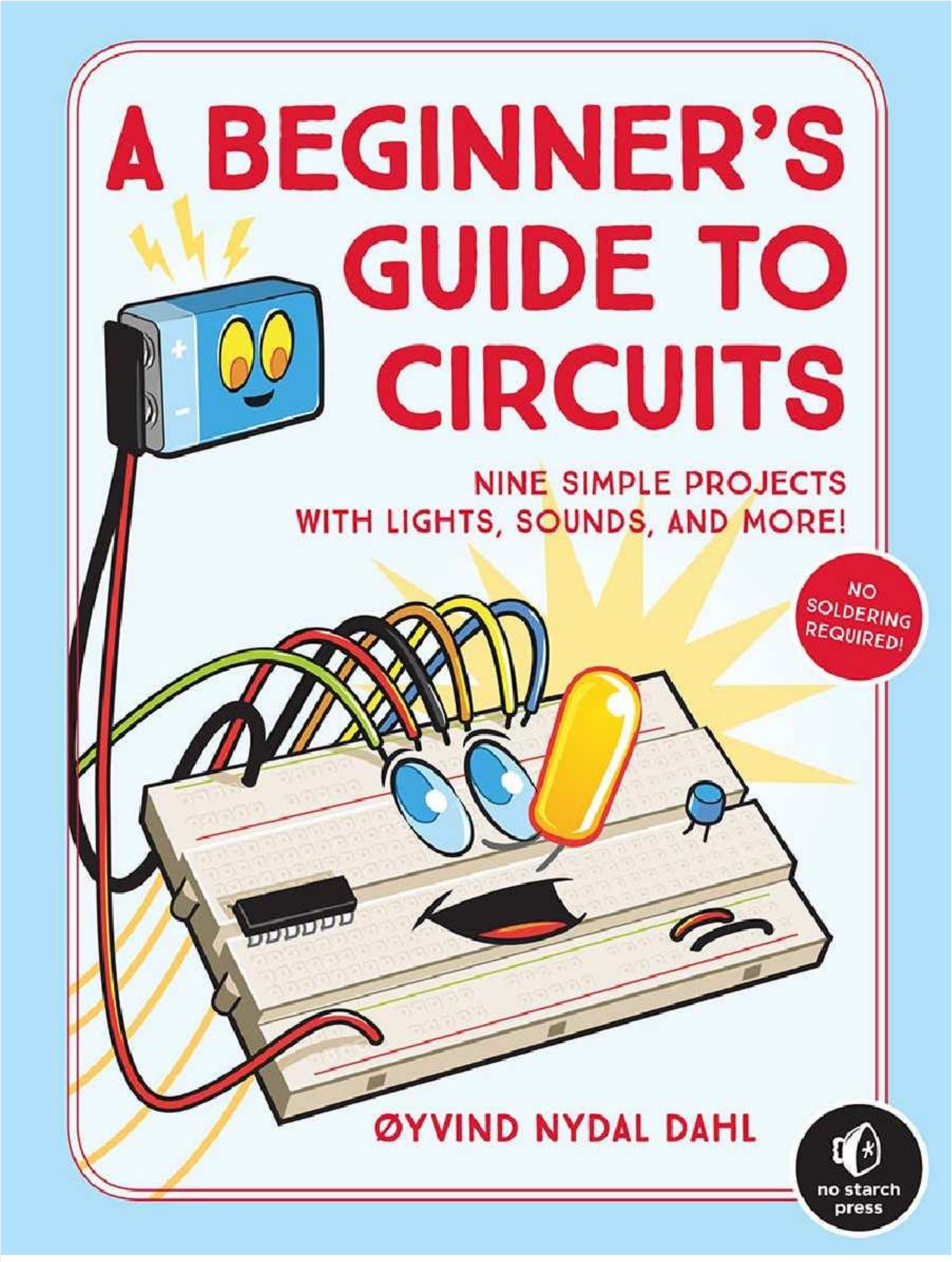
A BEGINNER'S GUIDE TO CIRCUITS
NINE SIMPLE PROJECTS WITH LIGHTS, SOUNDS, AND MORE!
NO SOLDERING REQUIRED!
ØYVIND NYDAL DAHL
no starch press

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INTRODUCTION

This book will help you improve your electronics skills. I'll teach you how to interpret circuit diagrams and use breadboards. Then I'll show you, step-by-step, how to build a simple circuit on a breadboard. After that, you're on your own: you'll rely on parts lists and circuit diagrams to build your circuits. Building circuits from diagrams is an essential skill for anyone interested in electronics, from beginners to experts.

THE CIRCUITS

The circuits become more and more difficult to build as you progress through the book. Here's a brief description of each circuit project:

- **Project 1: The Steady-Hand Game** With this super-simple circuit, you'll create an *Operation*-style game where you need a steady hand to win.
- **Project 2: The Touch-Enabled Light** Using a touchpad, you'll build a touch-enabled light switch to turn on a light with your finger.
- **Project 3: The Cookie Jar Alarm** Keep your cookies safe with this cookie jar alarm, which will scare any cookie thieves away with a buzzing noise.
- **Project 4: The Night-Light** Here you'll build a light that turns on in the dark to help you see things at night.
- **Project 5: The Blinking LED** In this project, you'll learn some of the basics of digital electronics and use an integrated circuit to blink an LED.
- **Project 6: The Railroad Crossing Light** Add to your model train set with the railroad crossing light, a classic circuit that everyone should build at some point.
- **Project 7: The Party Lights** This string of blinking lights is a perfect project to prepare for an upcoming party.
- **Project 8: The Digital Piano** Build your own musical instrument from scratch

and entertain your friends and family!

- **Project 9: The LED Marquee** In this final circuit, you'll use your new skills to create an awesome LED light show.

You can find resources for the circuits through the book's website at *https://nostarch.com/circuits/*.

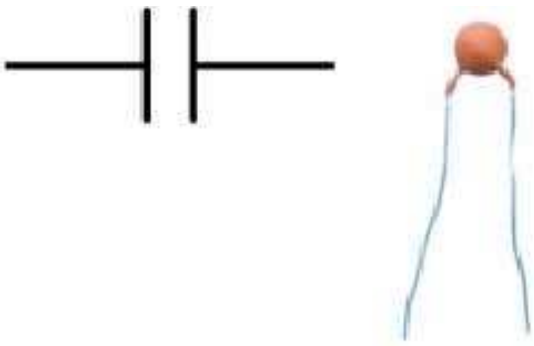
THE MATERIALS

All of the materials you'll need to build the circuits in this book are inexpensive and easy to find. Here's a list of all the electronic components you'll need.

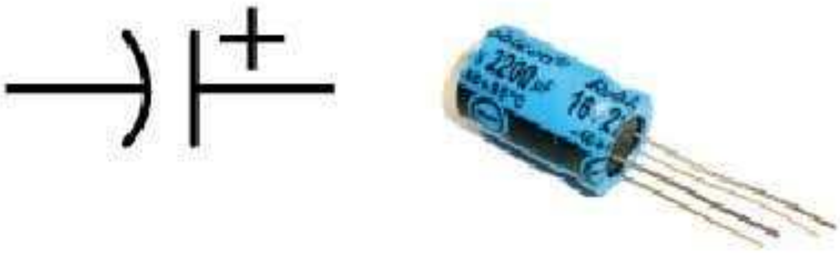
> **NOTE**
>
> *The part numbers shown here are for Jameco Electronics* (https://www.jameco.com/). *These components should be available from any electronics supply store.*

#	JAMECO PART NUMBER	VALUE	DESCRIPTION
1	#198731	9 V battery	Standard 9 V battery
1	#109154	Battery clip	Component that connects the battery to the breadboard
1	#20601	Breadboard	Breadboard with around 400 holes
20	#2237044	Jumper wires	Pack of at least 20 breadboard jumper wires

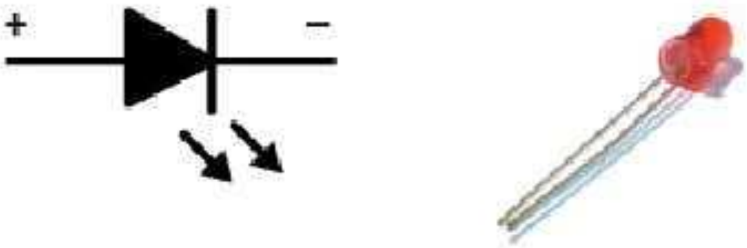
1	Included in #2217511	100 Ω	Standard resistor
4	Included in #2217511	1 kΩ	Standard resistors
2	Included in #2217511	10 kΩ	Standard resistors
1	Included in #2217511	100 kΩ	Standard resistor
2	Included in #2217511	470 Ω	Standard resistors
2	Included in #2217511	47 kΩ	Standard resistors
1	#151116	0.1 µF	Nonpolarized capacitor
1	#31000	4.7 µF	Polarized capacitor
2	#94212	10 µF	Polarized capacitors
1	#158394	100 µF	Polarized capacitor
2	#254801	BC547	Any general-purpose NPN transistor will work



Capacitor, polarized

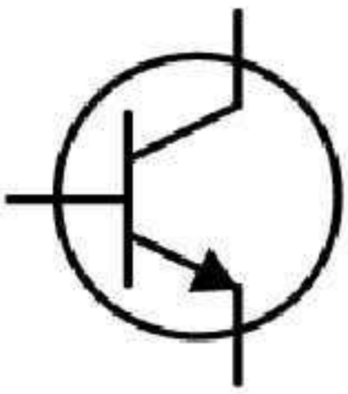


Light-emitting diode (LED)

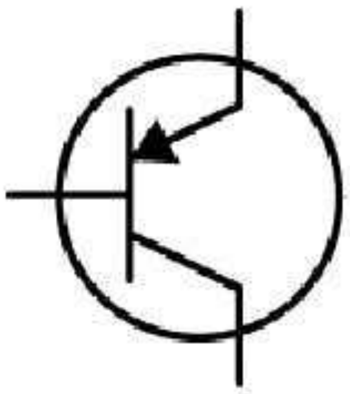


Light-dependent resistor (LDR)

