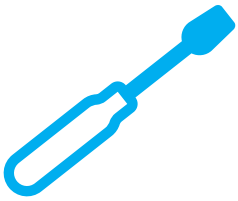
Burn things out, mess things up—that's how you learn.

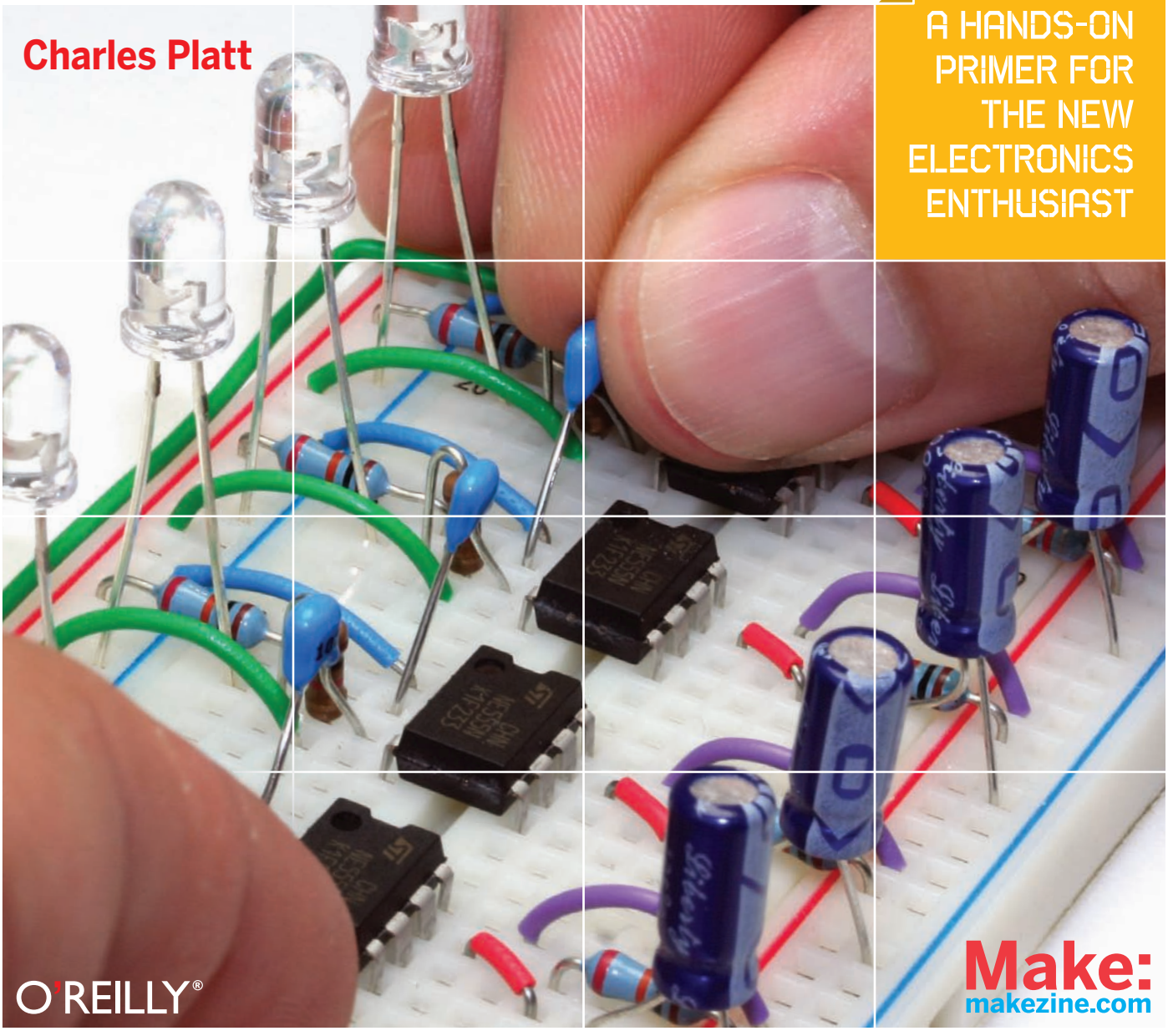


Learn by Discovery

# Make: Electronics

Charles Platt

A HANDS-ON PRIMER FOR THE NEW ELECTRONICS ENTHUSIAST



O'REILLY®

Make:
makezine.com

# Make: Electronics

Learning by Discovery

Charles Platt

*with photographs and illustrations by the author*

O'REILLY®

Beijing • Cambridge • Farnham • Köln • Sebastopol • Taipei • Tokyo

# Make: Electronics

by Charles Platt

Copyright © Helpful Corporation. All rights reserved.
Printed in Canada.

Published by O'Reilly Media, Inc., 1005 Gravenstein Highway North, Sebastopol, CA 95472.

O'Reilly Media books may be purchased for educational, business, or sales promotional use. Online editions are also available for most titles (*my.safaribooksonline.com*). For more information, contact our corporate/institutional sales department: 800-998-9938 or *corporate@oreilly.com*.

**Editors:** Dale Dougherty and Brian Jepson

**Development Editor:** Gareth Branwyn

**Production Editor:** Rachel Monaghan

**Technical Editor:** Andrew "Bunnie" Huang

**Copyeditor:** Nancy Kotary

**Proofreader:** Nancy Reinhardt

**Indexer:** Julie Hawks

**Cover Designer:** Mark Paglietti

**Interior Designer:** Ron Bilodeau

**Illustrator/Photographer:** Charles Platt

**Cover Photographer:** Marc de Vinck

## Print History:

December 2009: First Edition.

The O'Reilly logo is a registered trademark of O'Reilly Media, Inc. Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and O'Reilly Media, Inc., was aware of a trademark claim, the designations have been printed in caps or initial caps.

While every precaution has been taken in the preparation of this book, the publisher and author assume no responsibility for errors or omissions, or for damages resulting from the use of the information contained herein.

ISBN: 978-0-596-15374-8
[TI]

*For my dearest Erico*

# Contents

Preface ..... ix

1. Experiencing Electricity ..... 1
Shopping List: Experiments 1 Through 5 ..... 1
Experiment 1: Taste the Power! ..... 5
Experiment 2: Let's Abuse a Battery! ..... 9
Experiment 3: Your First Circuit ..... 13
Experiment 4: Varying the Voltage ..... 18
Experiment 5: Let's Make a Battery ..... 32

2. Switching Basics and More ..... 39
Shopping List: Experiments 6 Through 11 ..... 39
Experiment 6: Very Simple Switching ..... 43
Experiment 7: Relay-Driven LEDs ..... 55
Experiment 8: A Relay Oscillator ..... 60
Experiment 9: Time and Capacitors ..... 68
Experiment 10: Transistor Switching ..... 73
Experiment 11: A Modular Project ..... 82

3. Getting Somewhat More Serious ..... 95
Shopping List: Experiments 12 Through 15 ..... 95
Experiment 12: Joining Two Wires Together ..... 104
Experiment 13: Broil an LED ..... 114
Experiment 14: A Pulsing Glow ..... 117
Experiment 15: Intrusion Alarm Revisited ..... 127

## 4. Chips, Ahoy! ..... 147

Shopping List: Experiments 16 Through 24 ..... 147
Experiment 16: Emitting a Pulse ..... 153
Experiment 17: Set Your Tone ..... 162
Experiment 18: Reaction Timer ..... 170
Experiment 19: Learning Logic ..... 181
Experiment 20: A Powerful Combination ..... 197
Experiment 21: Race to Place ..... 205
Experiment 22: Flipping and Bouncing ..... 211
Experiment 23: Nice Dice ..... 214
Experiment 24: Intrusion Alarm Completed ..... 223

## 5. What Next? ..... 227

Shopping List: Experiments 25 Through 36 ..... 228
Customizing Your Work Area ..... 228
Reference Sources ..... 233
Experiment 25: Magnetism ..... 236
Experiment 26: Tabletop Power Generation ..... 239
Experiment 27: Loudspeaker Destruction ..... 242
Experiment 28: Making a Coil React ..... 246
Experiment 29: Filtering Frequencies ..... 249
Experiment 30: Fuzz ..... 257
Experiment 31: One Radio, No Solder, No Power ..... 262
Experiment 32: A Little Robot Cart ..... 268
Experiment 33: Moving in Steps ..... 284
Experiment 34: Hardware Meets Software ..... 293
Experiment 35: Checking the Real World ..... 306
Experiment 36: The Lock, Revisited ..... 311
In Closing ..... 317

## Appendix. Online Retail Sources and Manufacturers ..... 319

## Index ..... 325

# Preface

## How to Have Fun with This Book

Everyone uses electronic devices, but most of us don't really know what goes on inside them.

Of course, you may feel that you don't need to know. If you can drive a car without understanding the workings of an internal combustion engine, presumably you can use an iPod without knowing anything about integrated circuits. However, understanding some basics about electricity and electronics can be worthwhile for three reasons:

- By learning how technology works, you become better able to control your world instead of being controlled by it. When you run into problems, you can solve them instead of feeling frustrated by them.
- Learning about electronics can be fun—so long as you approach the process in the right way. The tools are relatively cheap, you can do all the work on a tabletop, and it doesn't consume a lot of time (unless you want it to).
- Knowledge of electronics can enhance your value as an employee or perhaps even lead to a whole new career.

## Learning by Discovery

Most introductory guides begin with definitions and facts, and gradually get to the point where you can follow instructions to build a simple circuit.

This book works the other way around. I want you to start putting components together right away. After you see what happens, you'll figure out what's going on. I believe this process of *learning by discovery* creates a more powerful and lasting experience.

### Stay Within the Limits!

*Although I believe that everything suggested in this book is safe, I'm assuming that you will stay within the limits that I suggest. Please always follow the instructions and pay attention to the warnings, denoted by the icon you see here. If you go beyond the limits, you will expose yourself to unnecessary risks.*

Learning by discovery occurs in serious research, when scientists notice an unusual phenomenon that cannot be explained by current theory, and they start to investigate it in an effort to explain it. This may ultimately lead to a better understanding of the world.

We're going to be doing the same thing, although obviously on a much less ambitious level.

Along the way, you will make some mistakes. This is good. Mistakes are the best of all learning processes. I want you to burn things out and mess things up, because this is how you learn the limits of components and materials. Since we'll be using low voltages, there'll be no chance of electrocution, and so long as you limit the flow of current in the ways I'll describe, there will be no risk of burning your fingers or starting fires.

Figure P-1. *Learning by discovery allows you to start building simple circuits right away, using a handful of cheap components, a few batteries, and some alligator clips.*

## How Hard Will It Be?

I assume that you're beginning with no prior knowledge of electronics. So, the first few experiments will be ultra-simple, and you won't even use solder or prototyping boards to build a circuit. You'll be holding wires together with alligator clips.

Very quickly, though, you'll be experimenting with transistors, and by the end of Chapter 2, you will have a working circuit that has useful applications.

I don't believe that hobby electronics has to be difficult to understand. Of course, if you want to study electronics more formally and do your own circuit design, this can be challenging. But in this book, the tools and supplies will be inexpensive, the objectives will be clearly defined, and the only math you'll need will be addition, subtraction, multiplication, division, and the ability to move decimal points from one position to another.

# Moving Through This Book

Basically there are two ways to present information in a book of this kind: in tutorials and in reference sections. I'm going to use both of these methods. You'll find the tutorials in sections headed as follows:

- Shopping Lists
- Using Tools
- Experiments

You'll find reference sections under the following headings:

- Fundamentals
- Theory
- Background

How you use the sections is up to you. You can skip many of the reference sections and come back to them later. But if you skip many of the tutorials, this book won't be of much use to you. Learning by discovery means that you absolutely, positively have to do some hands-on work, and this in turn means that you have to buy some basic components and play with them. You will gain very little by merely imagining that you are doing this.

