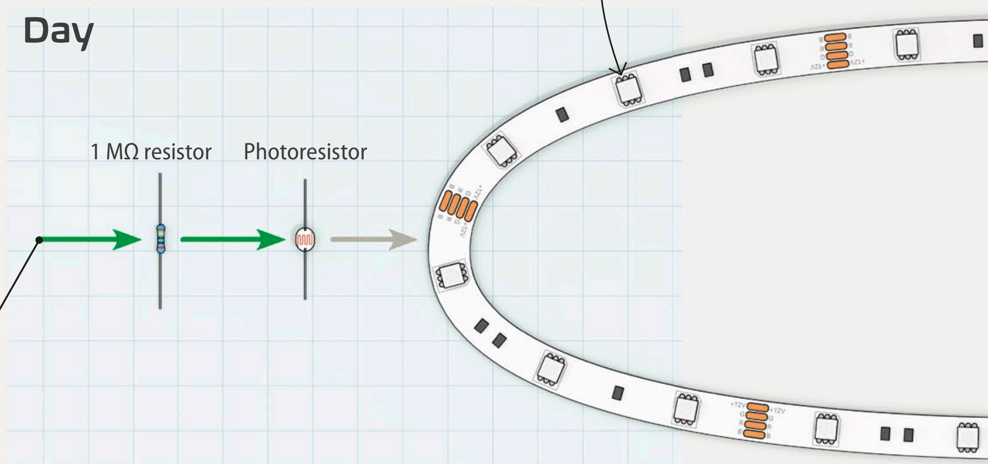
You can use this hole to attach your night-light to the wall.

The Velcro will hold the breadboard securely in place.

How it works

Electric current will always flow through the path of least resistance. The photoresistor opens a path for current during the day, but shuts it at night, causing the current to divert to the other parts of the circuit.

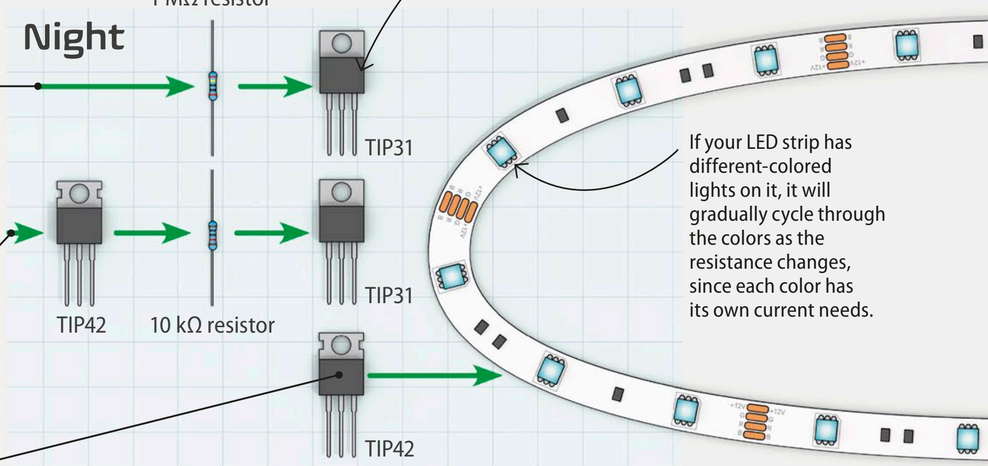
1. During the day, the photoresistor's resistance is low. This allows current from the mains to flow through it, and away from the other parts of the circuit. As it gets darker, the photoresistor's resistance increases, making it harder for current to flow through it. This leads to a chain reaction in the circuit.

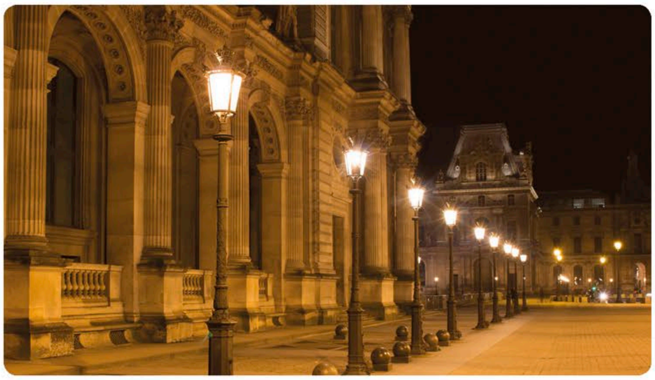


2. Current cannot flow through the photoresistor. Instead, some current flows to the TIP31 transistor. This turns it on, and amplifies the current.

3. Some current then flows to the TIP42 transistor, turning it on, and amplifying the current again.

4. The path is then open, and the current has been amplified enough for it to flow through the LED strip, causing it to light up.