Transistor

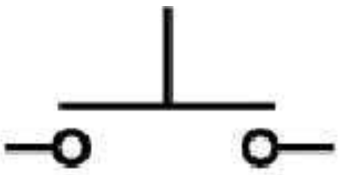


NPN

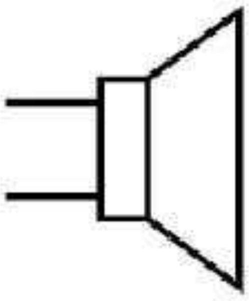


PNP

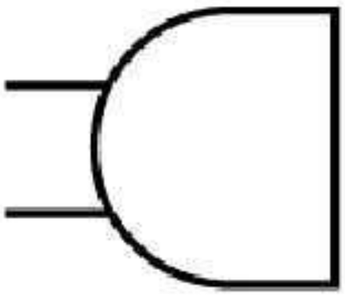
Pushbutton (switch)



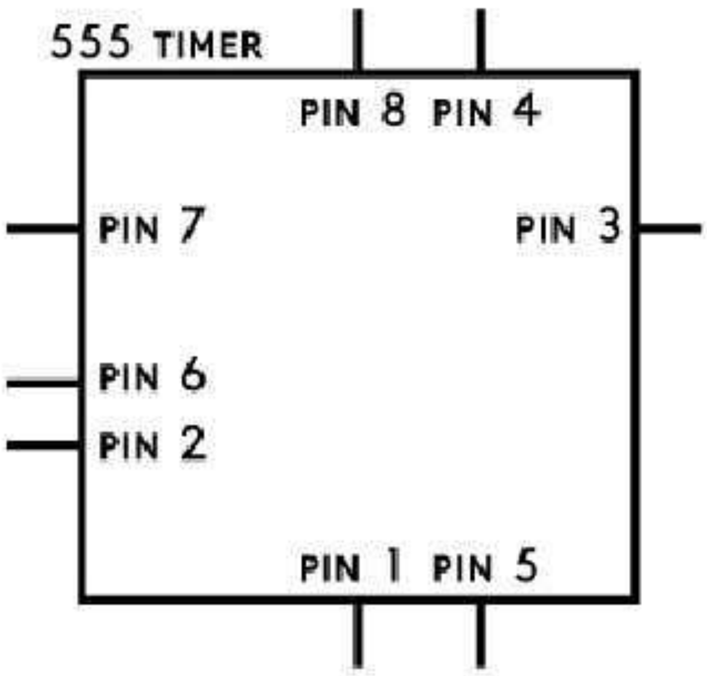
Speaker



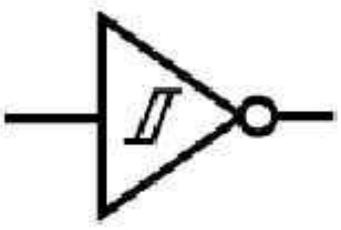
Buzzer



Integrated circuit



Note that some integrated circuits, such as the following Schmitt trigger inverter, use a symbol that represents their function instead of the box symbol.



Building Circuits on a Breadboard

A *breadboard* is a really simple tool for building a circuit. Because you don't have to solder—you just plug in the components—you can easily reuse components if you want to build something else later.

Most breadboards have two areas for components and two areas for power supplies. I've labeled these four areas in Figure 2. The five holes of each row in a component area —labeled with a numeral—are connected by metal strips inside the board. The rows in the left component area are not connected to the rows in the right component area.

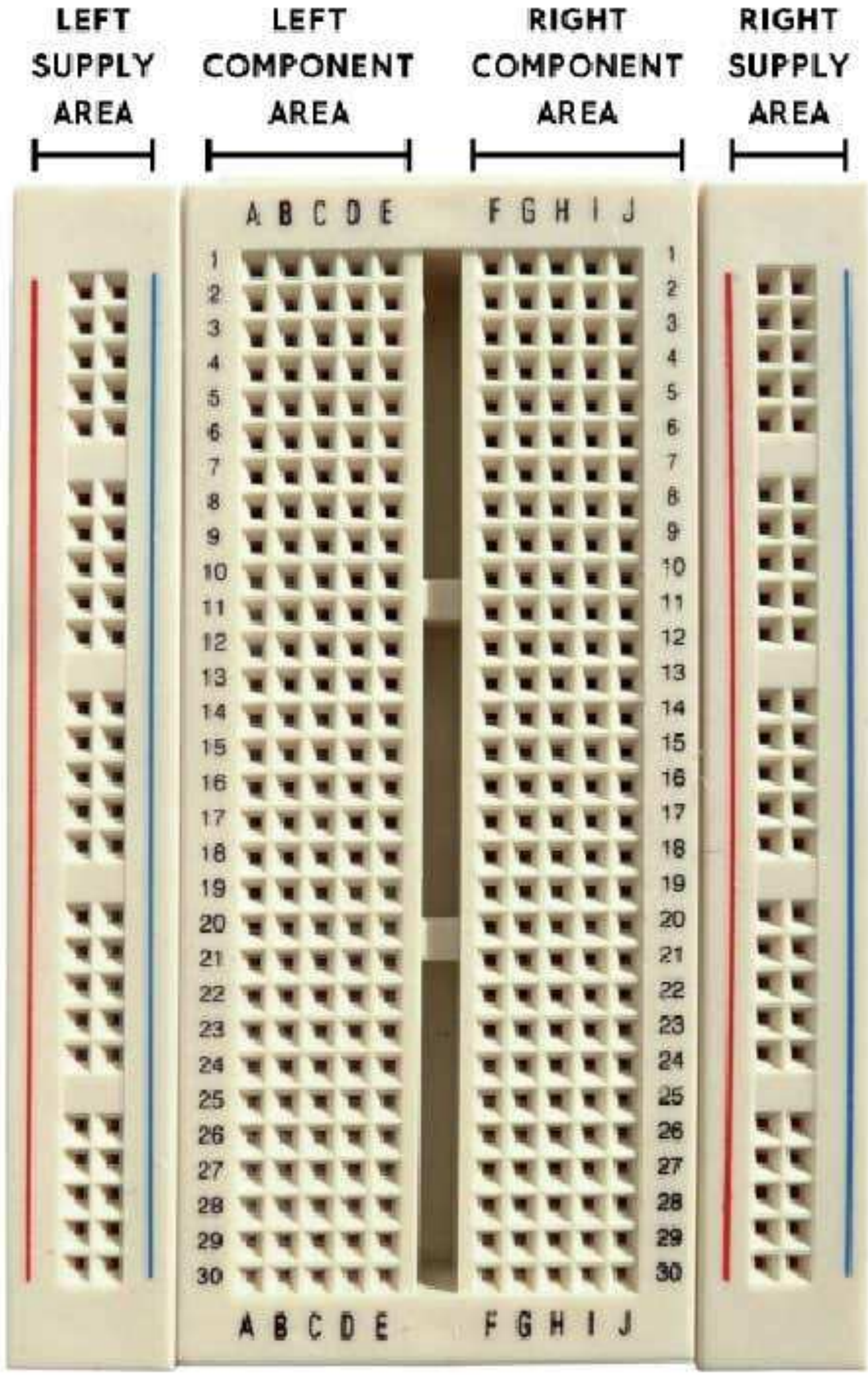


FIGURE 2 A typical breadboard with labeled areas

The wires of a component are called its *pins*, *legs*, or *leads*. To make a connection between two components, you plug their pins into the same row in one of the component areas. If you can't connect them on the same row, you can use a jumper wire in order to make the connection from one row to another.

In Figure 3, the lower pin of the resistor and the upper pin of the LED are connected to

YOU'RE READY TO BUILD THE NINE CIRCUITS!

Now that you've built your first breadboard circuit, you're almost ready to move on to this book's nine circuit projects. First, though, I recommend that you play around a little with the circuit you built in this chapter. Try to really understand why those connections make the circuit work. Understanding this is crucial to building the rest of the circuits in this book. A good test is to see if you can build the circuit again in the *left-hand* component and power supply areas, just by looking at the circuit diagram.

For all the circuits in this book, you'll need a breadboard, a bunch of breadboard jumper wires, a battery, and a battery clip. But for simplicity's sake, you won't see these components in the parts list.