It's easy and inexpensive to buy what you need. In almost any urban or suburban area in the United States, chances are you live near a store that sells electronic components and some basic tools to work with them. I am referring, of course, to RadioShack franchises. Some Shacks have more components than others, but almost all of them have the basics that you'll need.

You can also visit auto supply stores such as AutoZone and Pep Boys for basics such as hookup wire, fuses, and switches, while stores such as Ace Hardware, Home Depot, and Lowe's will sell you tools.

If you prefer to buy via mail order, you can easily find everything you need by searching online. In each section of the book, I'll include the URLs of the most popular supply sources, and you'll find a complete list of URLs in the appendix.

# Fundamentals

## Mail-ordering components and tools

Here are the primary mail-order sources that I use myself online:

*http://www.radioshack.com*
: RadioShack, a.k.a. The Shack. For tools and components. Not always the cheapest, but the site is easy and convenient, and some of the tools are exactly what you need.

*http://www.mouser.com*
: Mouser Electronics.

*http://www.digikey.com*
: Digi-Key Corporation.

*http://www.newark.com*
: Newark.

Mouser, Digi-Key, and Newark are all good sources for components, usually requiring no minimum quantities.

*http://www.allelectronics.com*
: All Electronics Corporation. A narrower range of components, but specifically aimed at the hobbyist, with kits available.

*http://www.ebay.com*
: You can find surplus parts and bargains here, but you may have to try several eBay Stores to get what you want. Those based in Hong Kong are often very cheap, and I've found that they are reliable.

*http://www.mcmaster.com*
: McMaster-Carr. Especially useful for high-quality tools.

Lowe's and Home Depot also allow you to shop online.

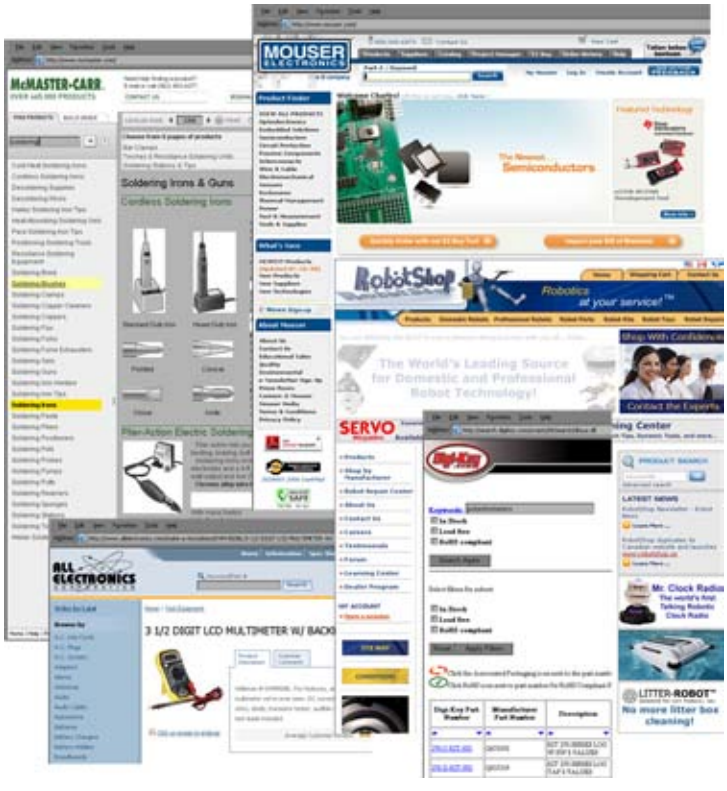



Figure P-2. *You'll find no shortage of parts, tools, kits, and gadgets online.*

## Companion Kits

Maker Shed (*www.makershed.com*) offers a number of *Make: Electronics* companion kits, both toolkits and bundles of the various components used in the book's experiments. This is a simple, convenient, and cost-effective way of getting all the tools and materials you need to do the projects in this book.

## Comments and Questions

Please address comments and questions concerning this book to the publisher:

O'Reilly Media, Inc.
1005 Gravenstein Highway North
Sebastopol, CA 95472
800-998-9938 (in the United States or Canada)
707-829-0515 (international or local)
707-829-0104 (fax)

We have a web page for this book, where we list errata, examples, larger versions of the book's figures, and any additional information. You can access this page at:

*http://oreilly.com/catalog/9780596153748*

To comment or ask technical questions about this book, send email to:

*bookquestions@oreilly.com*

For more information about our books, conferences, Resource Centers, and the O'Reilly Network, see our website at:

*http://oreilly.com*

## Safari® Books Online

Safari Books Online is an on-demand digital library that lets you easily search over 7,500 technology and creative reference books and videos to find the answers you need quickly.

With a subscription, you can read any page and watch any video from our library online. Read books on your cell phone and mobile devices. Access new titles before they are available for print, and get exclusive access to manuscripts in development and post feedback for the authors. Copy and paste code samples, organize your favorites, download chapters, bookmark key sections, create notes, print out pages, and benefit from tons of other time-saving features.

O'Reilly Media has uploaded this book to the Safari Books Online service. To have full digital access to this book and others on similar topics from O'Reilly and other publishers, sign up for free at *http://my.safaribooksonline.com*.

# Experiment 4: Varying the Voltage

Potentiometers come in various shapes and sizes, but they all do the same thing: they allow you to vary voltage and current by varying resistance. This experiment will enable you to learn more about voltage, amperage, and the relationship between them. You'll also learn how to read a manufacturer's data sheet.

You will need the same batteries, battery carrier, alligator clips, and LED from the last experiment, plus:

- Potentiometer, 2KΩ linear. Quantity: 2. (See Figure 1-46.) Full-sized potentiometers that look like this are becoming less common, as miniature versions are taking their place. I'd like you to use a large one, though, because it's so much easier to work with.
- One extra LED.
- Multimeter.

## Look Inside Your Potentiometer

The first thing I want you to do is find out how a potentiometer works. This means you'll have to open it, which is why your shopping list required you to buy two of them, in case you can't put the first one back together again.

Most potentiometers are held together with little metal tabs. You should be able to grab hold of the tabs with your wire cutters or pliers, and bend them up and outward. If you do this, the potentiometer should open up as shown in Figures 1-47 and 1-48.

Figure 1-46

Figure 1-47

Figure 1-48. *To open the potentiometer, first pry up the four little metal tabs around the edge (you can see one sticking out at the left and another one sticking out at the right in Figure 1-47). Inside is a coil of wire around a flat plastic band, and a pair of springy contacts (the wiper), which conduct electricity to or from any point in the coil when you turn the shaft.*

Depending whether you have a really cheap potentiometer or a slightly more high-class version, you may find a circular track of conductive plastic or a loop of coiled wire. Either way, the principle is the same. The wire or the plastic

possesses some resistance (a total of 2K in this instance), and as you turn the shaft of the potentiometer, a wiper rubs against the resistance, giving you a shortcut to any point from the center terminal.

You can try to put it back together, but if it doesn't work, use your backup potentiometer instead.

To test your potentiometer, set your meter to measure resistance (ohms) and touch the probes while turning the potentiometer shaft to and fro, as shown in Figure 1-49.

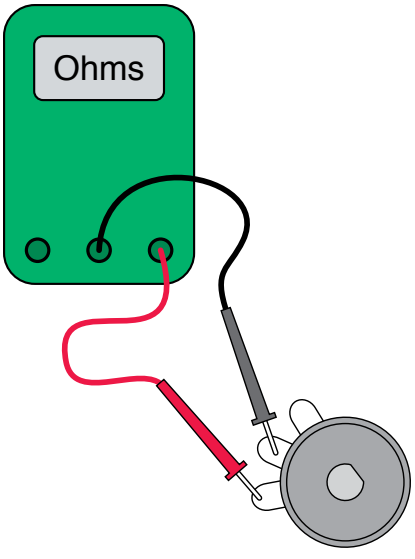



Figure 1-49. *Measure the resistance between these two terminals of the potentiometer while you turn its shaft to and fro.*

## Dimming Your LED

Begin with the potentiometer turned all the way counterclockwise, otherwise you'll burn out the LED before we even get started. (A very, very small number of potentiometers increase and decrease resistance in the opposite way to which I'm describing here, but as long as your potentiometer looks like the one in Figure 1-48 after you open it up, my description should be accurate.)

Now connect everything as shown in Figures 1-50 and 1-51, taking care that you don't allow the metal parts of any of the alligator clips to touch each other. Now turn up the potentiometer *very* slowly. You'll notice the LED glowing brighter, and brighter, and brighter—until, oops, it goes dark. You see how easy it is to destroy modern electronics? Throw away that LED. It will never glow again. Substitute a new LED, and we'll be more careful this time.

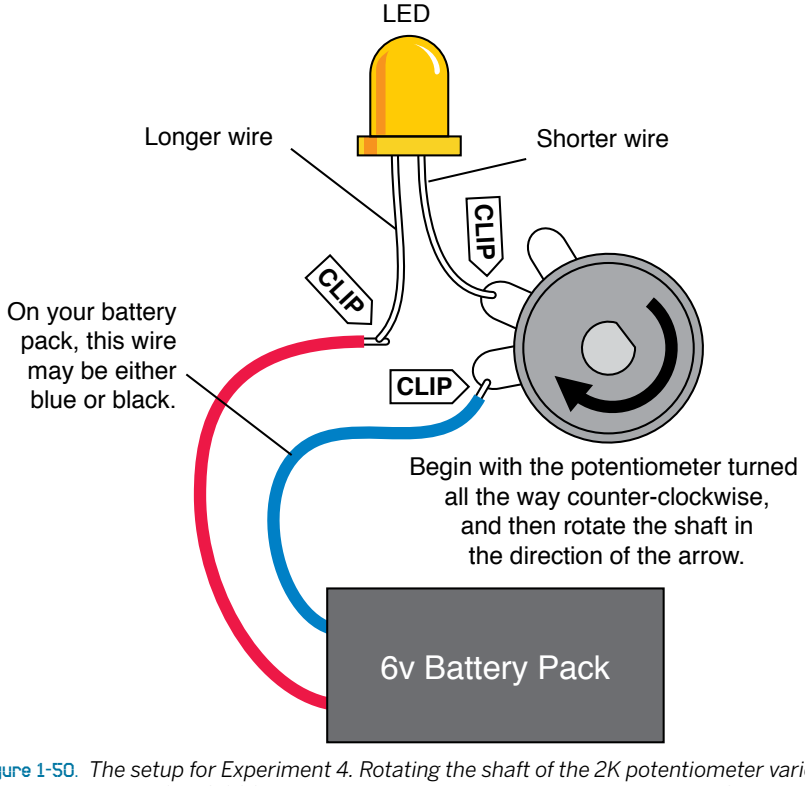



Figure 1-50. *The setup for Experiment 4. Rotating the shaft of the 2K potentiometer varies its resistance from 0 to 2,000Ω. This resistance protects the LED from the full 6 volts of the battery.*

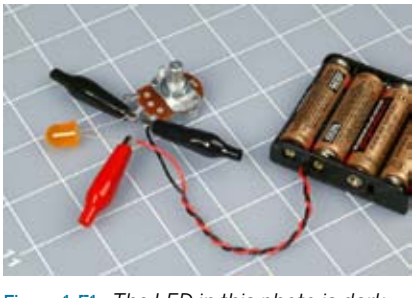


Figure 1-51. *The LED in this photo is dark because I turned the potentiometer up just a little bit too far.*

Figure 1-52

Figure 1-53

Figure 1-54. *Each meter has a different way to measure volts DC. The manually adjusted meter (top) requires you to move a slider switch to "DC" and then choose the highest voltage you want to measure: In this case, the selected voltage is 20 (because 2 would be too low). Using the autoranging RadioShack meter, you set it to "V" and the meter will figure out which range to use.*

While the batteries are connected to the circuit, set your meter to measure *volts DC* as shown in Figures 1-52 through 1-54. Now touch the probes either side of the LED. Try to hold the probes in place while you turn the potentiometer up a little, and down a little. You should see the voltage pressure around the LED changing accordingly. We call this the *potential difference* between the two wires of the LED.