Real-world inventions

Streetlights

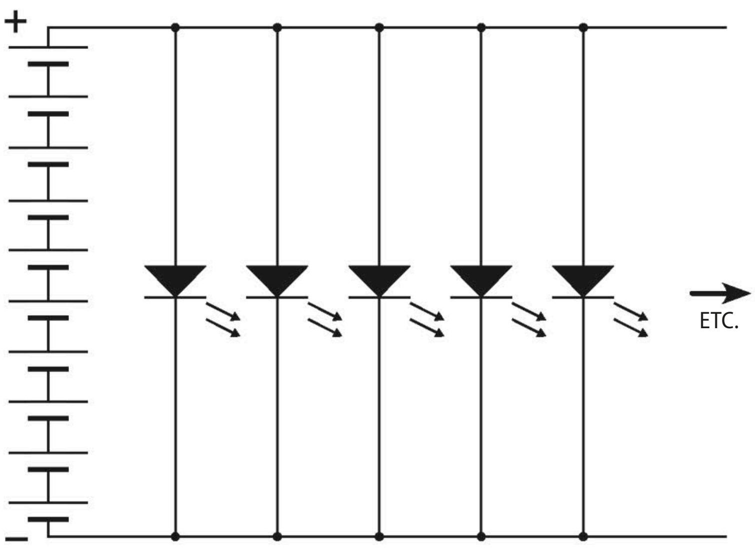
The streetlights alongside roads are fitted with circuits like the one you have made—including the photoresistor. The lights remain off during the day, so they do not waste energy, and only come on as it begins to get dark. This is why they come on at slightly different times every evening.

Circuit diagrams

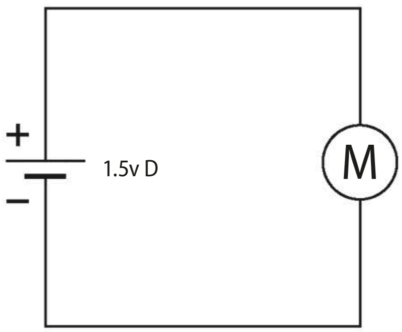
On these pages you will find the circuit diagrams for every project included in the book. These show how the components in each project are joined together by using simple images for each part of the circuit. Refer to p.33 for how circuit diagrams work.

Key

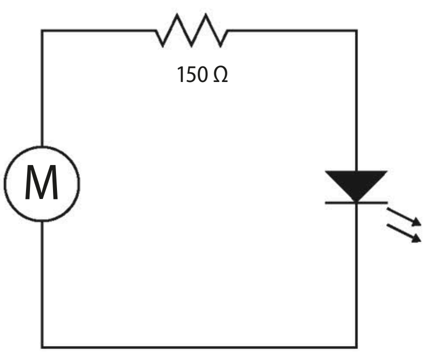
Circuit diagrams use simple images to represent the parts of circuits. Here are the ones we've used, but some people draw certain components—such as resistors—a little differently. These parts are joined together by lines, that symbolize wires in actual circuits. We've also included labels and annotations that give a little more info on the components used.