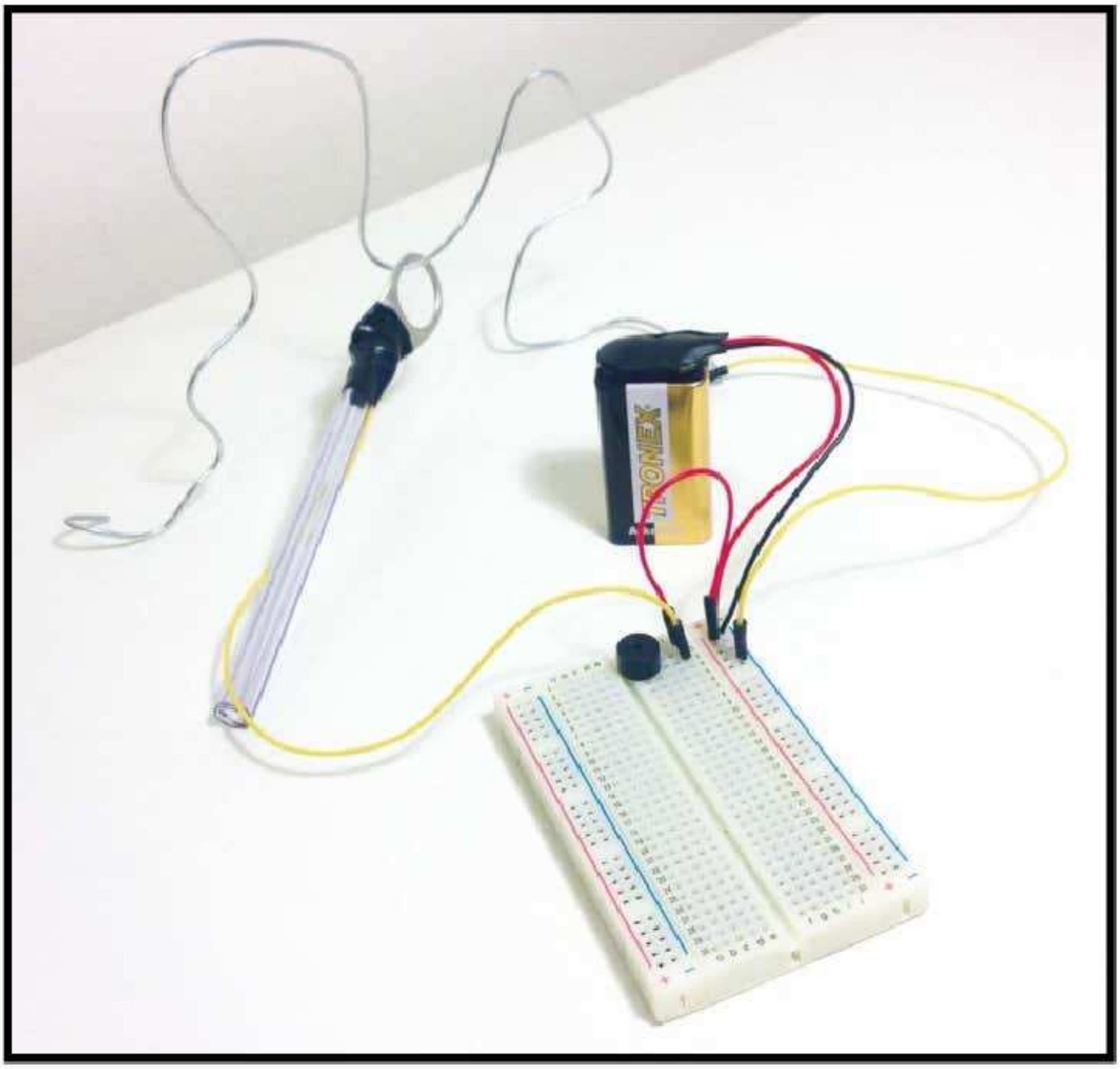
The circuits are sorted by difficulty, starting from the easiest. The challenge is to figure out how to connect each of the circuits on the breadboard. Some of the later circuits might be challenging if you don't have any previous experience with circuits, but the trick is to not give up.

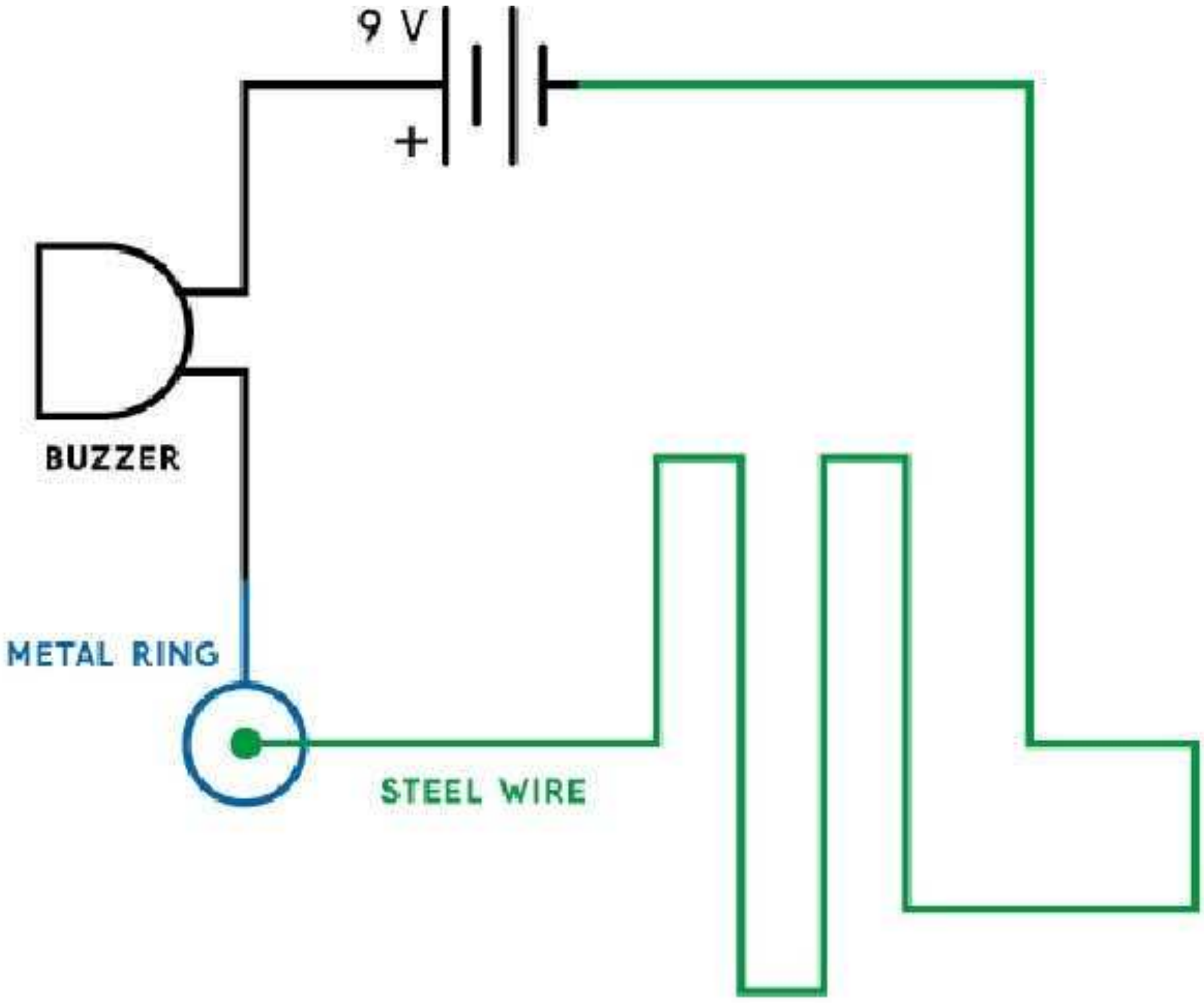
You can find resources for all the circuits through the book's website at *https://nostarch.com/circuits/*.

1

THE STEADY-HAND GAME

THIS CIRCUIT WILL SOUND A BUZZER IF YOU LET THE RING TOUCH THE WIRE.





THE PARTS LIST

PART	DESCRIPTION
Buzzer	Buzzer that works with 9 V battery
Steel wire	Bare and stiff wire, like a clothes hanger
Metal ring	Bare metal ring, like a soda can ring
An old pen	Old pen for mounting the metal ring
Tape	Electrical tape is best, but any tape should work

place these horizontally on two rows. Leave one hole open for connecting the touchpad to the rest of the circuit.

> **CAUTION**
>
> *Do not allow the two metal pads of the touchpad to make contact when the battery is connected. If they touch, a lot of current will flow from the base to the emitter and you might damage your transistor, making it unusable.*

FIGURE 2-2 Cutting the pins off your LED to use as a touchpad

Place the cut-off pins horizontally on two rows. Make sure you leave one hole in each of those rows open so you can connect the touchpad to the rest of the circuit.

COMMON MISTAKES

If you can't get the circuit to work, make sure you haven't made any of these common mistakes:

- Mixing up the pins of the transistor
- Destroying the transistor by letting the two metal pads of the touchpad make direct contact
- Connecting the LED backward
- Dry fingertip; try wetting your finger a bit (damp skin has a lower resistance, allowing a bit more current to flow)

If you're still struggling with this circuit, you can find more resources through the book's website at *https://nostarch.com/circuits/*.

HOW THE CIRCUIT WORKS

To get current to flow in a circuit, you need a path from the battery's positive terminal to its negative terminal. If you don't have this path, current can't flow and the LED won't light up. Turning the transistor "on" allows current to flow through it from its collector to its emitter.

To turn the transistor on, you need to have current flowing from its base to its emitter, which in turn lets current flow from its collector to its emitter. The amount of current flowing from the base to the emitter controls how much current can flow from the collector to the emitter.