If you were using a miniature old-fashioned lightbulb instead of an LED, you'd see the potential difference varying much more, because a lightbulb behaves like a "pure" resistor, whereas an LED self-adjusts to some extent, modifying its resistance as the voltage pressure changes.

Now touch the probes to the two terminals of the potentiometer that we're using, so that you can measure the potential difference between them. The potentiometer and the LED share the total available voltage, so when the potential difference (the voltage drop) around the potentiometer goes up, the potential difference around the LED goes down, and vice versa. See Figures 1-55 through 1-57. A few things to keep in mind:

- If you add the voltage drops across the devices in the circuit, the total is the same as the voltage supplied by the batteries.
- You measure voltage relatively, between two points in a circuit.
- Apply your meter like a stethoscope, without disturbing or breaking the connections in the circuit.

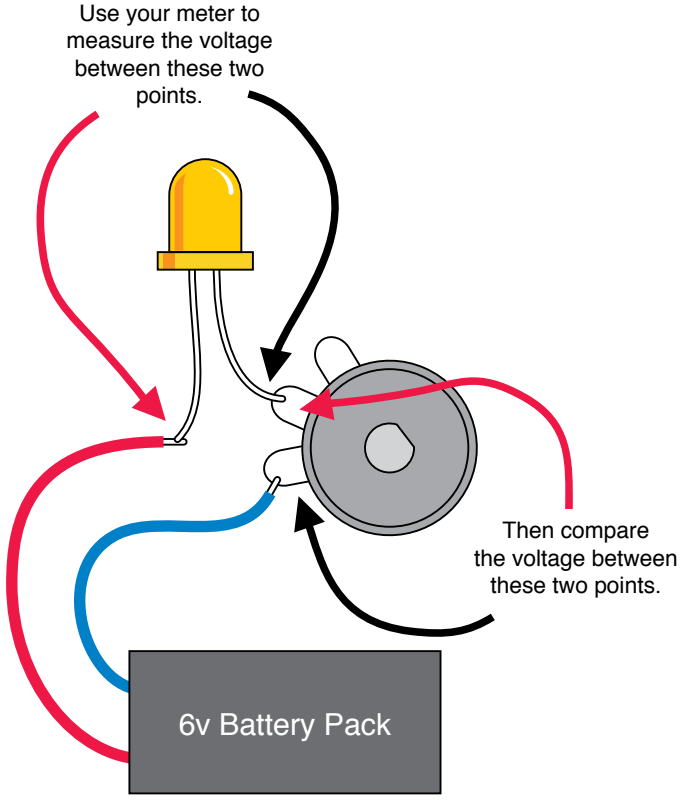



Figure 1-55. *How to measure voltage in a simple circuit.*

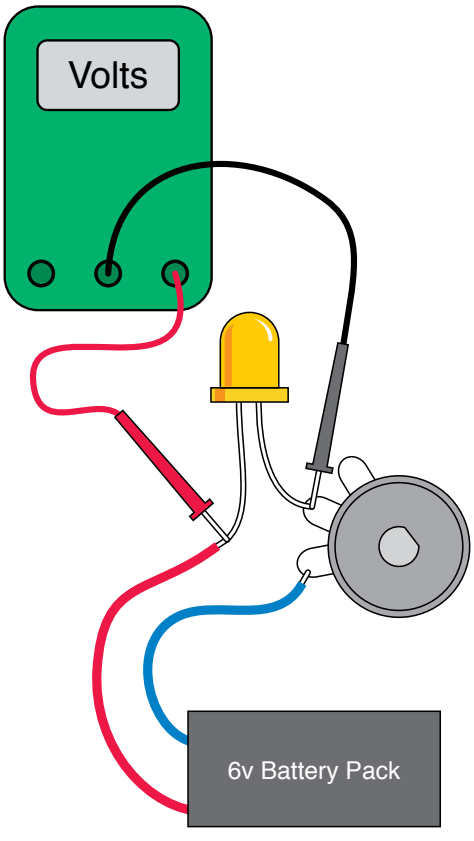



Figure 1-56. *The meter shows how much voltage the LED takes.*

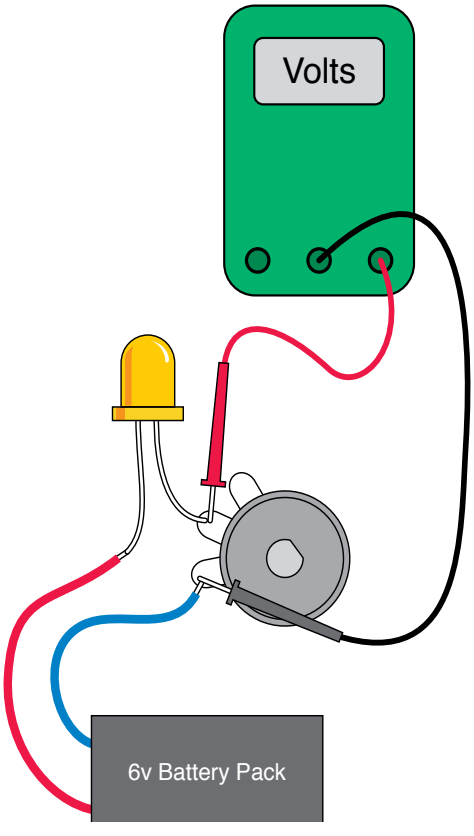



Figure 1-57. *The meter shows how much voltage the potentiometer takes.*

## Checking the Flow

Now I want you to make a different measurement. I want you to measure the flow, or current, in the circuit, using your meter set to mA (milliamps). Remember, to measure current:

- You can only measure current when it passes *through* the meter.
- You have to insert your meter into the circuit.
- Too much current will blow the fuse inside your meter.

Make sure you set your meter to measure mA, not volts, before you try this. Some meters require you to move one of your leads to a different socket on the meter, to measure mA. See Figures 1-58 through 1-61.

Figure 1-58. *Any meter will blow its internal fuse if you try to make it measure too high an amperage. In our circuit, this is not a risk as long as you keep the potentiometer in the middle of its range. Choose "mA" for milliamps and remember that the meter displays numbers that mean thousandths of an amp.*

Figure 1-59

Figure 1-60

Figure 1-61. *A manual meter such as the one here may require you to shift the red lead to a different socket, to measure milliamps. Most modern meters don't require this until you are measuring higher currents.*

Insert your meter into the circuit, as shown in Figure 1-62. Don't turn the potentiometer more than halfway up. The resistance in the potentiometer will protect your meter, as well as the LED. If the meter gets too much current, you'll find yourself replacing its internal fuse.

As you adjust the potentiometer up and down a little, you should find that the varying resistance in the circuit changes the flow of current—the amperage. This is why the LED burned out in the previous experiment: too much current made it hot, and the heat melts it inside, just like the fuse in the previous experiment. *A higher resistance limits the flow of current, or amperage*.

Now insert the meter in another part of the circuit, as shown in Figure 1-63. As you turn the potentiometer up and down, you should get exactly the same results as with the configuration in Figure 1-64. This is because the current is the same at all points in a similar circuit. *It has to be, because the flow of electrons has no place else to go*.

It's time now to nail this down with some numbers. Here's one last thing to try. Set aside the LED and substitute a 1KΩ resistor, as shown in Figure 1-64. The total resistance in the circuit is now 1KΩ plus whatever the resistance the potentiometer provides, depending how you set it. (The meter also has some resistance, but it's so low, we can ignore it.)

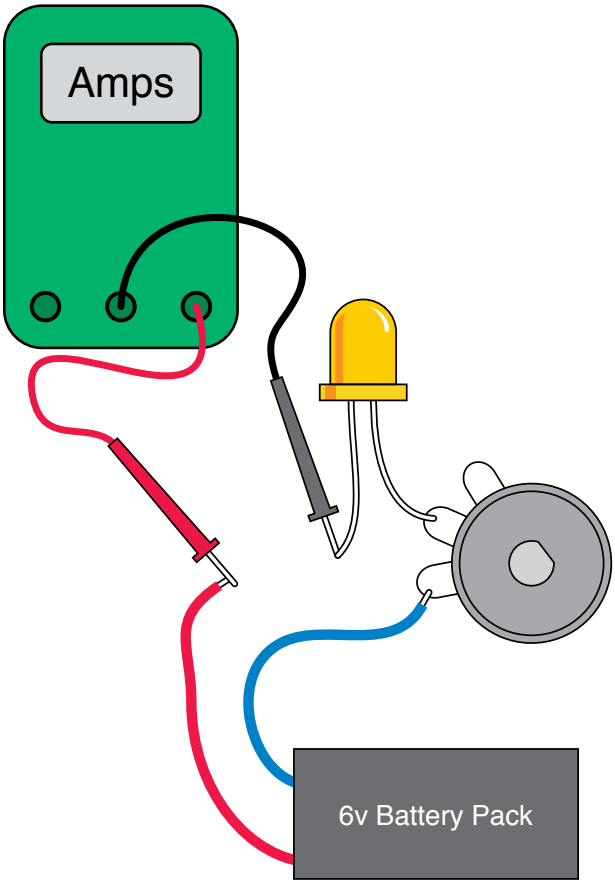



Figure 1-62. *To measure amps, as illustrated here and in Figure 1-63, the current has to pass through the meter. When you increase the resistance, you restrict the current flow, and the lower flow makes the LED glow less brightly.*