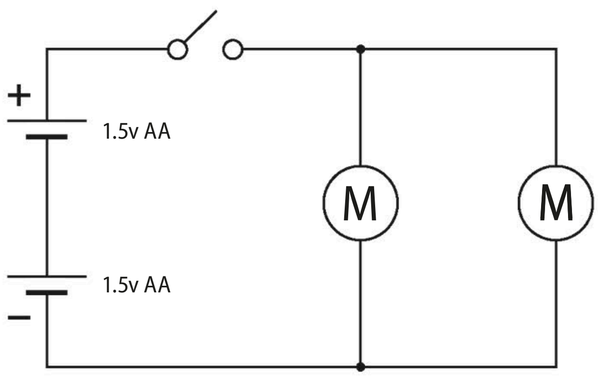
Coin battery
see pp.40–43



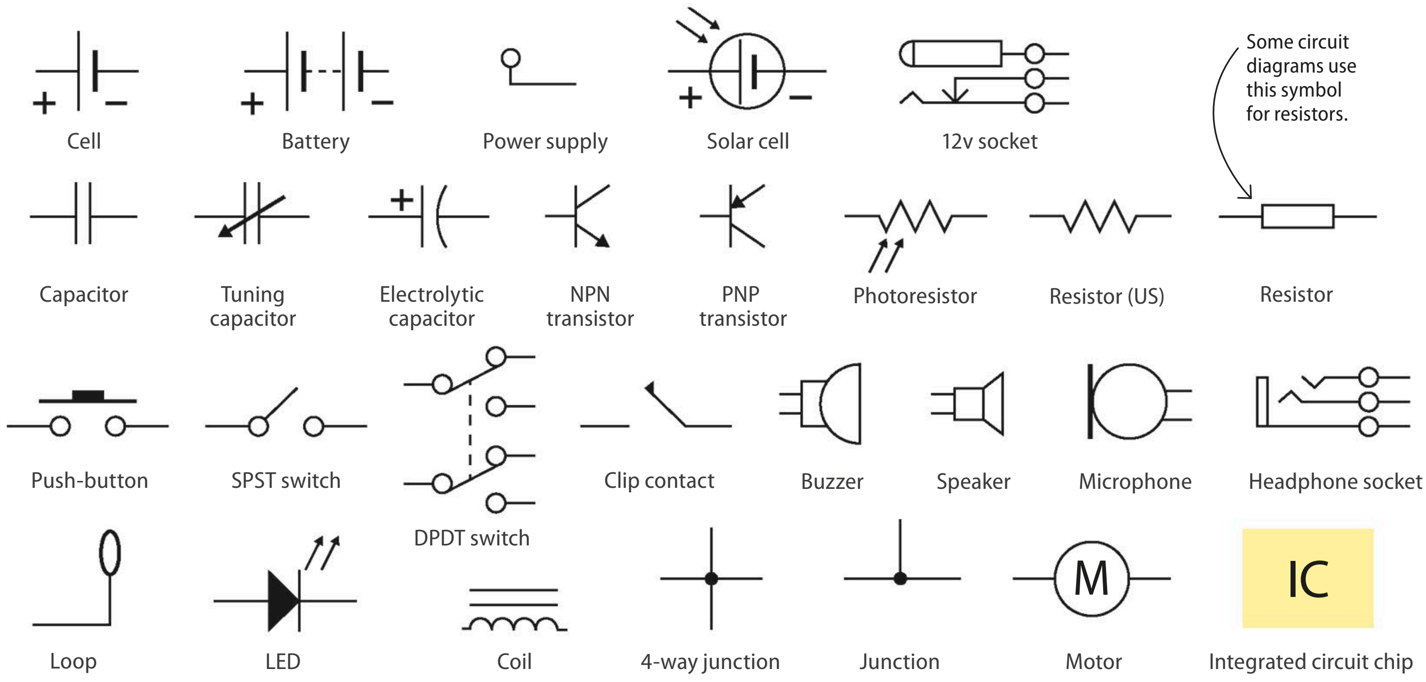
Motor
see pp.44–47

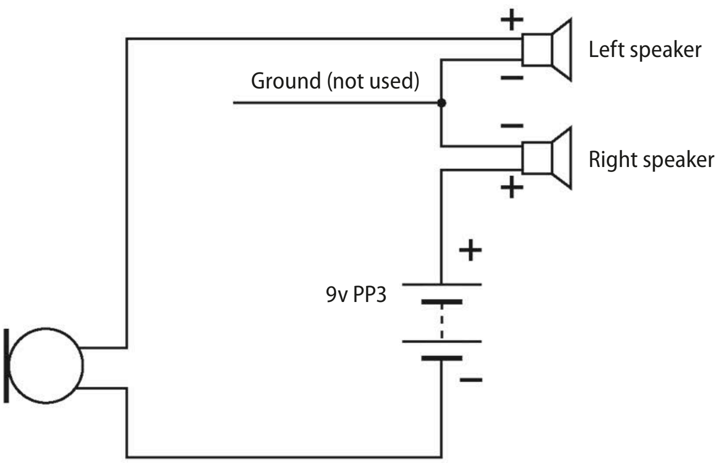


Generator
see pp.48–55



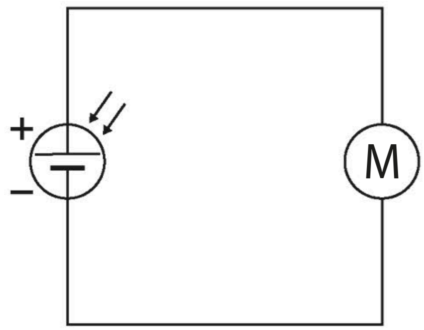
Handheld fan
see pp.56–59





Matchbox microphone

see pp.60–63



Bugbot

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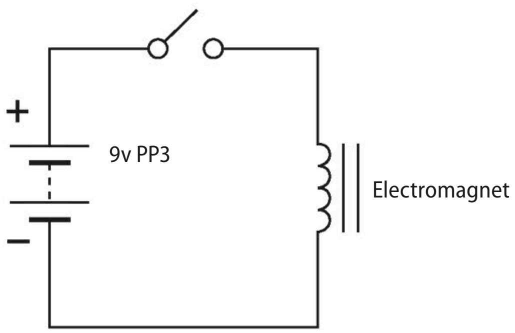

Electromagnetic crane

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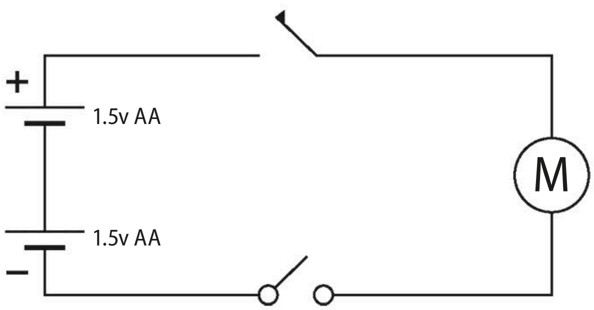