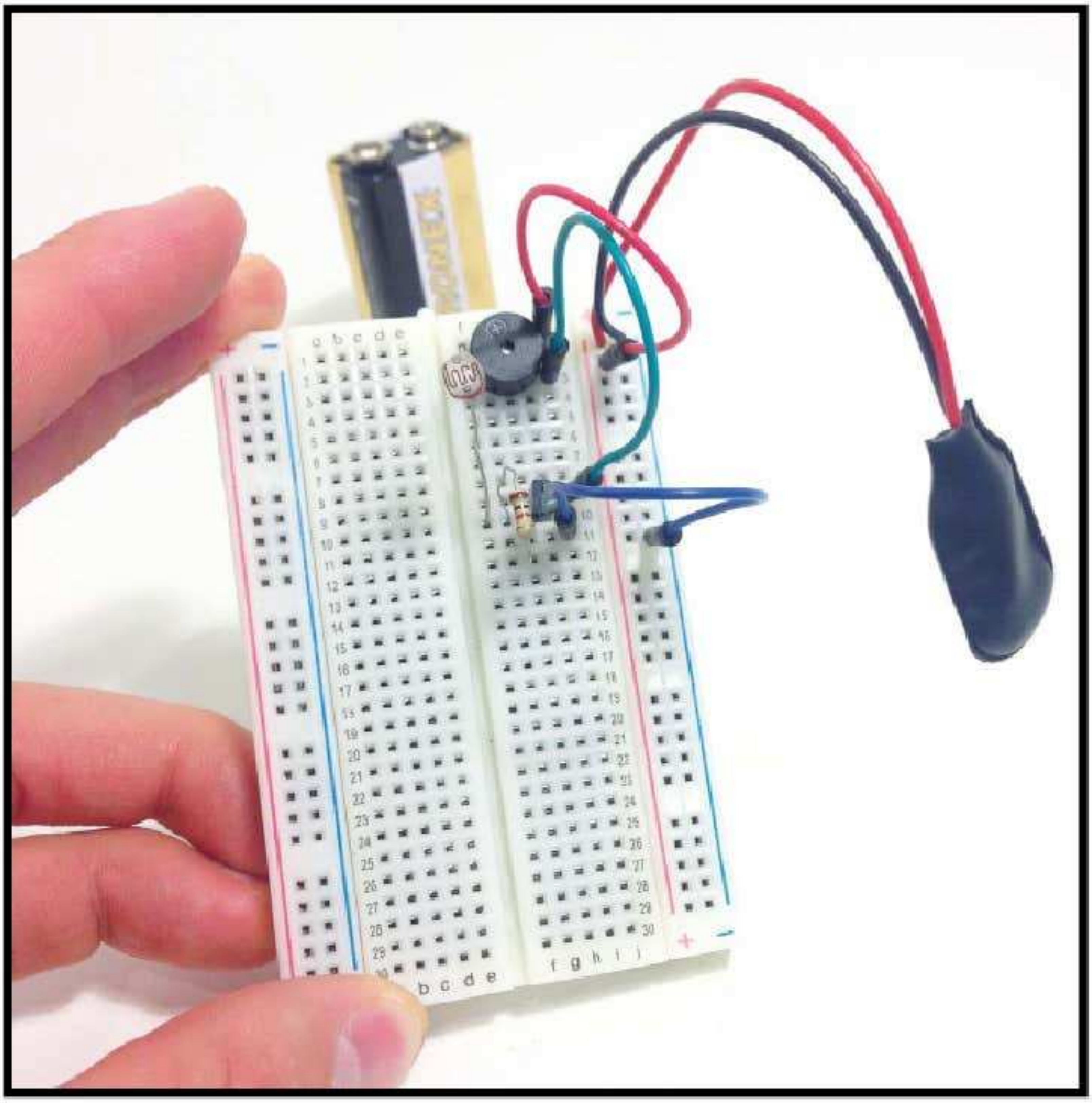
You can find the relationship between the base-to-emitter and the collector-to-emitter currents from the *current gain* of the transistor. The gain is often called h_{FE} or β (beta). For a general-purpose transistor like the one you're using here, the current gain is about 100. This means the collector-to-emitter current can be up to 100 times larger than the base-to-emitter current.

In this circuit, when no one is touching the touchpad, there is no current flowing from the base to the emitter. This means the transistor is "off" and there's no current flowing through the resistor and the LED.

When you touch the touchpad, your finger acts as a resistor from the positive terminal of the battery to the base of the transistor. A tiny current runs through the base to the emitter, which produces a larger current from the collector to the emitter. Current will also run through your LED, lighting it up.

3
THE COOKIE JAR ALARM

THIS ALARM BUZZES WHEN IT SENSES LIGHT.



THE CIRCUIT DIAGRAM

ABOUT THE CIRCUIT

This circuit turns on an LED when it gets dark. During the day, the light stays off, but at night, it can help you see things like the keyhole in your front door or a glass of water on your nightstand.

This circuit is similar to the one in Project 3, but here the transistor controls an LED instead of a buzzer. Remember, the LED has a resistor connected in series to limit its current.

Also, the resistor and LDR, which form the voltage divider that sets the voltage to the base of the transistor, have switched places.

In Project 3, the LDR was the upper resistor on the voltage divider. So when the resistance of the LDR was *low*—that is, when it sensed light from the opened cookie jar—the transistor turned on. In this circuit, the LDR is the lower resistor of the voltage divider. That means the transistor turns on when the resistance of the LDR is *high*, which happens when it's dark.

COMMON MISTAKES

If your circuit isn't working correctly, check for the following:

- The R1 resistance value is too high, so the LED never turns on. If you change R1, its resistance must not be less than 1 kΩ (see "How the Circuit Works" next).
- The R1 resistance value is too low, so the LED is always on.
- You used the wrong value for R3—either too much or too little resistance.
- You connected the transistor the wrong way.
- You connected the LED the wrong way.

You can change the circuit's sensitivity to light by changing the resistance of R1, but as mentioned previously, it must not be less than 1 kΩ (otherwise you may destroy the transistor).

If you're still struggling with this circuit, you can find more resources through the book's website at *https://nostarch.com/circuits/*.

HOW THE CIRCUIT WORKS

Just as in the Cookie Jar Alarm, the LDR and the resistor (R1) make up a voltage divider in this circuit. But since the LDR is now placed at the bottom of the voltage divider (between the transistor base and negative battery terminal), it works opposite to how the Cookie Jar Alarm works. In this circuit, when it's dark and the LDR resistance is high, the voltage on the transistor's base will be high enough to turn the LED on (shown in Figure 4-1). This means the transistor switches on the LED when it's dark.

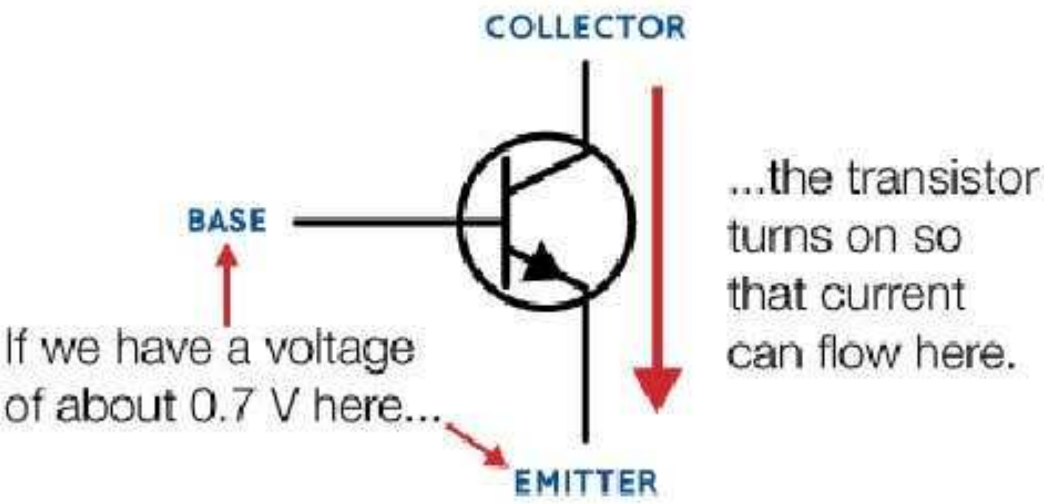


FIGURE 4-1 The amount of current flowing from the base to the emitter determines how much current can flow from the collector to the emitter.

The LDR that I used for this project has around 5 to 10 kΩ resistance when it's in light. With the 100 kΩ resistor (R1), the LED will turn on when the value of the LDR goes above about 10 kΩ.

A curious thing about this circuit is that the R1 resistor will also set the maximum brightness of the LED. This is because R1 determines the amount of current that flows into the base of the transistor, which in turn decides how much current can flow into the collector.

For a general-purpose transistor like the one you're using in this project, the amount of current flowing from the collector to the emitter can be up to 100 times greater than the current flowing from the base to the emitter.

That means that if you have 0.1 mA of current flowing from the base to the emitter, you can have up to 10 mA flowing from the collector to the emitter. If 10 mA is the upper limit from the collector to the emitter, that's the maximum that can flow through the LED too.

The current that flows into the base of the transistor has to first flow through R1. Not all the current that flows through R1 will go into the base—some will go through the LDR too—but when it's dark, the LDR resistance is so high that you can simplify for the sake of the calculation and say that all the current goes into the base.

Finding the current (I) through R1 is actually quite simple. Just find the voltage (V) across the resistor and divide it by the resistor value (R):

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

This calculation is based on *Ohm's law*, which describes the relationship among voltage, resistance, and current. You can learn more about Ohm's law at *https://www.build-electronic-circuits.com/ohms-law/*.

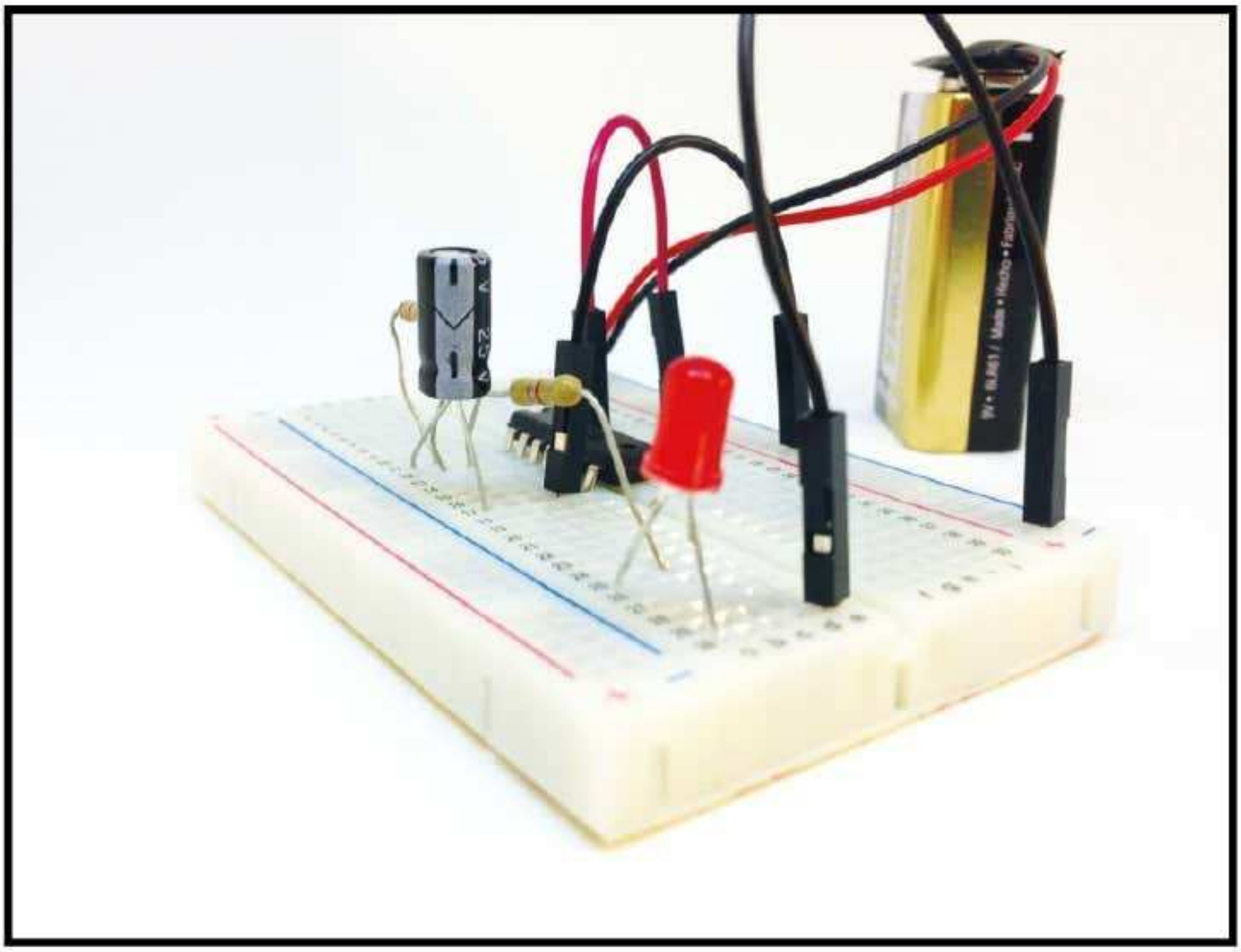
The voltage on the upper side of the resistor is easy. It's 9 V because it is connected to the positive terminal of the battery, but what about the lower side? Since you're looking for the maximum current that can flow through the transistor, it only makes sense to look at the current when the transistor is turned on. When the transistor is on, the voltage on the base of the transistor is around 0.7 V.