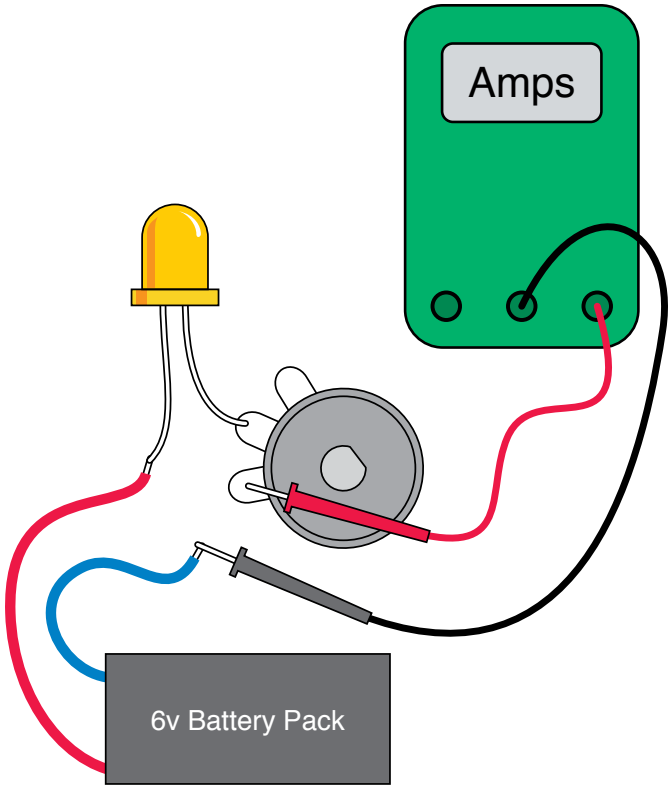



Figure 1-63

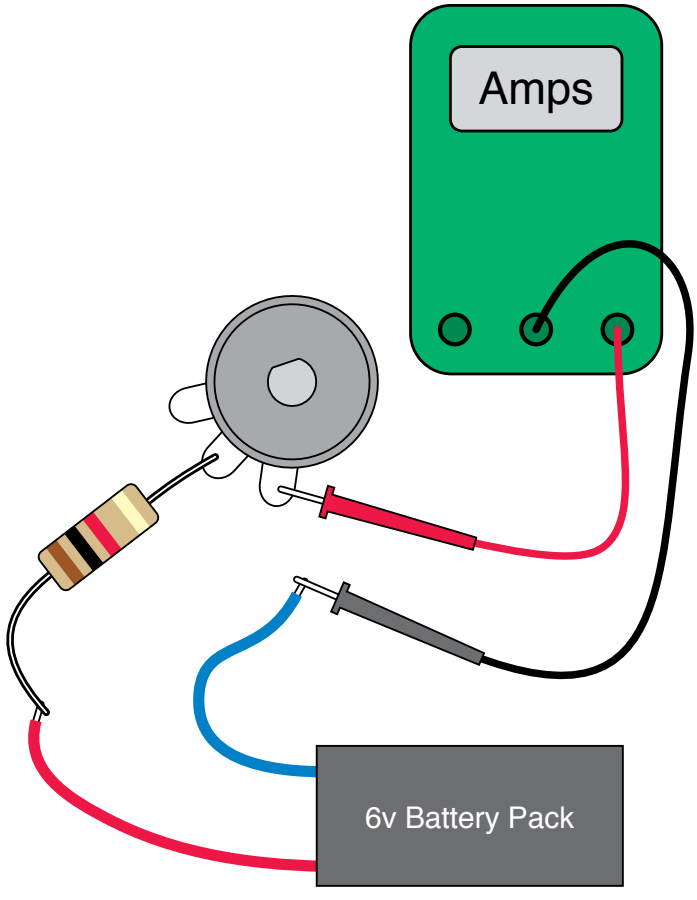



Figure 1-64. *If you substitute a resistor instead of the LED, you can confirm that the current flowing through the circuit varies with the total resistance in the circuit, if the voltage stays the same.*

Turn the potentiometer all the way counterclockwise, and you have a total of 3K resistance in the circuit. Your meter should show about 2 mA flowing. Now turn the potentiometer halfway, and you have about 2K total resistance. You should see about 3 mA flowing. Turn the potentiometer all the way clockwise, so there's a total of 1K, and you should see 6 mA flowing. You may notice that if we multiply the resistance by the amperage, we get 6 each time—which just happens to be the voltage being applied to the circuit. See the following table.

| Total resistance | Current | Voltage |
|---|---|---|
| (KΩ) | (mA) | (Volts) |
| 3 | 2 | 6 |
| 2 | 3 | 6 |
| 1 | 6 | 6 |

In fact, we could say:

voltage = kilohms × milliamps

But wait a minute: 1K is 1,000 ohms, and 1mA is 1/1,000 of an amp. Therefore, our formula should really look like this:

voltage = (ohms × 1,000) × (amps/1,000)

The two factors of 1,000 cancel out, so we get this:

volts = ohms × amps

This is known as Ohm's Law. See the section, "Fundamentals: Ohm's Law," on the following page.

## FUNDAMENTALS

### Series and parallel

Before we go any further, you should know how resistance in a circuit increases when you put resistors in series or in parallel. Figures 1-65 through 1-67 illustrate this. Remember:

- Resistors in series are oriented so that one follows the other.
- Resistors in parallel are oriented side by side.

When you put two equal-valued resistors in series, you double the total resistance, because electricity has to pass through two barriers in succession.

When you put two equal-valued resistors in parallel, you divide the total resistance by two, because you're giving the electricity two paths which it can take, instead of one.

In reality we don't normally need to put resistors in parallel, but we often put other types of components in parallel. Lightbulbs in your house, for instance, are all wired that way. So, it's useful to understand that resistance in a circuit goes down if you keep adding components in parallel.

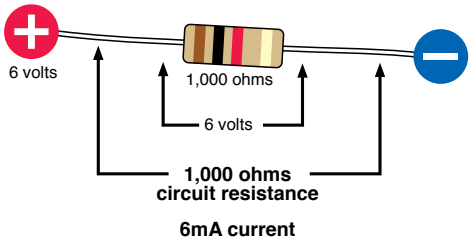



Figure 1-65. *One resistor takes the entire voltage, and according to Ohm's Law, it draws v/R = 6/1,000 = 0.006 amps = 6mA of current.*

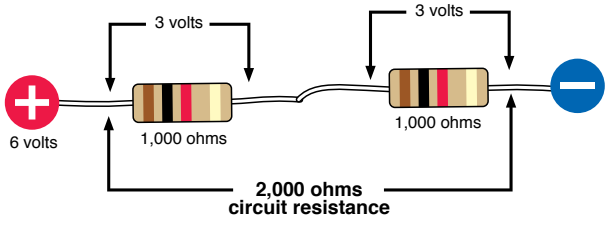



Figure 1-66. *When two resistors are in series, the electricity has to pass through one to reach the other, and therefore each of them takes half the voltage. Total resistance is now 2,000 ohms, and according to Ohm's Law, the circuit draws v/R = 6/2,000 = 0.003 amps = 3mA of current.*

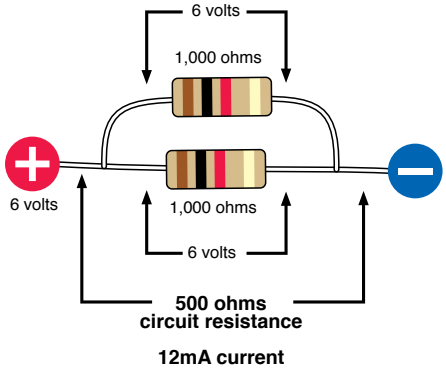



Figure 1-67. *When two resistors are in parallel, each is exposed to the full voltage, so each of them takes 6 volts. The electricity can now flow through both at once, so the total resistance of the circuit is half as much as before. According to Ohm's Law, the circuit draws v/R = 6/500 = 0.012 amps = 12mA of current.*

FUNDAMENTALS

### Ohm's Law

For reasons I'll explain in a moment, amps are normally abbreviated with the letter I. V stands for volts and R stands for resistance in ohms (because the omega symbol, Ω, is not easily generated from most keyboards). Using these symbols, you can write Ohm's Law in three different ways:

$V = I \times R$

$I = V/R$

$R = V/I$

Remember, V is a *difference* in voltage between two points in a simple circuit, R is the resistance in ohms *between* the same two points, and I is the current in amps flowing *through* the circuit between the two points.

Letter I is used because originally current was measured by its *inductance*, meaning the ability to induce magnetic effects. It would be much less confusing to use A for amps, but unfortunately it's too late for that to happen.

## Using Ohm's Law

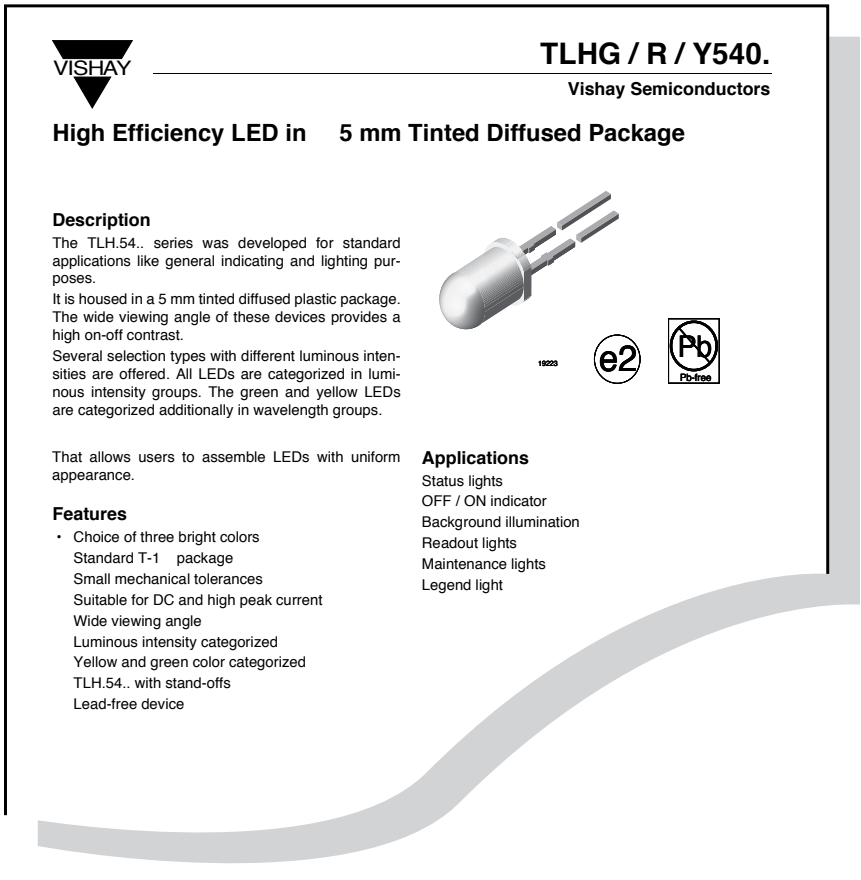
Ohm's Law is extremely useful. For example, it helps us to figure out whether a component can be used safely in a circuit. Instead of stressing the component until we burn it out, we can predict whether it will work.

For instance, the first time you turned the potentiometer, you didn't really know how far you could go until the LED burned out. Wouldn't it be useful to know precisely what resistance to put in series with an LED, to protect it adequately while providing as much light as possible?

## How to Read a Data Sheet

Like most information, the answer to this question is available online.

Here's how you find a manufacturer's data sheet (Figure 1-68). First, find the component that you're interested in from a mail-order source. Next, Google the part number and manufacturer's name. Usually the data sheet will pop up as the first hit. A source such as *Mouser.com* makes it even easier by giving you a direct link to manufacturers' data sheets for many products.



VISHAY

**TLHG / R / Y540.**

**Vishay Semiconductors**

**High Efficiency LED in 5 mm Tinted Diffused Package**

**Description**

The TLH.54.. series was developed for standard applications like general indicating and lighting purposes.

It is housed in a 5 mm tinted diffused plastic package. The wide viewing angle of these devices provides a high on-off contrast.

Several selection types with different luminous intensities are offered. All LEDs are categorized in luminous intensity groups. The green and yellow LEDs are categorized additionally in wavelength groups.

That allows users to assemble LEDs with uniform appearance.

**Features**

- Choice of three bright colors
  Standard T-1 package
  Small mechanical tolerances
  Suitable for DC and high peak current
  Wide viewing angle
  Luminous intensity categorized
  Yellow and green color categorized
  TLH.54.. with stand-offs
  Lead-free device

**Applications**

Status lights
OFF / ON indicator
Background illumination
Readout lights
Maintenance lights
Legend light

Figure 1-68. *The beginning of a typical data sheet, which includes all relevant specifications for the product, freely available online.*

## BACKGROUND

### How much voltage does a wire consume?

Normally, we can ignore the resistance in electric wires, such as the little leads of wire that stick out of resistors, because it's trivial. However, if you try to force large amounts of current through long lengths of thin wire, the resistance of the wire can become important.