Door alarm

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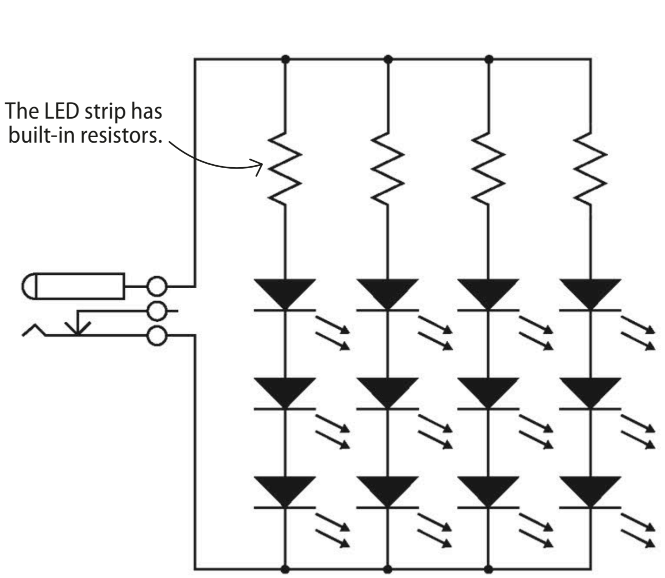

Infinity mirror

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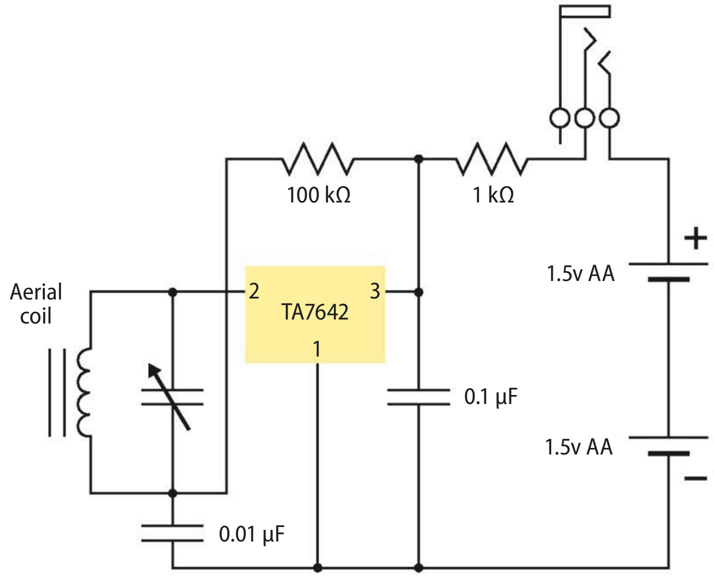

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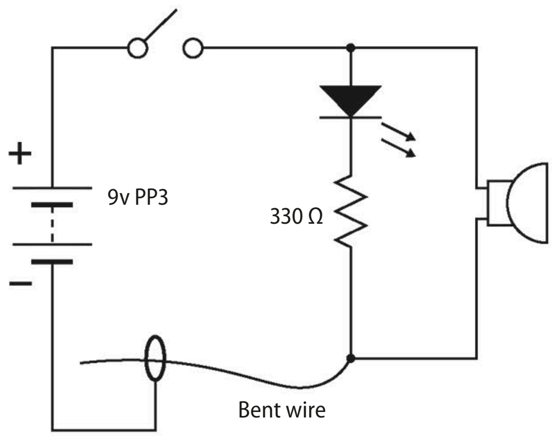

Buzzer game

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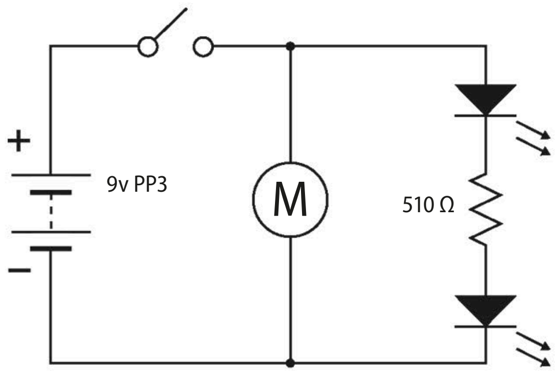

Breadboard car

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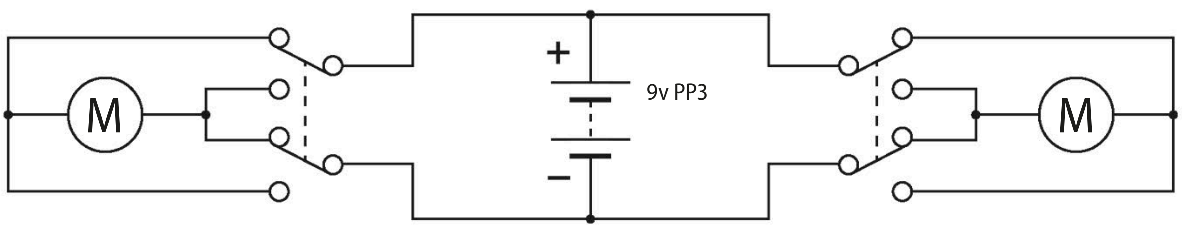