So you have 9 V on one side and 0.7 V on the other. This means you have 8.3 V across the resistor (R1). Using Ohm's law, you can divide 8.3 V by 100,000 Ω (= 100 kΩ) to get 0.000083 A (= 0.083 mA), so the maximum current that can flow through the LED and into the collector of the transistor is 100 times larger, or 8.3 mA.

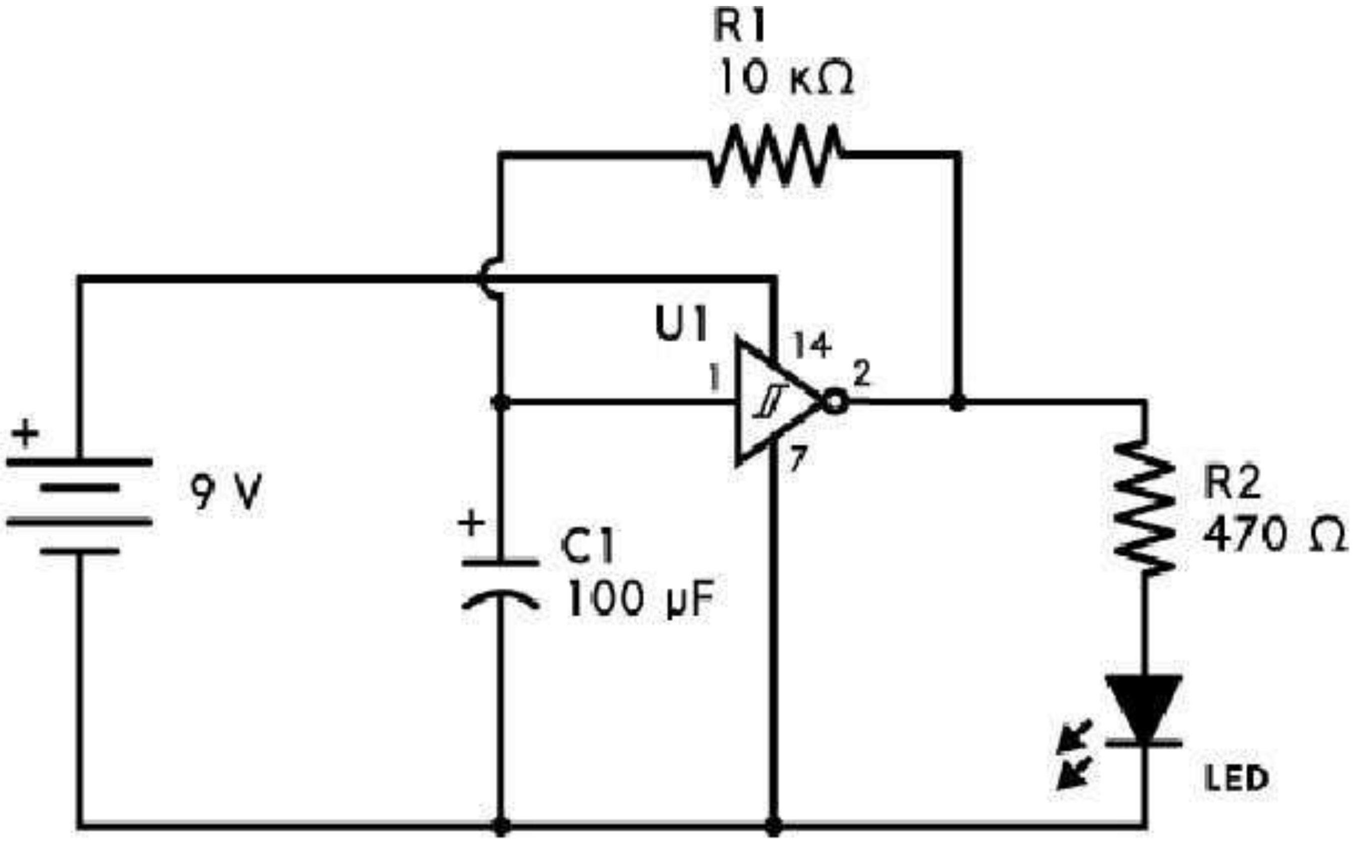
Since R1 is limiting the current to a value that is safe for the LED, in this circuit you could actually skip the R3 resistor, whose job is also to limit the current to the LED.

5
THE BLINKING LED

THIS CIRCUIT MAKES AN LED BLINK ON AND OFF.



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
U1	74C14	Hex Schmitt trigger inverter
C1	100 μF	Polarized capacitor
R1	10 kΩ	Standard resistor
R2	470 Ω	Standard resistor
LED		Standard-output light-emitting diode

ABOUT THE CIRCUIT

One of the first things I wanted to learn in electronics as a kid was how to blink a light. You can do this in one of several ways, but this circuit is probably the easiest way to do it, especially because it requires so few components. In fact, you need only five components, including the resistor and the LED.

The circuit works around an *inverter*, a component that outputs the opposite voltage of what it takes in. If it gets a *high* voltage in, it gives a *low* voltage out, and vice versa. A high voltage is a voltage close to the positive supply voltage (9 V in this case), and a low voltage is a voltage close to 0 V.

The output of the inverter (U1) is connected back to the input with a resistor, which causes *oscillation*, or jumping back and forth between high and low voltage. If the inverter input is high, then its output will be low. You connect that low-voltage output back to the inverter's input, and because the input is low, the output will be high. That high-voltage output is directed back to the inverter's input, and so on.

To slow down the oscillation enough to see the LED blink, you use a capacitor on the input of the inverter. A *capacitor* stores and discharges energy; the charging and discharging of the capacitor in this circuit (C1) will increase the time it takes for the input to go from low to high and from high to low. The resistor (R1) controls how much current goes back and forth to charge and discharge the capacitor, so the size of R1 and C1 determines the speed of the oscillation.

You should use a 74C14 IC *Schmitt trigger* inverter; its threshold for switching from high to low voltage is different from the threshold for switching from low to high. This ensures that the inverter doesn't get stuck in a state in between high and low.

The Schmitt trigger inverter comes as a 14-pin *integrated circuit (IC)*, a single chip with its own internal circuitry. The number next to each pin in the circuit diagram represents the pin number on the integrated circuit. Figure 5-1 shows how the pins are arranged on the 74C14 IC Schmitt trigger inverter.

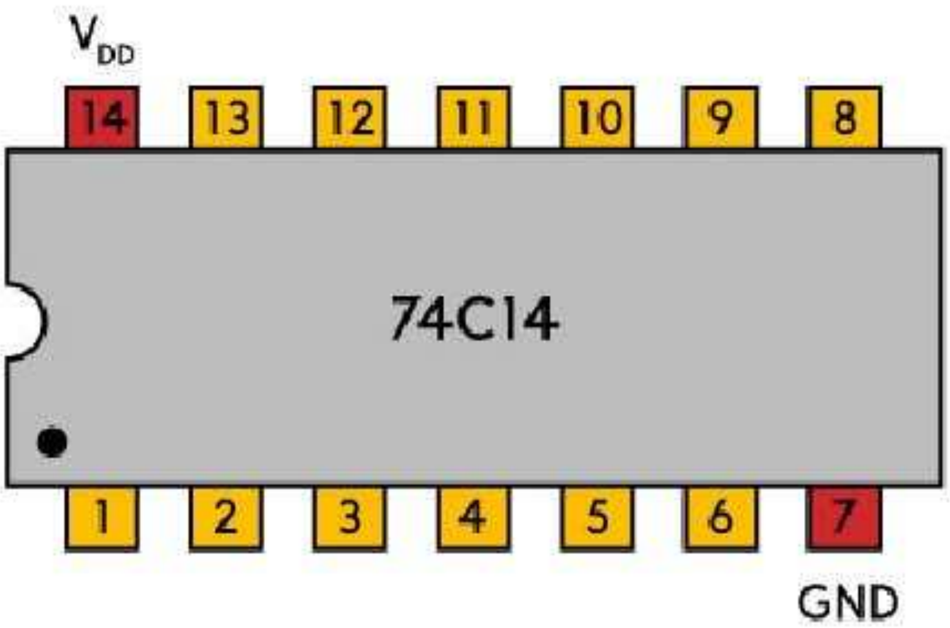
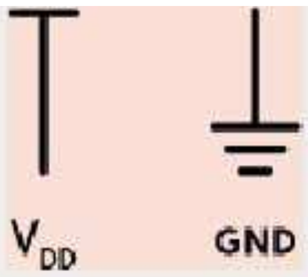


FIGURE 5-1 Pinout of the 74C14 Schmitt trigger inverter



You can use these two symbols to simplify your circuit diagrams a bit, because they let you omit the battery symbol and the lines connecting it to the circuit.