How important? Once again, we can use Ohm's Law to find out.

Suppose that a very long piece of wire has a resistance of 0.2Ω. And we want to run 15 amps through it. How much voltage will the wire steal from the circuit, because of its resistance?

Once again, you begin by writing down what you know:

$R = 0.2$

$I = 15$

We want to know V, the potential difference, for the wire, so we use the version of Ohm's Law that places V on the left side:

$V = I \times R$

Now plug in the values:

$V = 15 \times 0.2 = 3$ volts

Three volts is not a big deal if you have a high-voltage power supply, but if you are using a 12-volt car battery, this length of wire will take one-quarter of the available voltage.

Now you know why the wiring in automobiles is relatively thick—to reduce its resistance well below 0.2Ω. See Figure 1-69.

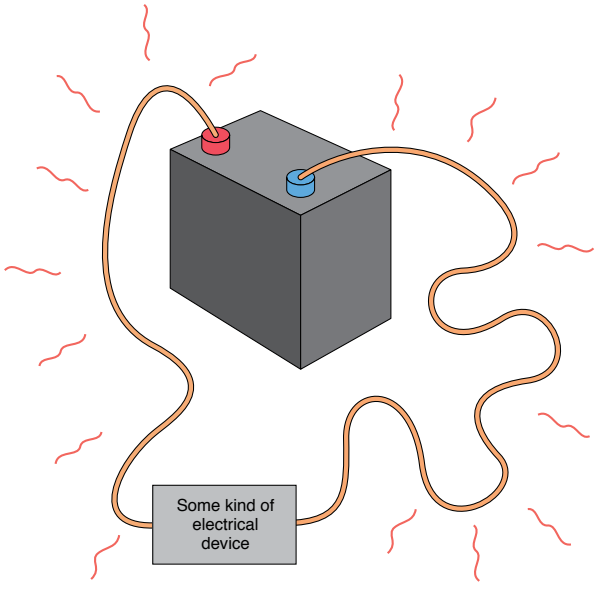



Figure 1-69. *When a 12-volt car battery runs some kind of electrical device through a long piece of thin wire, the resistance of the wire steals some of the voltage and dissipates it as heat.*

BACKGROUND

## The origins of wattage

James Watt (Figure 1-70) is known as the inventor of the steam engine. Born in 1736 in Scotland, he set up a small workshop in the University of Glasgow, where he struggled to perfect an efficient design for using steam to move a piston in a cylinder. Financial problems and the primitive state of the art of metal working delayed practical applications until 1776.

Despite difficulties in obtaining patents (which could only be granted by an act of parliament in those times), Watt and his business partner eventually made a lot of money from his innovations. Although he predated the pioneers in electricity, in 1889 (70 years after his death), his name was assigned to the basic unit of electric power that can be defined by multiplying amperes by volts. See the Fundamentals section, "Watt Basics," on page 31.

Figure 1-70. *James Watt's development of steam power enabled the industrial revolution. After his death, he was honored by having his name applied to the basic unit of power in electricity.*

Here's an example. Suppose I want a red LED, such as the Vishay part TLHR5400, which has become such a common item that I can buy them individually for 9 cents apiece. I click the link to the data sheet maintained by the manufacturer, Vishay Semiconductor. Almost immediately I have a PDF page on my screen. This data sheet is for TLHR, TLHG, and TLHY types of LED, which are red, green, and yellow respectively, as suggested by the R, G, and Y in the product codes. I scroll down and look at the "Optical and Electrical Characteristics" section. It tells me that under conditions of drawing a current of 20 mA, the LED will enjoy a "Typ," meaning, typical, "forward voltage" of 2 volts. The "Max," meaning maximum, is 3 volts.

Let's look at one other data sheet, as not all of them are written the same way. I'll choose a different LED, the Kingbright part WP7113SGC. Click on the link to the manufacturer's site, and I find on the second page of the data sheet a typical forward voltage of 2.2, maximum 2.5, and a maximum forward current of 25 mA. I also find some additional information: a maximum reverse voltage of 5 and maximum reverse current of 10 uA (that's microamps, which are 1,000 times smaller than milliamps). This tells us that you should avoid applying excessive voltage to the LED the wrong way around. If you exceed the reverse voltage, you risk burning out the LED. Always observe polarity!

Kingbright also warns us how much heat the LED can stand: 260° C (500° F) for a few seconds. This is useful information, as we'll be putting aside our alligator clips and using hot molten solder to connect electrical parts in the near future. Because we have already destroyed a battery, a fuse, and an LED in just four experiments, maybe you won't be surprised when I tell you that we will destroy at least a couple more components as we test their limits with a soldering iron.

Anyway, now we know what an LED wants, we can figure out how to supply it. If you have any difficulties dealing with decimals, check the Fundamentals section "Decimals," on the next page, before continuing.

## How Big a Resistor Does an LED Need?

Suppose that we're use the Vishay LED. Remember its requirements from the data sheet? Maximum of 3 volts, and a safe current of 20mA.

I'm going to limit it to 2.5 volts, to be on the safe side. We have 6 volts of battery power. Subtract 2.5 from 6 and we get 3.5. So we need a resistor that will take 3.5 volts from the circuit, leaving 2.5 for the LED.

The current flow is the same at all places in a simple circuit. If we want a maximum of 20mA to flow through the LED, the same amount of current will be flowing through the resistor.

Now we can write down what we know about the resistor in the circuit. Note that we have to convert all units to volts, amps, and ohms, so that 20mA should be written as 0.02 amps:

V = 3.5 (the potential drop across the resistor)
I = 0.02 (the current flowing through the resistor)

We want to know R, the resistance. So, we use the version of Ohm's Law that puts R on the left side:

$$R = V/I$$

Now plug in the values:

$$R = 3.5/0.02$$

Run this through your pocket calculator if you find decimals confusing. The answer is:

$$R = 175\Omega$$

It so happens that 175Ω isn't a standard value. You may have to settle for 180 or 220Ω, but that's close enough.

Evidently the 470Ω resistor that you used in Experiment 3 was a very conservative choice. I suggested it because I said originally that you could use any LED at all. I figured that no matter which one you picked, it should be safe with 470Ω to protect it.

## Cleanup and Recycling

The dead LED can be thrown away. Everything else is reusable.

### FUNDAMENTALS

### Decimals

Legendary British politician Sir Winston Churchill is famous for complaining about "those damned dots." He was referring to decimal points. Because Churchill was Chancellor of the Exchequer at the time, and thus in charge of all government expenditures, his difficulty with decimals was a bit of a problem. Still, he muddled through in time-honored British fashion, and so can you.

You can also use a pocket calculator—or follow two basic rules.

### Doing multiplication: combine the zeros

Suppose you need to multiply 0.04 by 0.005:

1. Count the total number of zeros following both of the decimal points. In this case, three zeros.
2. Multiply the numbers which follow the zeros. In this case, $4 \times 5 = 20$.
3. Write down the result as 0 followed by a decimal point, followed by the number of zeros, followed by the multiplication result. Like this: 0.00020, which is the same as 0.0002.

### Doing division: cancel the zeros

Suppose you need to divide 0.006 by 0.0002:

1. Shift the decimal points to the right, in both the numbers, by the same number of steps, until both the numbers are greater than 1. In this case, shift the point four steps in each number, so you get 60 divided by 2.
2. Do the division. The result in this case is 30.

THEORY

## Doing the math on your tongue

I'm going to go back to the question I asked in the previous experiment: why didn't your tongue get hot?

Now that you know Ohm's Law, you can figure out the answer in numbers. Let's suppose the battery delivered its rated 9 volts, and your tongue had a resistance of 50K, which is 50,000 ohms. Write down what you know:

V = 9

R = 50,000

We want to know the current, I, so we use the version of Ohm's Law that puts this on the left:

I = V/R

Plug in the numbers:

I = 9/50,000 = 0.00018 amps

Move the decimal point three places to convert to milliamps:

I = 0.18 mA

That's a tiny current that will not produce much heat at 9 volts.

What about when you shorted out the battery? How much current made the wires get hot? Well, suppose the wires had a resistance of 0.1 ohms (probably it's less, but I'll start with 0.1 as a guess). Write down what we know:

V = 1.5

R = 0.1

Once again we're trying to find I, the current, so we use:

I = V/R

Plug in the numbers:

I = 1.5/0.1 = 15 amps

That's 100,000 times the current that may have passed through your tongue, which would have generated much more heat, even though the voltage was lower.

Could that tiny little battery really pump out 15 amps? Remember that the battery got hot, as well as the wire. This tells us that the electrons may have met some resistance inside the battery, as well as in the wire. (Otherwise, where else did the heat come from?) Normally we can forget about the internal resistance of a battery, because it's so low. But at high currents, it becomes a factor.

I was reluctant to short-circuit the battery through a meter, to try to measure the current. My meter will fry if the current is greater than 10A. However I did try putting other fuses into the circuit, to see whether they would blow. When I tried a 10A fuse, it did not melt. Therefore, for the brand of battery I used, I'm fairly sure that the current in the short circuit was under 10A, but I know it was over 3A, because the 3A fuse blew right away.

The internal resistance of the 1.5-volt battery prevented the current in the short circuit from getting too high. This is why I cautioned against using a larger battery (especially a car battery). Larger batteries have a much lower internal resistance, allowing dangerously high currents which generate explosive amounts of heat. A car battery is designed to deliver literally hundreds of amps when it turns a starter motor. That's quite enough current to melt wires and cause nasty burns. In fact, you can weld metal using a car battery.

Lithium batteries also have low internal resistance, making them very dangerous when they're shorted out. High current can be just as dangerous as high voltage.

FUNDAMENTALS

## Watt basics

So far I haven't mentioned a unit that everyone is familiar with: watts.

A watt is a unit of work. Engineers have their own definition of work—they say that work is done when a person, an animal, or a machine pushes something to overcome mechanical resistance. Examples would be a steam engine pulling a train on a level track (overcoming friction and air resistance) or a person walking upstairs (overcoming the force of gravity).

When electrons push their way through a circuit, they are overcoming a kind of resistance, and so they are doing work, which can be measured in watts. The definition is easy:

watts = volts × amps

Or, using the symbols customarily assigned, these three formulas all mean the same thing:

$W = V \times I$

$V = W/I$

$I = W/V$

Watts can be preceded with an "m," for "milli," just like volts:

| Number of watts | Usually expressed as | Abbreviated as |
|---|---|---|
| 0.001 watts | 1 milliwatt | 1mW |
| 0.01 watts | 10 milliwatts | 10 mW |
| 0.1 watts | 100 milliwatts | 100 mW |
| 1 watt | 1,000 milliwatts | 1W |

Because power stations, solar installations, and wind farms deal with much larger numbers, you may also see references to kilowatts (using letter K) and megawatts (with a capital M, not to be confused with the lowercase m used to define milliwatts):

| Number of watts | Usually expressed as | Abbreviated as |
|---|---|---|
| 1,000 watts | 1 kilowatt | 1 KW |
| 1,000,000 watts | 1 megawatt | 1 MW |

Lightbulbs are calibrated in watts. So are stereo systems. The watt is named after James Watt, inventor of the steam engine. Incidentally, watts can be converted to horsepower, and vice versa.