Remote-controlled snake

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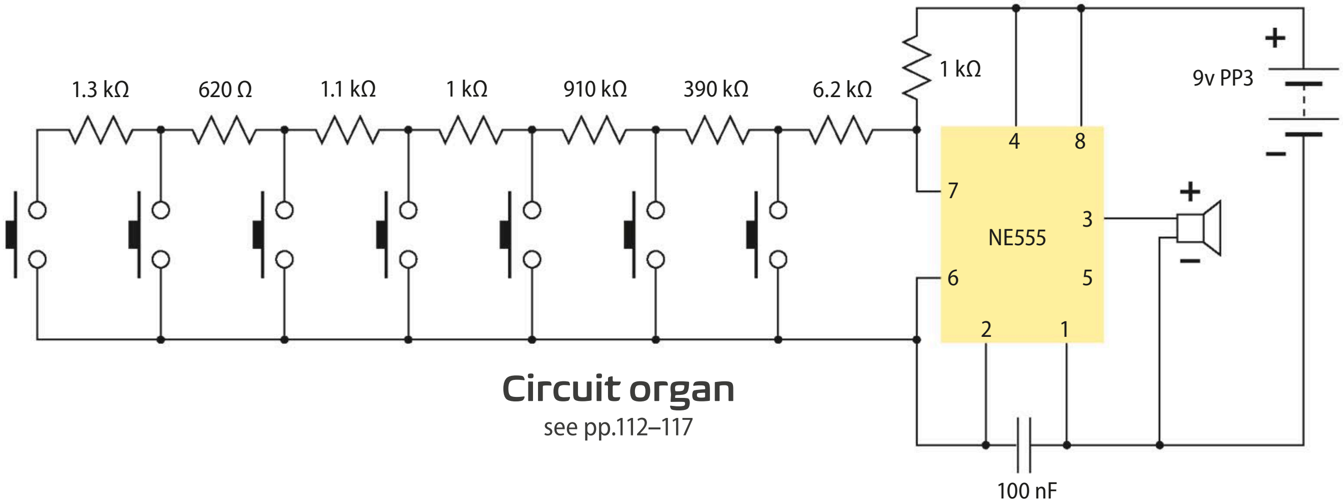

Circuit organ

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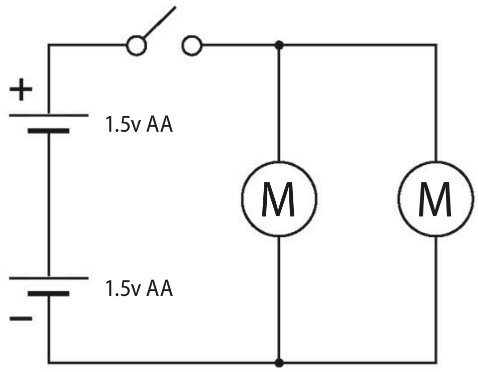

Bottle boat

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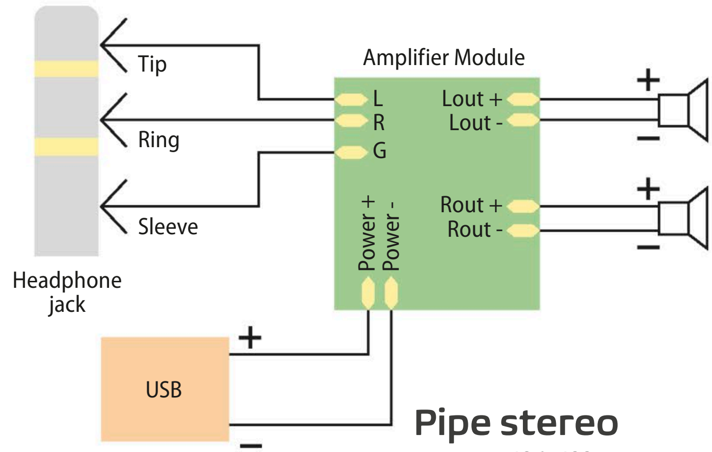
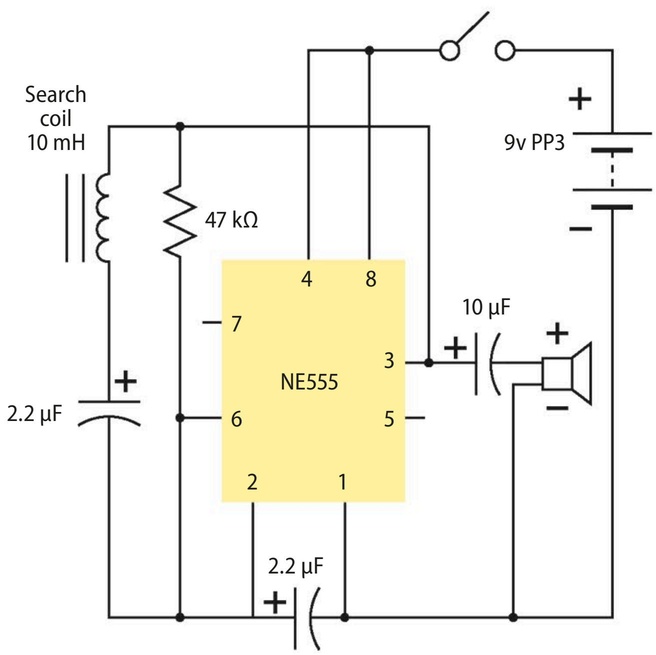