When the transistor is off, you can think of it as a resistor with very high resistance between the collector and emitter (Rt in the diagram), and when the transistor is on, you can look at it as a resistor with zero resistance. You might find this easier to understand if you ignore the input for a second and just look at the output circuit, as in Figure 5-4. You may have noticed that you get a voltage divider.

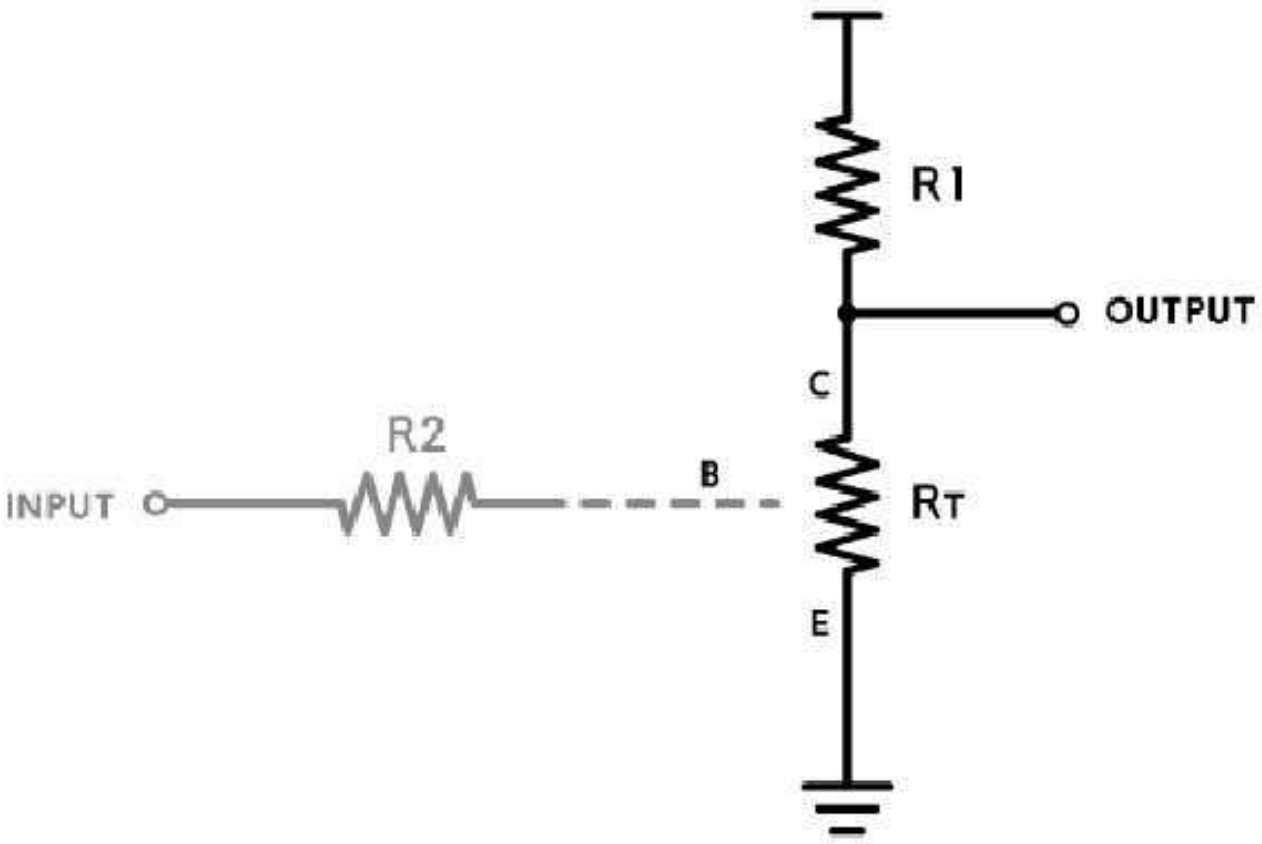


FIGURE 5-4 The simple resistor with the transistor turned off

In Project 3, you learned how to calculate the voltage from a voltage divider. For R1 and Rt in Figure 5-4, the formula for calculating the output voltage becomes:

$$V_{out} = V_{in} \times \frac{Rt}{R1 + Rt}$$

When you have a high input, you can look at the transistor as a resistor (Rt) with zero resistance (or a wire). If you replace Rt with 0 in this formula, it doesn't matter what the other values are: you'll get 0 V as the output voltage, so that's a low output.

When you have a low input, you can look at the transistor as a resistor with really high resistance—say, billions of ohms. A normal value for R1 is 1,000 Ω, so if you have 9 V as V_{in} and you try to put 1 billion ohms into the formula as Rt, the result is 9 V—a high output.

The Schmitt trigger inverter works in a similar way, but with some additional components built into the IC to make the circuit switch from high to low and from low to high at different input voltages.

The 74C14 chip you use in this project is an integrated circuit containing six inverters, which is why it has so many pins. You can see the circuit's pinout and internal inverters in Figure 5-5.

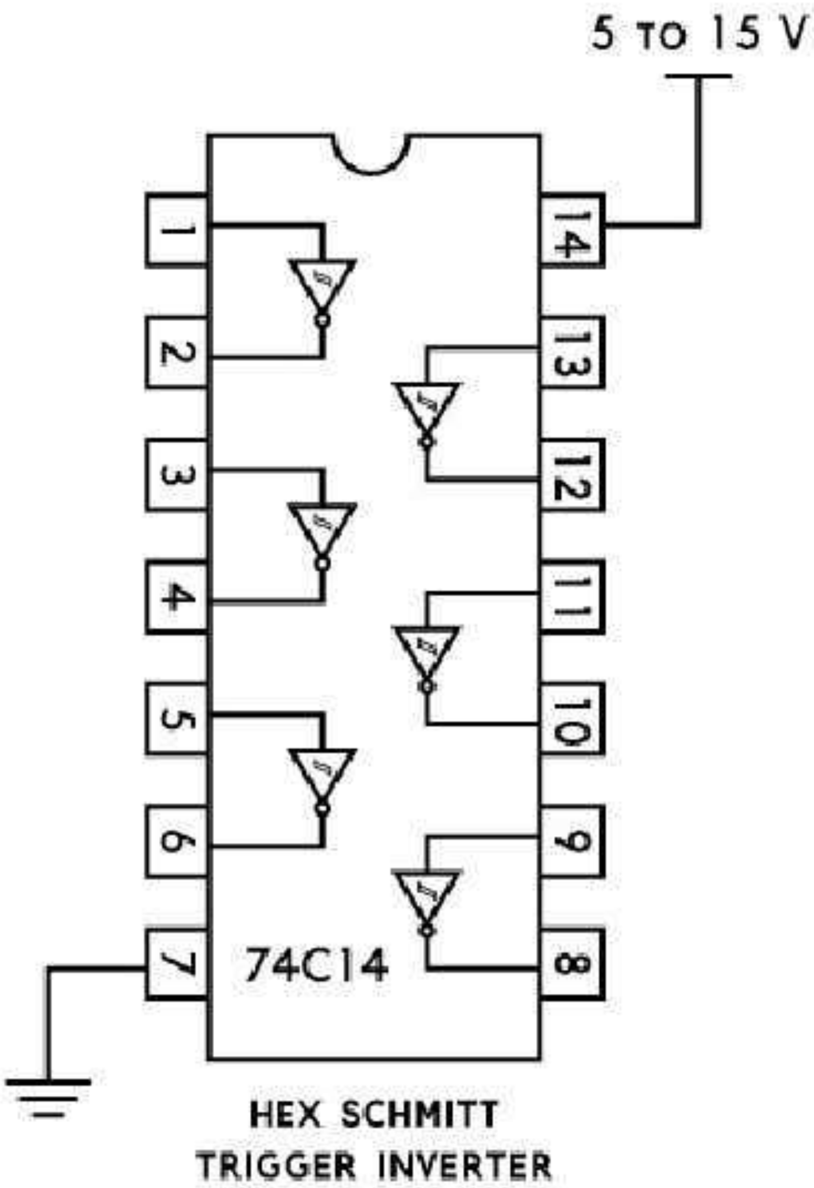
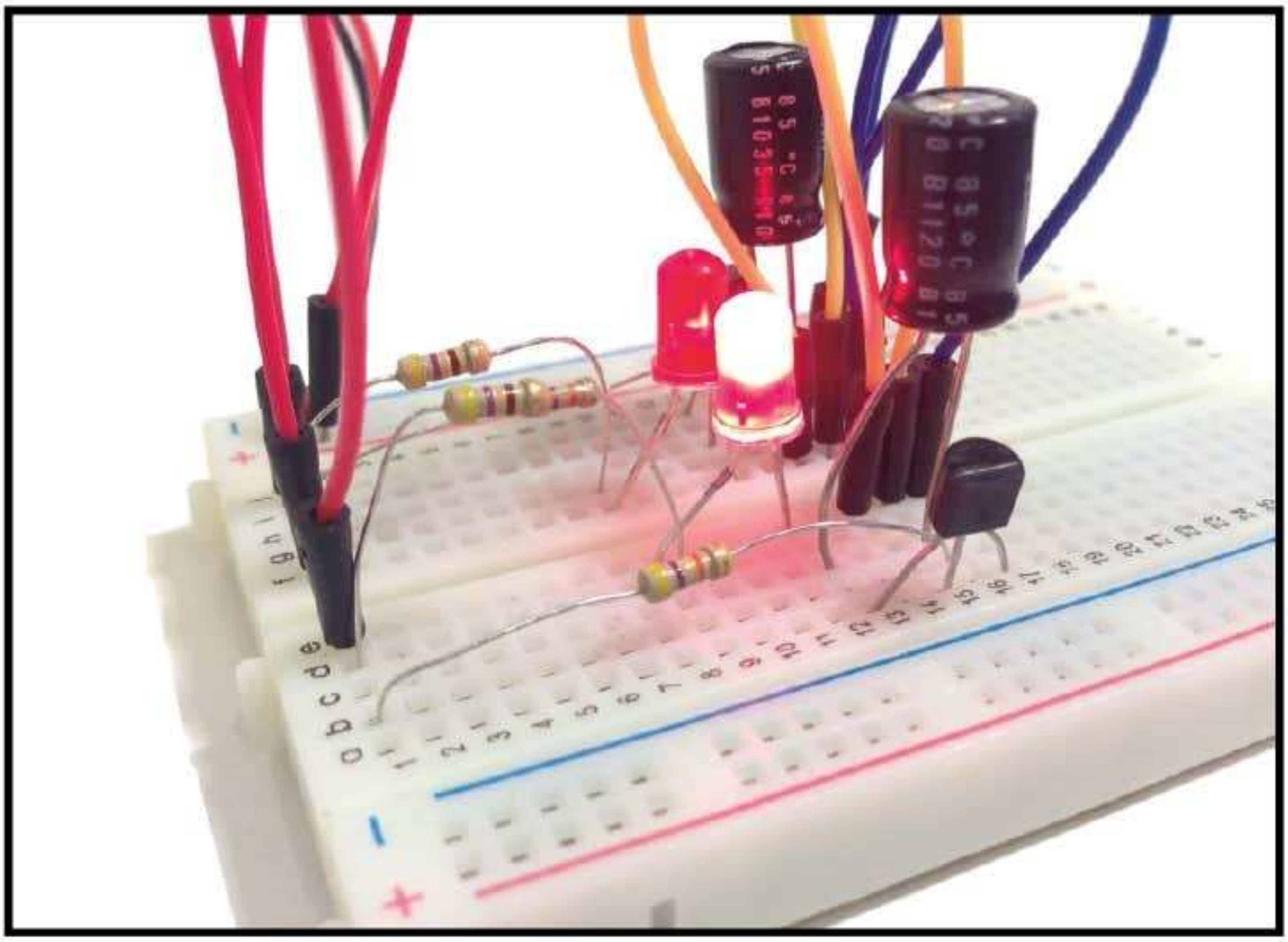