THEORY

## Power assessments

I mentioned earlier than resistors are commonly rated as being capable of dealing with 1/4 watt, 1/2 watt, 1 watt, and so on. I suggested that you should buy resistors of 1/4 watt or higher. How did I know this?

Go back to the LED circuit. Remember we wanted the resistor to drop the voltage by 3.5 volts, at a current of 20 mA. How many watts of power would this impose on the resistor?

Write down what you know:

V = 3.5 (the voltage drop imposed by the resistor)

I = 20mA = 0.02 amps (the current flowing through the resistor)

We want to know W, so we use this version of the formula:

$W = V \times I$

Plug in the values:

$W = 3.5 \times 0.02 = 0.07$ watts (the power being dissipated by the resistor)

Because 1/4 watt is 0.25 watts, obviously a 1/4 watt resistor will have about four times the necessary capacity. In fact you could have used a 1/8 watt resistor, but in future experiments we may need resistors that can handle 1/4 watt, and there's no penalty for using a resistor that is rated for more watts than will actually pass through it.

# Experiment 26: Tabletop Power Generation

If you have just three components, you can see magnetism generating electricity right in front of you, right now.

You will need:

- Cylindrical neodymium magnet, 3/4-inch diameter, axially magnetized. Quantity: 1. (Obtainable online at sites such as *http://www.kjmagnetics.com*.)
- Spool of hookup wire, 26-gauge, 100 feet. Quantity: 1.
- Spool of magnet wire, quarter-pound, 26-gauge, about 350 feet. Quantity: 1. (Search online for sources for "magnet wire.")
- Generic LED. Quantity: 1.
- 100 µF electrolytic capacitor. Quantity: 1.
- Signal diode, 2N4001 or similar. Quantity: 1.
- Jumper wires with alligator clips on the ends. Quantity: 2.

## Procedure

You may be able to make this experiment work with the spool of hookup wire, depending on the size of the spool relative to the size of your magnet, but as the results are more likely to be better with the magnet wire, I'll assume that you're using that—initially, at least. The advantage of the magnet wire is that its very thin insulation allows the coils to be closely packed, increasing their inductance.

First peek into the hollow center of the spool to see if the inner end of the wire has been left accessible, as is visible in Figures 5-18 and 5-19. If it hasn't, you have to unwind the wire onto any large-diameter cylindrical object, then rewind it back onto the spool, this time taking care to leave the inner end sticking out.

Scrape the transparent insulation off each end of the magnet wire with a utility knife or sandpaper, until bare copper is revealed. To check, attach your meter, set to measure ohms, to the free ends of the wire. If you make a good contact, you should measure a resistance of 30 ohms or less.

Place the spool on a nonmagnetic, nonconductive surface such as a wooden, plastic, or glass-topped table. Attach the LED between the ends of the wire using jumper wires. The polarity is not important. Now take a cylindrical neodymium magnet of the type shown in Figure 5-20 and push it quickly down into the hollow core, then pull it quickly back out. See Figure 5-21. You should see the LED blink, either on the down stroke or the up stroke.

The same thing may or may not happen if you use 100 feet of 26-gauge hookup wire. Ideally, your cylindrical magnet should fit fairly closely in the hollow center of the spool. If there's a big air gap, this will greatly reduce the effect of the magnet. Note that if you use a weaker, old-fashioned iron magnet instead of a neodymium magnet, you may get no result at all.

Figure 5-18. *An everyday 100-foot spool of hookup wire is capable of demonstrating the inductive power of a coil.*

Figure 5-19. *Magnet wire has thinner insulation than hookup wire, allowing the turns to be more densely packed, inducing a more powerful magnetic field.*

## Blood Blisters and Dead Media

*Neodymium magnets can be hazardous. They're brittle and can shatter if they slam against a piece of magnetic metal (or another magnet). For this reason, many manufacturers advise you to wear eye protection.*

*Because a magnet pulls with increasing force as the distance between it and another object gets smaller, it closes the final gap very suddenly and powerfully. You can easily pinch your skin and get blood blisters.*

*If there's an object made of iron or steel anywhere near a neodymium magnet, the magnet will find it and grab it, with results that may be unpleasant, especially if the object has sharp edges and your hands are in the vicinity. When using a magnet, create a clear area on a nonmagnetic surface, and watch out for magnetic objects underneath the surface. My magnet sensed a steel screw embedded in the underside of a kitchen countertop, and slammed itself into contact with the countertop unexpectedly.*

*Be aware that magnets create magnets. When a magnetic field passes across an iron or steel object, the object picks up some magnetism of its own. Be careful not to magnetize your watch!*

*Don't use magnets anywhere near a computer, a disk drive, credit cards with magnetic stripes, cassettes of any type, and other media. Also keep magnets well away from TV screens and video monitors (especially cathode-ray tubes). Last but not least, powerful magnets can interfere with the normal operation of cardiac pacemakers.*

Figure 5-20. *Three neodymium magnets, 1/4-, 1/2-, and 3/4-inch in diameter. I would have preferred to photograph them standing half-an-inch apart, but they refused to permit it.*

Figure 5-21. *By moving a magnet vigorously up and down through the center of a coil, you generate enough power to make the LED flash brightly.*

Here's another thing to try. Disconnect the LED and connect a 100 µF electrolytic capacitor in series with signal diode, as shown in Figure 5-23. Attach your meter, measuring volts, across the capacitor. If your meter has a manual setting for its range, set it to 20V DC. Make sure the positive (unmarked) side of the diode is attached to the negative (marked) side of the capacitor, so that positive voltage will pass through the capacitor and then through the diode.

Now move the magnet vigorously up and down in the coil. The meter should show that the capacitor is accumulating charge, up to about 10 volts. When you stop moving the magnet, the voltage reading will gradually decline, mostly because the capacitor discharges itself through the internal resistance of your meter.

This experiment is more important than it looks. Bear in mind that when you push the magnet into the coil, it induces current in one direction, and when you pull it back out again, it induces current in the opposite direction. You are actually generating alternating current.

The diode only allows current to flow one way through the circuit. It blocks the opposite flow, which is how the capacitor accumulates its charge. If you jump to the conclusion that diodes can be used to change alternating current to direct current, you're absolutely correct. We say that the diode is "rectifying" the AC power.

Experiment 24 showed that voltage can create a magnet. Experiment 25 has shown that a magnet can create voltage. We're now ready to apply these concepts to the detection and reproduction of sound.

Figure 5-22. *Because inductance increases with the diameter of a coil and with the square of the number of turns, your power output from moving a magnet through the coil can increase dramatically with scale. Those wishing to live "off the grid" may consider this steam-powered configuration, suitable for powering a three-bedroom home.*

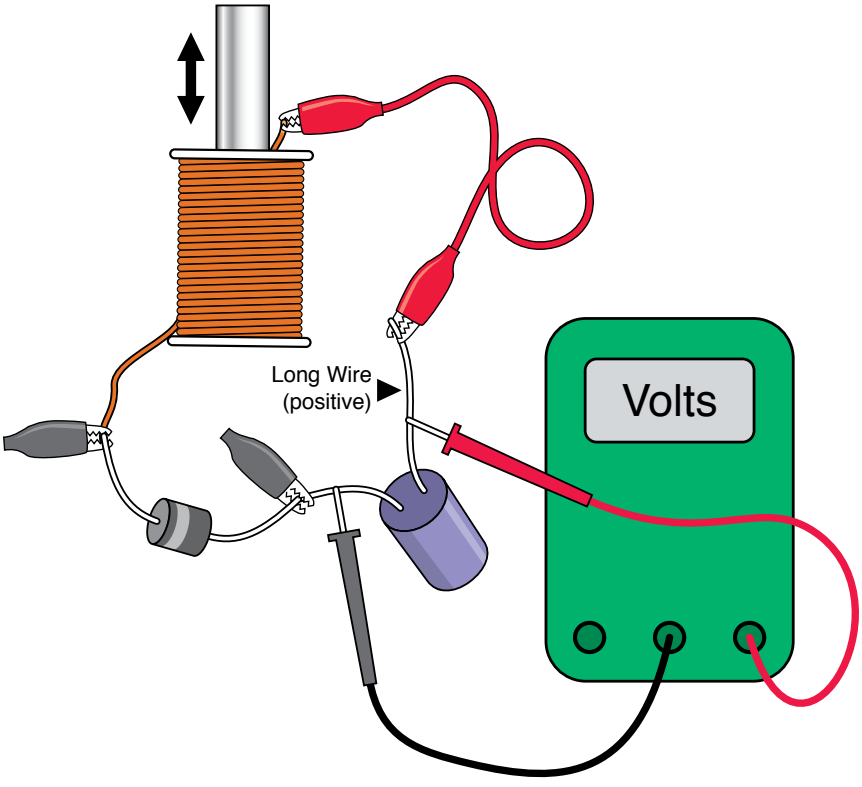



Figure 5-23. *Using a diode in series with a capacitor, you can charge the capacitor with the pulses of current that you generate by moving the magnet through the center of the coil. This demo illustrates the principle of rectifying alternating current.*

# Acknowledgments

My association with MAKE magazine began when its editor, Mark Frauenfelder, asked me to write for it. I have always been very grateful to Mark for his support of my work. Through him I became acquainted with the exceptionally capable and motivated production staff at MAKE. Gareth Branwyn eventually suggested that I might like to write an introductory guide to electronics, so I am indebted to Gareth for initiating this project and supervising it as my editor. After I wrote an outline in which I described my idea for "Learning by Discovery" and the associated concept that cutting open components or burning them up can be an educational activity, MAKE's publisher, Dale Dougherty, uttered the memorable phrase, "I want this book!" Therefore I offer special thanks to Dale for his belief in my abilities. Dan Woods, the associate publisher, was also extremely supportive.

The production process was swift, competent, and painless. For this I thank my editor at O'Reilly, Brian Jepson; senior production editor Rachel Monaghan; copyeditor Nancy Kotary; proofreader Nancy Reinhardt; indexer Julie Hawks; designer Ron Bilodeau; and Robert Romano, who tweaked my illustrations. Most of all I am indebted to Bunnie Huang, my technical advisor, who reviewed the text in detail and knows a bunch of stuff that I don't know. Any residual errors are still my fault, even though I would prefer to blame them on Bunnie.

Thanks also to Matt Mets, Becky Stern, Collin Cunningham, Marc de Vinck, Phillip Torrone, Limor Fried, John Edgar Park, John Baichtal, and Jonathan Wolfe for helping out with some last-minute project testing.

Lastly I have to mention the genius of John Warnock and Charles Geschke, founders of Adobe Systems and creators of the very beautiful PostScript language, which revolutionized all of publishing. The horror of attempting to create this book using graphic-arts tools from…some other company…is almost unimaginable. In fact, without Illustrator, Photoshop, Acrobat, and InDesign, I doubt I would have attempted the task. I am also indebted to the Canon 1Ds with 100mm macro lens, which took many of the pictures in this book.

No free samples or other favors were received from any of the vendors mentioned herein, with the exception of two sample books from MAKE, which I read to ensure that I was not duplicating anything that had already been published.