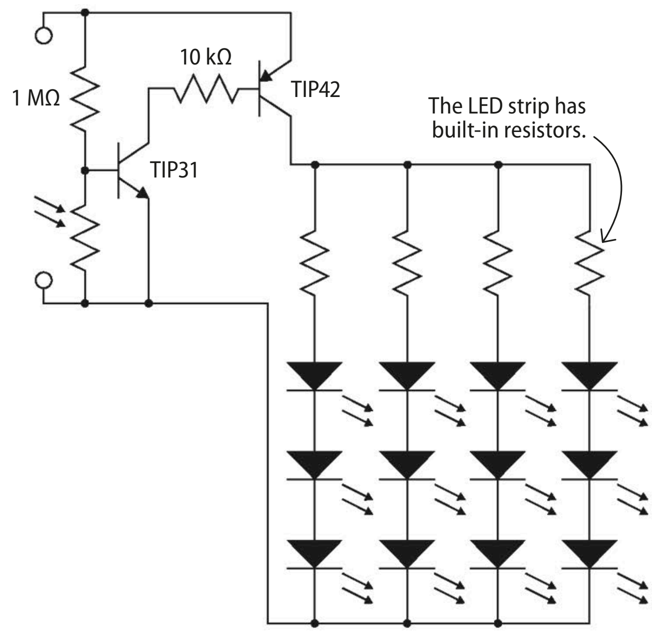
Pipe stereo

see pp.126–133



Ferrous metal sensor

see pp.134–141



Automatic night-light

see pp.142–151

Glossary

Alternating current (AC)
Electric current that repeatedly changes direction.

Ampere (A)
The unit of electric current, often shortened to "amp."

Amplifier
An electronic circuit that increases the amplitude of alternating currents. Amplifiers are normally used to make audio signals powerful enough to drive loudspeakers or headphones.

Amplitude modulation (AM)
"Amplitude" means the height of a wave, and "modulation" means to change something. AM radio stations take a base carrier wave and change its amplitude to carry sounds, which they then broadcast.

Anode
The part of any electrical device from which electrons leave. In a battery, this is the negative terminal.

Audio signal
An alternating current whose back-and-forth movement matches the vibrations carried by sound waves.

Axle
A rigid rod attached to one wheel or fixed between two wheels. The axle may turn with the wheels, or the wheels may turn around it.

Battery
A device that converts chemical energy into electrical energy through a chemical reaction. Batteries produce electrons, which can be used to create an electric current. Also called "cells."

Bradawl
A simple tool with a sharp point and a handle, used for making holes, or pilot holes to guide a drill bit when drilling.

Breadboard
A plastic board with holes and metal tracks that make it easy to assemble electronic circuits without the need for soldering. A perforated board is similar, but requires soldering.

Button switch
A type of switch that completes a circuit when you press it, but which contains a spring, so that the circuit opens again when you release it.

Capacitance
A measure of how much electric charge a capacitor can store. The unit of capacitance is the farad.

Capacitor
An electronic component, used in most electronic circuits, that stores electric charge. Most capacitors contain small metal plates separated by a small gap, coated in ceramic. *See also:* electrolytic capacitor.

Cathode
The part of any electrical device through which electrons enter. In a battery, this is the positive terminal.

Compact disc (CD)
A circle of plastic with aluminium on one side that carries music encoded digitally on a long spiral track.

Circuit
A path made of conductors—typically wires and electronic components—around which an electric current can flow.

Circuit diagram
A drawing that uses simple symbols to represent the wires and components in a circuit.

Coil
A long wire wound around many times.

Commutator
The part of an electric motor that transfers electric current from the motor's coils to its terminals.

Component
A small device used to control current or have some effect in an electric circuit. Examples include resistors, capacitors, and transistors.

Conductor
Any material that allows electric current to flow through it. Metals are very good conductors, while plastics and wood are not.

Conventional current
The name for electric current that involves the flow of positive electric charge. In electric circuits, it is negatively charged electrons that are moving, so the electron flow is opposite to conventional current.

Crocodile clip
A spring-loaded metal clip with jaws that hold on firmly to other objects. With wires soldered to them, they are often used to connect components in a circuit.

Current
See: electric current.

Cutting mat
A dense plastic mat that protects surfaces from sharp blades when cutting.

Digital
Anything represented by numbers (digits), specifically 0s and 1s. Inside computers, smartphones, and other digital devices, information is represented digitally.

Digital audio broadcasting (DAB)
A way of broadcasting that relies on computers to create the signals sent by the broadcaster.