FIGURE 5-5 The 74C14 chip contains six inverters

Because of its small size, using an integrated circuit like the 74C14 saves you a lot of space compared to building the inverter from scratch.

6
THE RAILROAD CROSSING LIGHT

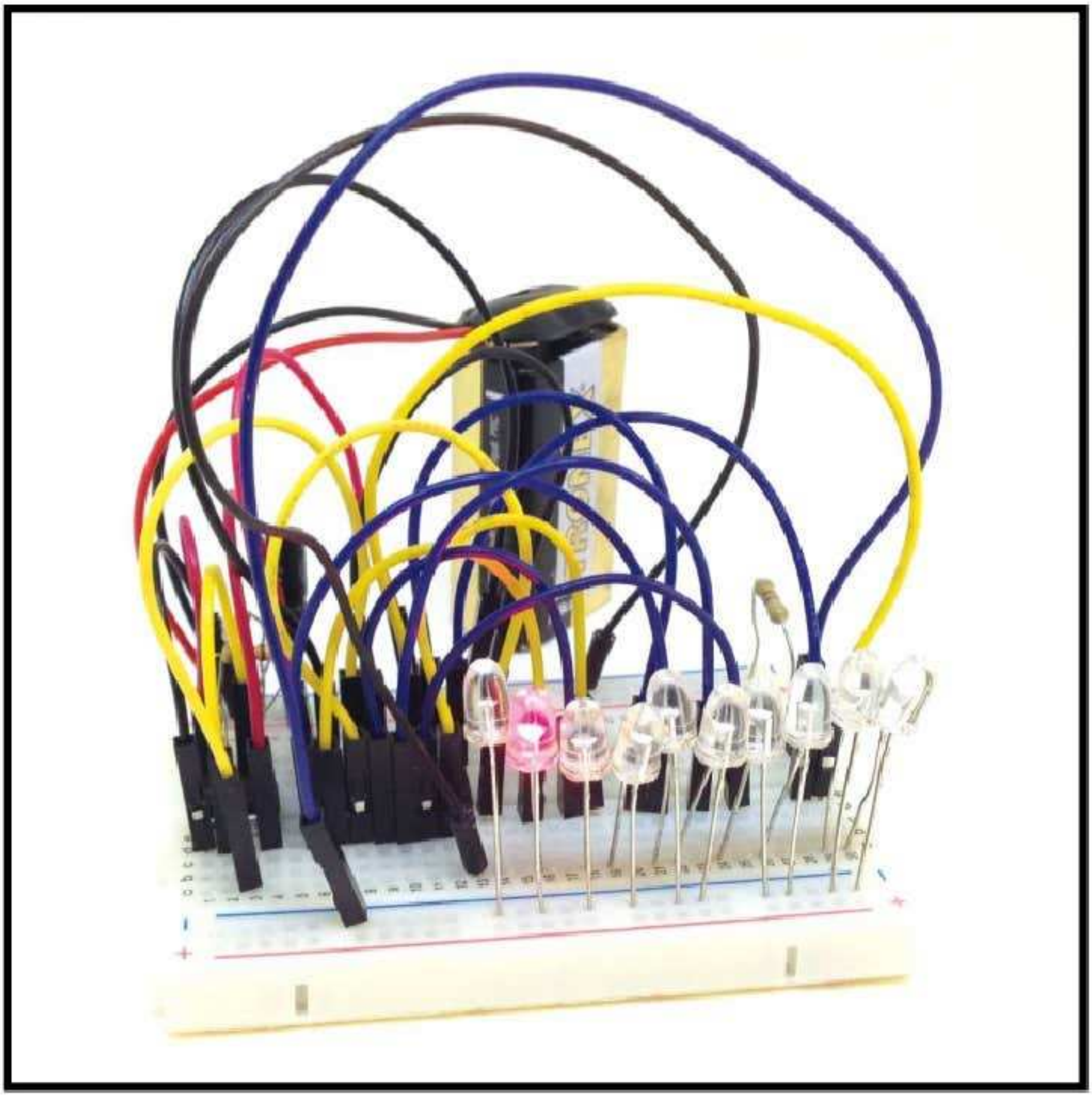
THIS CIRCUIT FLASHES TWO LEDS IN AN ALTERNATING PATTERN.



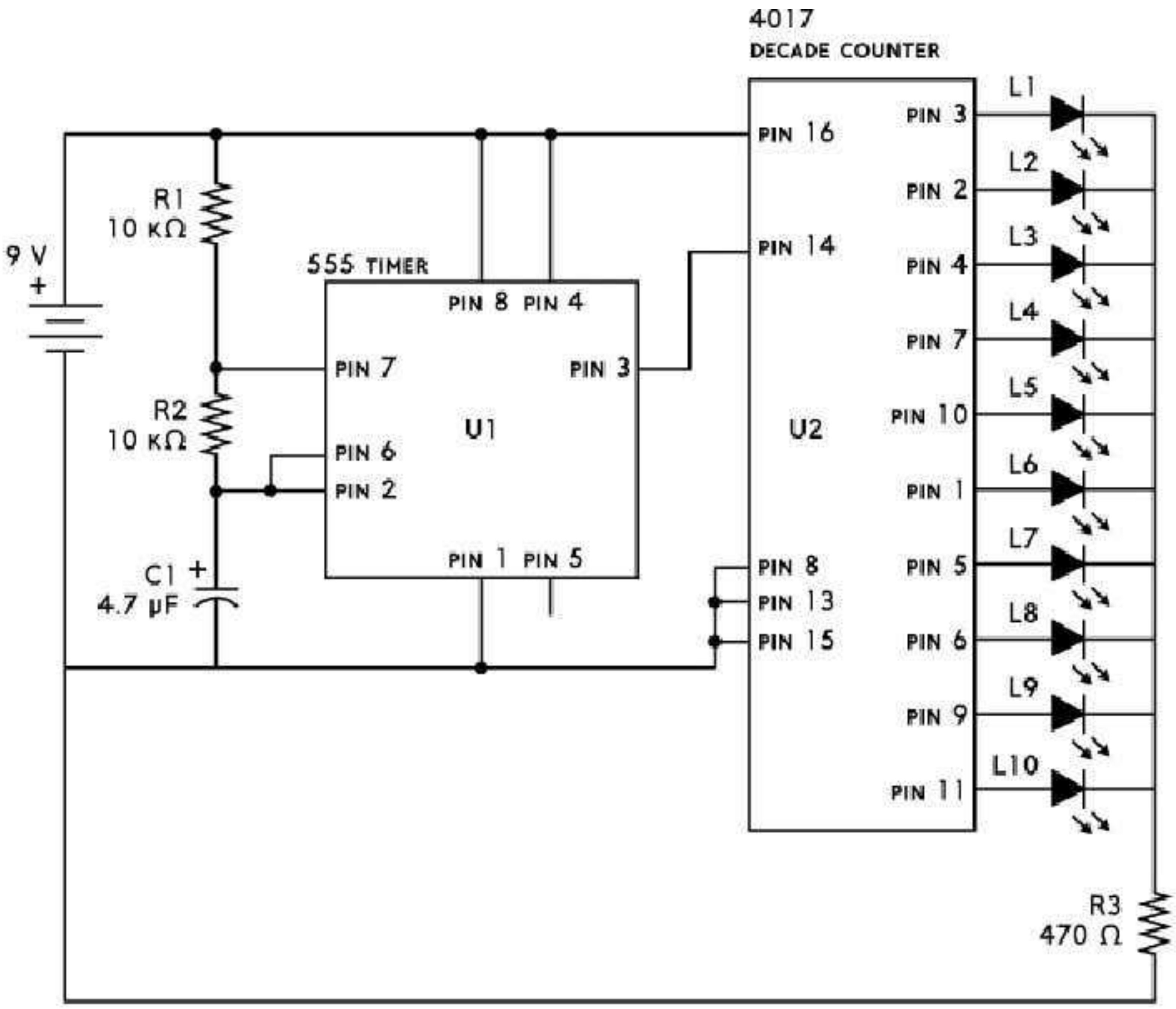
THE CIRCUIT DIAGRAM

9
THE LED MARQUEE

THIS CIRCUIT CREATES A RUNNING LIGHT, LIKE AN OLD THEATER MARQUEE.