# Index

## Numbers


2N2222 transistor, 73
  (see also Experiments 11 and 15)
2N6027 programmable unijunction transistor (see Experiment 14: A Pulsing Glow)
3M, 319
  breadboard, 39
  single inline sockets and headers, 103
9-volt battery, 5
12-key numeric keypad, 151
40xxB chip, 191
40xx chip, 191
74ACTxx chip, 191
74ACxx chip, 191
74AHCTxx chip, 191
74AHCxx chip, 191
74HC00 chip (see Experiment 22: Flipping and Bouncing)
74HC00 quad 2-input NAND chip (see Experiment 19: Learning Logic)
74HC02 chip (see Experiment 22: Flipping and Bouncing)
74HC04 chip, 149
  (see also Experiment 20: A Powerful Combination)
74HC08 quad 2-input AND chip (see Experiments 19 and 20)
74HC32 chip (see Experiment 21: Race to Place)
74HCTxx chip, 191
74HCxx chip, 191
74LS06 open-collector inverter chip, 150
74LS27 chip (see Experiment 23: Nice Dice)
74LS27 triple-input NOR chip, 150
74LS92 chip, 216
74LS92 chip (see Experiment 23: Nice Dice)
74LS92 counter chip, 150
74LVxx chip, 191
555 timer chip, 150
  alternating current, 248
  astable mode, 164–165
  audio frequencies, 256
  bistable configuration, 176–177
  frequency in astable mode, 166
  history, 160
  limits, 161
  monostable mode, 158–159
  powering up in bistable mode, 225
  pulse duration, 157
  reset voltage, 156
  square wave, 258
  trigger voltage, 156
  usefulness, 161
  (see also Experiments 16-24, 29, 32-33)
4026 chip, 150
  clock disable, 175
  (see also Experiment 18: Reaction Timer)
7400 family of integrated circuits, 192


## A


ABS (acrylonitrile butadiene styrene)
  cutting, 270
  (see also Experiment 32: A Little Robot Cart)
AC adapter, 39
  modifying, 111
AC adapter plugs, 55–56
AC (alternating current), 12
Ace Hardware, 319
  wire, 101
Advanced Micro Circuits, 319
Akro-Grids, 229
Akro-Mils, 229, 319
alarms
  installation, 145–146
  intrusion (see Experiments 11, 15, and 24)
  magnetic sensor switches, 128
Alcoswitch, 319
  pushbutton, 42
All-Battery.com, 319
All Electronics, xii, 42, 319
  12-key numeric keypad, 151
  alligator clips, 4
  battery holders and connectors, 4
  desoldering wick, 98
  jumper wire assortment, 41
  patch cords, 41
  project boxes, 102
  solder, 100
  soldering stand, 98
  solder pump, 98
  switches, 42

alligator clips, 4
  copper, 101
All Spectrum Electronics, 319
  LEDs, 4
Alpha potentiometers, 4, 319
ALPS pushbutton, 319
alternating current, 12, 248
Amazon, 319
  deburring tool, 99
  electronic solder, 100
  GB Automatic Wire Strippers, 40
  pick and hook set, 99
amperage, 10
Ampère, André-Marie, 13
amperes, 36
  basics, 11
amplification, 87
amplifiers, 49
Amprobe, 319
amps, 11
Arduino, 319
  microcontrollers, 227
ArtCity, 319
  miniature hand saw, 99
The Art of Electronics, 235
audio amplifier (see Experiment 29: Filtering Frequencies)
audio distortion (see Experiment 30: Fuzz)
audio electronics, 227
AutoZone, 319
  fuses, 4
Avago, 319
  diodes, 103

## B

Background
  Clipping, 257
  Early switching systems, 49
  Father of electromagnetism, 13
  From Boole to Shannon, 184–185
  How chips came to be, 152
  How much voltage does a wire consume?, 27
  How the timer was born, 160
  Inventor of the battery, 12
  Joseph Henry, 238
  Logic gate origins, 192
  Maddened by measurement, 124
  Michael Faraday and capacitors, 64
  Mounting a loudspeaker, 87
  Origins of loudspeakers, 243
  Origins of programmable chips, 294
  Positive and negative, 35
  Soldering myths, 106
  Stomp-box origins, 260–261
  The confusing world of TTL and CMOS, 190–192
  The man who discovered resistance, 8
  The origins of wattage, 28
  Transistor origins, 78
  Why didn't your tongue get hot?, 10
banana plugs, 97
Bardeen, John, 78
BASIC Stamp microcontrollers, 227, 294, 317, 319
batteries, 3, 103
  9-volt, 5
  abusing (see Experiment 2: Let's Abuse a Battery!)
  amperage, 10
  ampere basics, 11
  current, direct and alternating, 12
  heat, 10
  inventor, 12
  lithium, 9, 30
  making (see Experiment 5: Let's Make a Battery)
  schematics, 53
  voltage, 10
  volt basics, 11
  (see also Experiment 1: Taste the Power!)
battery holders and connectors, 3
battery life, 123
Bell, Alexander Graham, 243
benders, plastic, 272
binary arithmetic, 217
binary code, 214–220
BI Technologies, 319
  potentiometers, 4
BK Precision, 319
  multimeter, 2
boardmount sockets and pinstrip headers, 103
book sources, 234–235
Boolean logic, 184, 186
Boole, George, 184
Brattain, Walter, 78
breadboard alarm circuit, 135–136
breadboards, 39, 65–67
  (see also Experiments 8, 20, and 21)
break-to-make transistor circuit, 129–130
brushed DC motor, 280
Burkard, Johann, 261
Bussmann fuses, 319
Buzbee, Bill, 192

## C

calipers, 99
Camenzind, Hans, 160
capacitance, 3, 39, 64, 86, 133, 157, 180, 236, 246–248, 249, 252, 262
  farad, 61
capacitors, 42, 61
  basics, 62–63
  diodes, 241
  Faraday, Michael, 64
  getting zapped by, 62
  nonpolarized electrolytic capacitors, 249
  polarity, 63
  time and (see Experiment 9: Time and Capacitors)
  time constant, 71–72
  (see also Experiment 8: A Relay Oscillator)
ceramic capacitors, 43
Chicago lighting, 319
chips, 147
  74HC00 quad 2-input NAND chip (see Experiment 19: Learning Logic)
  74HC00 (see Experiment 22: Flipping and Bouncing)
  74HC02 (see Experiment 22: Flipping and Bouncing)
  74HC04 (see Experiment 20: A Powerful Combination)
  74HC08 quad 2-input AND chip (see Experiments 19 and 20)

74HC32 (see Experiment 21: Race to Place)
74LS06 open-collector inverter chip, 150
74LS27 (see Experiment 23: Nice Dice)
74LS27 triple-input NOR chip, 150
74LS92 counter chip, 150
74LS92 (see Experiment 23: Nice Dice)
555 timer (see 555 timer chip)
4026, 150
(see also Experiment 18: Reaction Timer)
choosing, 148–149
common part numbers, 193
floating pins, 175
history, 152
logic chips, 150
power supplies, 154
programmable chips, origins, 294
Churchill, Sir Winston, 29
circuit chips (see chips)
The Circuit Designer's Companion, 235
C&K
pushbutton, 42
switch, 319
clip-on meter test leads, 97
clipping, 257
CMOS chips, floating pins, 175
CMOS Sourcebook, 234
coil schematics, 238
coil voltage, 58
cold-weld, 106
combination lock circuit schematic, 198, 201
Common (COM) socket, 5, 6
Complementary metal–oxide semiconductor (CMOS), 190–192
computers, 232
magnets, 240
conductor, 6
control knobs, 229
controller chips
limitations, 315
programmable chips, origins, 294
(see also Experiment 34: Hardware Meets Software)
coulomb, 36
countersink, hand-cranked, 99
CraftAmerica, 319
crossover networks, 253–257
current
alternating, 248
checking flow, 21–25
direct and alternating, 12
transistors and, 80–81

## D

Darice, 319
Darice Mini-Storage boxes, 230
Davies, Ray, 260
DC (direct current), 12
DC power plug, 103
DC stepper motor, 280
DeArmond, Harry, 261
deburring tool, 99, 271
decimals, 29
Dellepiane, Flavio, 260
desoldering wick, 98
DeWalt, 320
DeWalt XRP jigsaw, 271
diesel engine, 236
Digi-Key, xi, 320
patch cords, 41
diodes, 103, 134
capacitors, 241
schematics, 134
direct current, 12
Directed switches, 320
distortion (see Experiment 30: Fuzz)
Doctronics, 233, 320
Doing the math on your tongue, 30
double-throw switch, 42, 46
DPDT relay, 103
Dummer, Geoffrey W. A., 152

## E

eBay, xii, 320
electrical potential, 36
electricity
magnetism, relationship, 236
nature of, 33
sound into, 244–245
electrolytic capacitors, 42, 61
electromagnetism, father of, 13
electromagnet (see Experiment 25: Magnetism)
Electronics Club, 233
electronic solder, 100
electronics-tutorials.ws, 233
Elenco, 320
helping hand, 96
The Encyclopedia of Electronic Circuits, 235
Essentials
All about diodes, 134
All about NPN and PNP transistors, 76–77
All about programmable unijunction transistors, 83–84
Battery life, 123
Logic gate basics, 186–189
Perfboard soldering procedure, 137
Real-world fault tracing, 139
Transistors and relays, 79
Everlight, 320
low-power LEDs, 150
Experiment 1: Taste the Power!, 5–9
cleanup and recycling, 9
further investigation, 8
procedure, 7
tools, 5
Experiment 2: Let's Abuse a Battery!, 9–13
cleanup and recycling, 13
procedure, 9–12
Experiment 3: Your First Circuit, 13–17
cleanup and recycling, 17
lighting LEDs, 16–17
setup, 13–15
Experiment 4: Varying the Voltage, 18–31
checking flow, 21–25
cleanup and recycling, 29
dimming LEDs, 19–25
manufacturer's data sheet, 26
Ohm's Law, 26
potentiometers, 18
size of resistor required by LED, 28
Experiment 5: Let's Make a Battery, 32–38
cleanup and recycling, 34
practical purposes, 37

Experiment 6: Very Simple Switching, 43–54
connection problems, 45
schematics, 50–54
testing, 45–49
tools, 44–45
Experiment 7: Relay-Driven LEDs, 55–59
AC adapter plugs, 55–56
how it works, 59
operating current, 58
procedure, 59
Experiment 8: A Relay Oscillator, 60–67
adding capacitance, 61–64
breadboarding circuits, 65–67
Experiment 9: Time and Capacitors, 68–72
voltage, resistance, and capacitance, 69–72
Experiment 10: Transistor Switching, 73–81
fingertip switching, 74–75
Experiment 11: A Modular Project, 82–93
amplification, 87–89
beyond persistence of vision, 86–87
enhancements, 92–93
pulsed output, 90–92
slow-speed oscillation, 85
wish list, 93
Experiment 12: Joining Two Wires Together, 104–113
adding insulation, 110–111
first solder join, 104–107
modifying AC adapter, 111
second solder join, 108
shortening power cords, 111–113
Experiment 13: Broil an LED, 114–116
heat-sinking, 115
Experiment 14: A Pulsing Glow, 117–126
finishing, 121–126
procedure for building this circuit, 120
resizing the circuit, 119–120
Experiment 15: Intrusion Alarm Revisited, 127–146
alarm installation, 145–146
blocking bad voltage, 132–134
breadboard alarm circuit, 135–136
break-to-make transistor circuit, 129–130
conclusion, 146
final test, 145
installing switches, 142–143
magnetic sensor switches, 128
perfboarding, 136–139
self-locking relay, 131–132
soldering switches, 143–144
switches and inputs for alarm, 140–141
Experiment 16: Emitting a Pulse, 153–161
procedure, 153–162
Experiment 17: Set Your Tone, 162–169
astable modifications, 166–167
chaining chips, 167–170
procedure, 162–166
Experiment 18: Reaction Timer, 170–181
counting, 171–174
delay, 178–179
display, 170–171
enhancements, 180
pulse generation, 175
refinements, 176
reflex tester, 179
summary, 181
Experiment 19: Learning Logic, 181–196
Experiment 20: A Powerful Combination, 197–204
breadboarding, 200–201
computer interface, 202–203
enhancements, 203
incorrect inputs, 200
questions, 200
schematic, 198–199
Experiment 21: Race to Place, 205–210
breadboarding, 209–210
conceptual experiment, 205–209
enhancements, 210
goal, 205
(see also Experiment 36: The Lock, Revisited)
Experiment 22: Flipping and Bouncing, 211–213
how it works, 212–214
Experiment 23: Nice Dice, 214–222
binary code, 214–220
enhancements, 220–222
Experiment 24: Intrusion Alarm Completed, 223–226
delay before deactivation, 225–226
delayed activation, 223
keypad deactivation, 223–224
summary, 226
Experiment 25: Magnetism, 236–238
procedure, 236
Experiment 26: Tabletop Power Generation, 239–241
procedure, 239–242
Experiment 27: Loudspeaker Destruction, 242–245
procedure, 242
Experiment 28: Making a Coil React, 246–248
procedure, 246–248
Experiment 29: Filtering Frequencies, 249–256
adding an amplifier, 250–252
crossover networks, 253–257
procedure, 250
Experiment 30: Fuzz, 257–261
schematic, 258
Experiment 31: One Radio, No Solder, No Power, 262–267
enhancements, 265
Experiment 32: A Little Robot Cart, 268–284
bending, 272–273
circuit, 276–281
curving cuts, 271
framing your cart, 274–276
making 90 degree joints, 273–274
making plans, 272
mechanical power, 281–284