Diode
An electronic component that allows electric current to flow through it in one direction only. A light-emitting diode (LED) produces light when current flows through it.

Direct current (DC)
Electric current that flows in one direction only.

Drill
A tool with a powerful motor that is used to make holes in materials such as wood, metal, and plastic.

Drill bit
A straight, sharp piece of metal that fits inside a drill to make holes in materials. Drill bits come in different sizes and for use with different materials.

Earphones
Small loudspeakers that fit inside a person's ears.

Electric charge
A basic property of electrons, protons, and other subatomic particles. Protons carry positive electric charge, while electrons carry negative charge. Charged particles attract or repel, depending on which kind of charge they carry.

Electric current
Any movement of electric charge. In electric circuits, it is the negatively charged electrons that move.

Electrical energy
Energy possessed by electrically charged particles, wherever there is a buildup of electric charge, or if charged particles are moving (in an electric current). In electric circuits, electrical energy can be transformed into other forms of energy, such as light or sound energy.

Electricity
A form of energy resulting from charged particles. Also used to mean the supply of electric current in a circuit.

Electrolyte
A substance that can conduct electric current. There is an electrolyte inside a battery.

Electrolytic capacitor
A capacitor that can store large amounts of electricity.

Electromagnet
A coil of wire wrapped around a piece of iron. When electric current flows through it, it produces a strong magnetic field.

Electromagnetism
The study of the link between electricity and magnetism.

Electromotive force (emf)
Any force that makes particles with electric charge move. In an electric circuit, a battery, solar cell, or a generator provides the emf, which makes electrons move around the circuit.

Electron
A tiny particle, several of which are found in each atom of matter. Electrons carry negative electric charge. They can break free from their atoms, and are then free to move around.

Enamel
In electronics, "enameled wire" is copper wire coated with a red plastic that insulates the wire.

Energy
The ability to make things happen. Many different things have energy, including sound, light, and electricity, and energy can be transferred between them, such as when electrical energy produces sound energy in a loudspeaker.

Farad (F)
The unit of capacitance.

Ferrite rod
A solid cylinder made of a material (ferrite) that is rich in iron. Ferrite rods with coils of wire wrapped around them are used in some circuits, particularly amplitude-modulation radios.

Ferrous metal
Any metal or alloy (mixture of metals) that contains the element iron. The most common ferrous metal is steel.

Frequency
The rate at which something repeats, measured in units called hertz (Hz).

Frequency modulation (FM)
"Frequency" means the rate at which something repeats, and "modulation" means to change something. FM radio stations take a base carrier wave and change its frequency to carry sounds, which they then broadcast.

Galvanization
A process in which metallic items are coated with the element zinc. The zinc coating prevents the metal beneath from rusting.

Generator
A device with magnets and coils arranged around a shaft; an electromotive force is produced when the shaft is turned.

Ground
The part of an electric circuit with the lowest voltage. In battery-powered circuits, it is the battery's negative terminal.

Heat-shrink tubing
A plastic tube that shrinks when heat is applied to it. In electronics, it is used to coat metal parts with a layer that will not conduct electricity, to prevent short circuits.

Hot glue gun
A handheld tool that has a heating element. The heat melts a solid glue stick, and the molten glue exits at the front of the tool.

Hydroelectricity
Any electricity whose energy comes from moving water.

Insulation
The coating on a wire, usually plastic. Insulation is made of an insulator—any material that does not allow electric current to pass through it.

Insulator
A material that does not allow electric current to flow through it. Plastic is a good insulator, and is used as the coating of wires so that current can only flow through the metal inside.

Integrated circuit (IC)
A complicated electric circuit whose components are embedded within a single piece of material, normally the element silicon. The silicon is housed in a plastic package with metal legs that allow it to be connected to a larger circuit.

Glossary

Iron
A very common metal. Steel is made of iron mixed with small amounts of other elements.

Jib
The part of a crane that holds the object to be lifted. Most jibs have a hook at the end.

Jumper wires
Small pieces of wire used to connect different parts of an electric circuit, especially circuits made on a breadboard.

Kinetic energy
The energy of anything that is moving.

LED strip
A plastic strip containing a row of light-emitting diodes.

Light-emitting diode (LED)
An electronic component that produces light when electric current flows through it. As with all diodes, current can only flow through it in one direction.

Loudspeaker
A device that turns electrical energy into sound energy.

Magnet
An object that produces a magnetic field. Permanent magnets have a magnetic field all the time, while the coil of an electromagnet has a magnetic field only when electric current flows through it.

Magnetic field
The area around a magnet or electromagnet, in which other magnets will be attracted or repelled.

Magnetic pole
One of the two opposite ends of a magnet, where the magnetic field is strongest. The poles are called north (N) and south (S).

Magnetism
Describes anything to do with magnets, but particularly the forces between any two magnets.

Mains electricity
Powerful electricity supplied to homes and businesses.

Metal
A solid material that is a good conductor of electricity.