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
R1, R2	10 kΩ	Two standard resistors
R3	470 Ω	Standard resistor
C1	4.7 μF	Polarized capacitor
L1 to L10	LED	Standard light-emitting diodes
U1	NE555	555 timer IC

U2	CD4017B	4017 decade counter IC

ABOUT THE CIRCUIT

This circuit uses a 555 timer and a 4017 decade counter, both integrated circuits. The voltage of the 555 timer's pin 3 switches between high and low repeatedly, as you saw in Project 8. You connect this signal to pin 14 of the 4017 IC, and the 4017 counts the number of times the voltage on pin 14 goes from low to high. The 4017 has 10 outputs—marked Q0 to Q9—that represent this count. For example, after three counts, output Q3 is high, while the others are low. On the 10th count, the counter starts from Q0 again. Figure 9-1 shows the pinout for the 4017 IC.

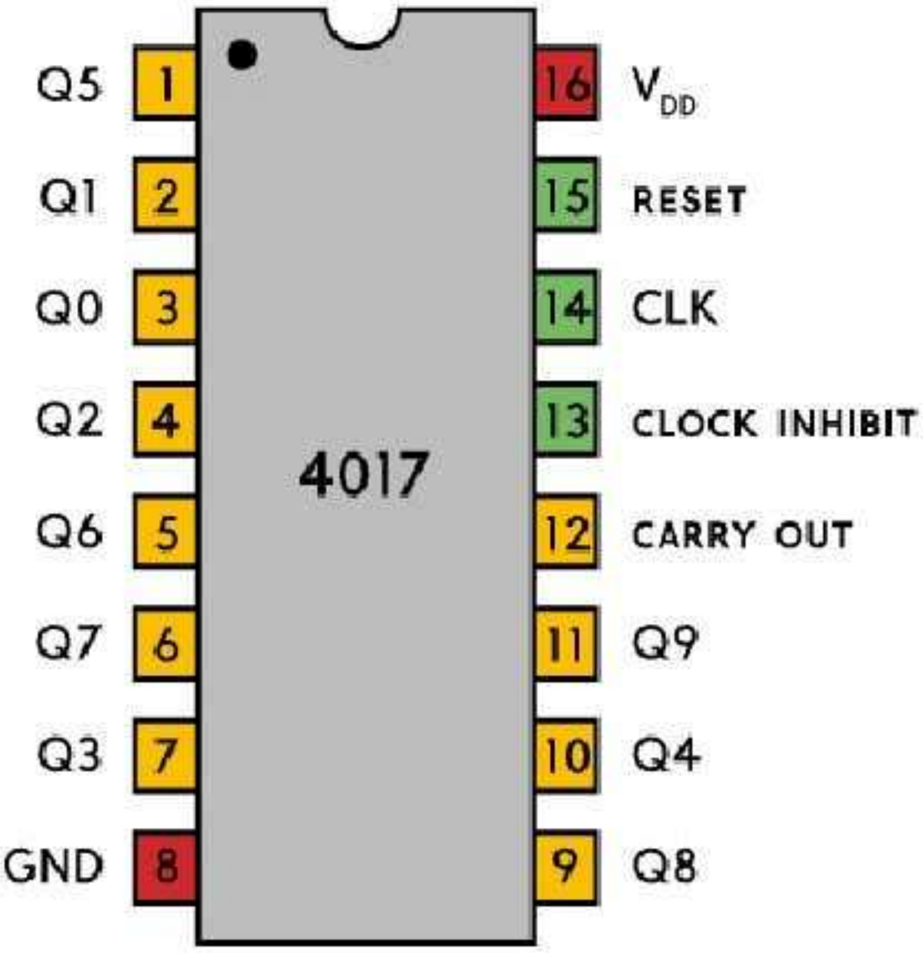


FIGURE 9-1 The pinout for the 4017 IC

The running speed is set by R1, R2, and C1. Change one of the values, and the lights' running speed will change. Larger values slow it down, and smaller values speed it up.

This is a large circuit, so it's pretty easy to connect a wire or a component in the wrong place. I suggest you connect only the 555 timer part first. After that, add a 470 Ω resistor in series with an LED between the 555 output on pin 3 and the negative terminal of the battery. You should see the LED blink really fast. When you do, you can disconnect the LED and resistor and continue connecting the rest of the circuit.

WHERE TO GO FROM HERE

Congratulations, you've made it all the way to the end!

If you've built all nine circuits, you should have a solid practical foundation for creating great things with electronics. If you're new to electronics, you might not have understood all the details of each circuit in this book, but that's okay. This book was all about building circuits and improving your practical electronics skills.

If you want to understand more about how these circuits work and how you can build your own, check out my book *Electronics for Kids* (No Starch Press, 2016), which will teach you electronics from scratch, even if you're not necessarily a "kid" anymore.

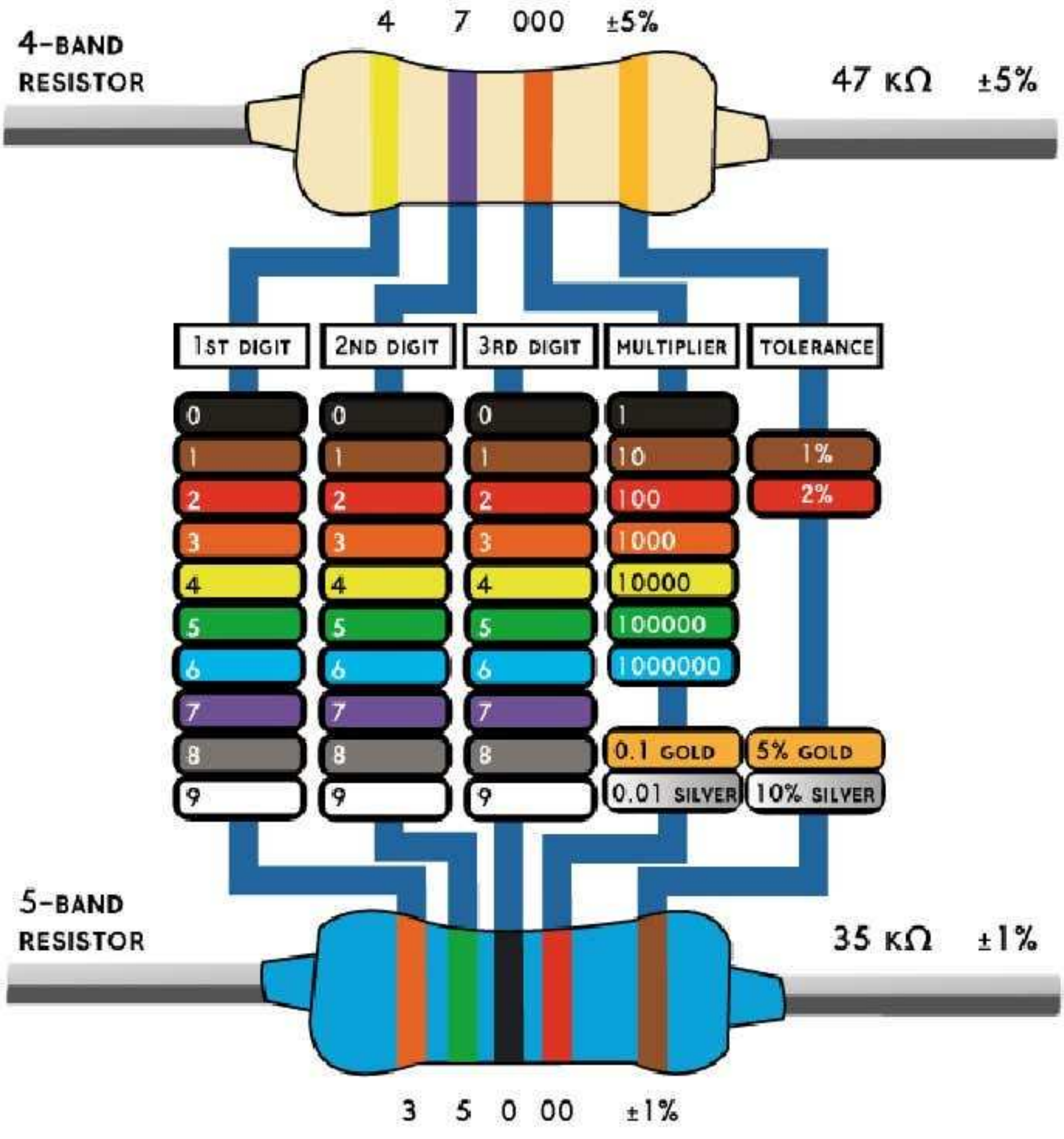
If you want to step up your game and learn to build projects that can do much more advanced things, like use graphical displays, create melodies, and connect to the internet, I recommend exploring a popular device called Arduino (*https://www.arduino.cc/*).

Whether you want to build an automatic cat door for your home or the next must-have gadget for the world, you'll need to develop the skills and knowledge necessary to build those projects. That's why I'm constantly creating new learning material to help people bring their own ideas to life with electronics. To help people from all backgrounds develop these abilities, I've created a learning portal for electronics called Ohmify. It's a place where you can sign up for courses to learn a variety of skills, including:

- Arduino programming
- Basic electronics
- Soldering
- Printed circuit board (PCB) design
- And much more!

You can learn more about Ohmify at *https://ohmify.com/*.

RESISTOR COLOR CODES



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