Motor
A device that contains magnets and coils arranged around a shaft. When electric current flows through the coils, the shaft turns.

Multimeter
A tool that is used to measure voltages and electric currents in electric circuits, or to test electronic components.

Negative
Used to describe the kind of electric charge carried by electrons, but it also refers to any value less than zero.

Ohm (Ω)
The unit of resistance.

Oscillating
Describes something that moves back and forth.

Parallel circuit
An electric circuit or part of a circuit that splits into two or more branches. Each of the electrons moving through the circuit can only flow along one branch, so the electric current splits, too.

Photoresistor
An electronic component whose resistance changes depending on how much light is falling on it.

Piezo sounder
An electronic component that has a membrane inside that oscillates rapidly when electric current flows through it, so that it produces sound.

Pitch
How high or low a sound is. Pitch depends on the frequency of the oscillation of the object creating the sound.

Pliers
A tool with two metal arms hinged together, used for gripping small objects, bending wires, or squashing things together with great force.

Polarity
The property of having poles or being polar. Some components have positive and negative poles that affect how they behave in circuits.

Positive
Used to describe the kind of electric charge carried by protons, but it also refers to any value greater than zero.

Potentiometer
Another name for a variable resistor, which is a kind of electronic component whose resistance can be changed, normally by turning a knob. A potentiometer is used as the volume control of a radio.

Power
The amount of energy a device uses or produces every second. It is measured in units called watts (W).

Propeller
An object with curved blades that pushes against air or water when it spins.

Pulley
A device that has a grooved wheel that is free to spin. A rope or chain fits into the groove, and transmits forces between pulleys in different parts of a machine.

Radio
An electronic device that receives signals broadcast using radio waves. Radios decode the audio signals carried by the radio waves, so we can hear sounds broadcast from far away.

Radio wave
An invisible wave produced by a metal pole called an antenna, that travels extremely quickly, and can be used to carry information, such as music.

Remote control
A device with switches and other controls on it that can be used to control machines, toys, or electric circuits at a distance.

Resistance
A measure of how well a material or a component allows electric current to flow. The higher the resistance, the less current will flow.

Resistor
An electronic component with a fixed resistance. Resistors are used to control how much electric current flows in different parts of an electric circuit.

Series circuit
An electric circuit in which all the wires and components are connected one after the other, with no branches.

Short circuit
A path through which electric current can flow between two parts of a circuit that should not be directly connected. It is a fault in a circuit, and can make a circuit fail.

Solar panel
A device that produces an electromotive force when light shines on it.

Solder
An alloy (mixture of metals) with a melting point low enough that it melts when heated by the tip of a soldering iron. It is used to form solid joints that can conduct electricity.

Soldering iron
A tool with a tip that becomes hot enough to melt solder, used in connecting parts of electric circuits.

Solid-core wire
Wire coated with insulation, that has a single metal wire inside. The metal is strong enough to be pushed into breadboards, but thin enough to be cut easily.

Solution
A liquid with other compounds dissolved in it.

Sound wave
A wave produced by a vibrating object, which travels through the air as disturbances in air pressure. Loudspeakers, earphones, and piezo sounders produce sound waves.

Spring clamp
A tool for holding things firmly—particularly useful when sawing or drilling.

Steel
A material made of iron with small amounts of other elements mixed in.

Stereo
Describes an audio signal or an audio device with two "channels"—one for the right and one for the left.

Stranded wire
Wire coated with insulation, that has several thin metal strands inside. Stranded wire is easier to work with than a solid-core wire, but it is more difficult to plug into a breadboard.

Switch
An electronic component that allows electric current to flow, or stops it from flowing, through wires connected to its terminals.

Terminal
Any metal part of a battery or an electronic component that allows electric current to flow.

Third-hand tool
A useful tool with crocodile clips that can hold wires and electronic components steady while you solder them.

Torque
A turning force. An electric motor produces a torque that can turn a propeller or a drill bit.

Transistor
An electronic component that acts as an electronic switch, or an amplifier of current.

Universal Serial Bus (USB)
A technology used to connect, carry information between, and power electronic devices.

Variable capacitor
An electronic component—a type of capacitor whose capacitance can be varied, typically by turning a knob.

Vibration
A rapid back-and-forth motion used to describe the motion of solid objects. Vibrating objects produce sound waves.

Volt (V)
The unit of electromotive force (emf) or voltage.

Voltage
A measure of the electromotive force (emf) produced by a battery or generator, but also the amount of emf at any point of a circuit. Voltage is measured in volts (V).

Watt (W)
The unit of power.

Wire
A flexible piece of thin metal, normally copper, used to connect different parts of an electric circuit. Most wires are coated in plastic insulation.

Wire cutters
Sharp-bladed tools like scissors but strong enough to cut through wires.

Wireless
Describes any electronic device that is connected to another device, but not by wires. A wireless network is a group of computers connected wirelessly, using radio waves.

Wire strippers
A tool used to strip the insulation off the ends of wires, to reveal the metal inside, making it possible to connect them to components or other wires when building an electric circuit.

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