Experiment 33: Moving in Steps, 284–292
adding autonomy, 291
exploring your motor, 285–286
quick demo, 286–289
setting up light seeking robot, 291–292
speed control, 290–291
Experiment 34: Hardware Meets Software, 293–305
decoding the code, 302
editing code, 303
first program, 301
loops, 304–305
simulation, 303
software installation and setup, 296–300
Programming Editor software, 297–298
setting up hardware, 298–300
USB driver, 296–297
troubleshooting, 300–301
verifying connection, 300
Experiment 35: Checking the Real World, 306–310
procedure, 306–310
Experiment 36: The Lock, Revisited, 311–317
other controllers, 317–318
user input, 311–315
(see also Experiment 21: Race to Place)
Extech, 320
multimeter, 2

## F

Fairchild, 320
integrated circuit chips, 150
transistor, 42
voltage regulators, 151
Faraday, Michael, 64
farad basics, 61
fault tracing, 139
Field, Simon Quellan, 265
flat-format storage boxes, 230
floating pins, 175
Formosa, Dan, 261
Franklin, Benjamin, 35
frequencies (see Experiment 29: Filtering Frequencies)
FTM, 320
Fujitsu, 320
relays, 42
Fundamentals
555 timer chip frequency in astable mod, 166
555 timer chip pulse duration in monostable mode, 157
555 timer limits, 161
All about ABS, 269
All about limit switches, 278
All about motors, 280
All about perforated board, 116
All about switches, 46–48
Ampere basics, 11
A two-way relationship, 236
Basic PICAXE parameters, 305
Basic schematic symbols, 51–54
Capacitor basics, 62–63
Choosing chips, 148–149
Coil schematics and basics, 238
Common part numbers, 193
Counters and seven-segment displays, 173
Decimals, 29
Decoding resistors, 14–15
Direct and alternating current, 12
Farad basics, 61
Inside a relay, 58
Limitations of MCUs, 315
Ohms, 6
Ohm's Law, 26
PICAXE 08M extra features, 310
Rules for connecting logic gates, 194–195
Series and parallel, 25
Switch bounce, 174
The bistable 555 timer, 176–177
Unexplored territory, 316
Voltage regulators, 182
Volt basics, 11
Watt basics, 31
Where to find ABS, 269
Why the 555 is useful, 161
Wire gauges, 282
fuses, 4
fuzz box, 257, 260

## G

galvanometer, 13
GB Automatic Wire Strippers, 40
GB wire strippers, 320
general-duty soldering iron, 30 to 40 watts, 96
Getting Started in Electronic, 235
Getting Started with Arduino, 234
Gibson Maestro Fuzz-Tone, 260
grounding yourself, 172
Guru's Lair, 233

## H

hand-cranked countersink, 99
hand saw, miniature, 99
headphone, high-impedance (see Experiment 31: One Radio, No Solder, No Power)
heat, 10
heat guns, 98
warning, 110
heat-shrink tube, 101
heat-sinking, 115
helping hand, 96
Henry, Joseph, 237, 238
high-impedance headphone (see Experiment 31: One Radio, No Solder, No Power)
high voltage, 263
Hobbylinc, 320
miniature hand saw, 99
Home Depot, xii, 320
plywood, 102
wire, 101
hookup wire, 41

## I

IC sockets, 150
Ideal wire strippers, 320
incandescent lightbulb, 53
inductance, 26, 237, 241
self-inductance, 246
inductive reactance, 246

insulated binding posts, 103
insulator, 6
integrated circuit chips (see chips)
intrusion alarm (see Experiments 11, 15, and 24)

## J

jacks, 49
Jameco, 320
  potentiometer, 42
  solder, 100
joules, 36
jumper wire assortment, 41

## K

Kellogg, Edward, 243
keypads
  (see Experiment 20: A Powerful Combination)
Kilby, Jack, 152
Kingbright, 320
Kinks, 260
K&J Magnetics, 320
Kobiconn, 320
  clip-on meter test leads, 97
Kronus Automatic Wire Strippers, 40
KVM Tools, 320
  deburring tool, 99

## L

labeling, 231
Lancaster, Don, 233
latching relays, 151
leads, 5
LED numeric displays, 150
LEDs, 4
  dimming, 19–25
  lighting, 16–17
  low-powered, 150
  pulsing (see Experiment 14: A Pulsing Glow)
  relay-driven (see Experiment 7: Relay-Driven LEDs)
  schematics, 53, 54
  size of resistor required, 28
  too much heat (see Experiment 13: Broil an LED)
lemon battery, 32–38
lightbulb, 53
light-emitting diodes (see LEDs)
lightning, 35
limit switches, 278
lithium batteries, 9, 30
LM7805 voltage regulator (see Experiment 19: Learning Logic)
logic chips, 150
logic gates
  basics, 186–189
  origins, 192
  rules for connecting, 194–195
  (see also Experiments 19-24)
loudspeakers, 43, 104
  amplification, 87
  mounting, 87
  origins, 243
  sound into electricity, 244–245
  (see also Experiments 17, 27, and 29)
Lowe's hardware, xii, 320
  plywood, 102
  wire, 101
Lumex, 320
  diodes, 103

## M

machine screws, 102
magnetic sensor switches, 128
magnetism and electricity, relationship, 236
magnetism generating electricity (see Experiment 26: Tabletop Power Generation)
magnets
  warnings, 240
  (see also Experiments 25 and 26)
magnifying lens, 96
mail-order sources, xi
Make: Electronic kits, xiii
Maker Shed, xiii
Making Things Talk, 234
manufacturer's data sheet, 26
Marconi, Guglielmo, 266
McMaster-Carr, xii, 230, 320
  deburring tool, 99
  hand-cranked countersink, 99
  hookup wire, 41
  soldering iron, 96
MCUs
  limitations, 315
  programmable chips, origins, 294
  (see Experiment 34: Hardware Meets Software)
measurements, 36
  conversion table, 124–126
  in inches, 124
Megahobby, 320
  miniature vise, 99
Meter Superstore, 97, 320
metric system, 124
Michaels craft stores, 229, 320
microcontrollers, 227
  PICAXE (see PICAXE)
microfarads, 61
Mill-Max, 320
  single inline sockets and headers, 103
miniature hand saw, 99
miniature screwdriver set, 98
miniature vise, 99
Mitutoyo, 320
  calipers, 100
Motorola, 320
  transistor, 42
motors, 227, 280
  stepper (see Experiment 33: Moving in Steps)
Mouser Electronics, xi, 320
  battery holders and connectors, 3
  potentiometers, 4
moving-coil microphone, 244
Mueller alligator clips, 101, 320
multimeter, 2
mutual repulsion, 33

## N

NAND gates (see Experiments 19-24)
nanofarads, 61
negative charge, 35
neodymium magnet, 240
Newark, xii, 320

Newark Electronics
Vectorboard, 101
newtons, 36
NKK switches, 320
noisemaking circuit, 92
nonpolarized electrolytic capacitors, 249
nonpolarized relays, 58
NOR gates, 212
Noyce, Robert, 152
NPN and PNP transistors, 76–77, 79, 258
numeric keypads
(see Experiment 20: A Powerful Combination)
NXP semiconductors, 320

## O

Ohm, Georg Simon, 8
ohms, 6
Ohm's Law, 25, 26, 30, 283
Omron, 320
relays, 42
online sources, 233
On Semiconductor, 320
transistor, 42
open-collector inverter chip, 150, 222
operating current, 58
Optek, 320
diodes, 103
oscillator, relay (see Experiment 8: A Relay Oscillator)
oscilloscope, 231

## P

Panasonic, 320
PanaVise, 321
panel-mounted power jack, 103
Parallax, 321
patch cords, 41
pencil-type 15-watt soldering iron, 96
Pep Boys, 321
perforated boards, 101, 116, 136–139
common errors, 138
soldering procedure, 137
P. H. Anderson, 295
Philips, 321
photoresistors (see Experiment 33: Moving in Steps)
PICAXE, 227, 321
alphanumeric input/output, 310
infrared, 310
interrupts, 310
limitations, 315
origins of programmable chips, 294
pseudorandom numbers, 310
servo motor, 310
tone generator, 310
(see also Experiments 34-36)
pick and hook set, 99
picofarads, 61
Piedmont Plastics, 321
pin-shuffling, 161
Plano, 229
Plano storages boxes, 321
plastic benders, 272
pliers, 1
plywood, 102
PNP transistors (see NPN and PNP transistors)
point-to-point wiring connections, 106
Pomona
clip-on meter test leads, 97
test equipment, 321
positive charge, 35
potentiometers, 4, 42, 151, 229, 249
schematics, 53
(see also Experiments 4, 32, and 35)
power assessments, 31
power connectors, 229
power cords, shortening, 111–113
power outlet, 12
power supplies, 39, 231
chips, 154
Practical Electronics for Inventors, 234
programmable chips, origins, 294
Programmable Intelligent Computer (PIC), 294
Programmable Interface Controller (PIC), 294
programmable microcontrollers, 227
project boxes, 102
Prolatch, 230
prototyping board, 101
PSP breadboard, 39
pushbuttons, 42
options for toggle switches and pushbuttons, 47
PUTs (programmable unijunction transistors)
2N6027 (see Experiment 14: A Pulsing Glow)
schematics, 83
(see also Experiments 11 and 14)

## R

radio-frequency devices, 227
radio, how it works, 266–267
RadioShack, xi, 103, 321
alligator clips, 4, 101
battery holders and connectors, 3
breadboard, 39
clip-on meter test leads, 97
desoldering wick, 98
fuses, 4
heat-shrink tube, 101
helping hand, 96
hookup wire, 41
IC sockets, 150
insulated binding posts, 103
integrated circuit chips, 150
Kronus Automatic Wire Strippers, 40
LEDs, 4
loudspeaker, 43
magnifying lens, 96
panel-mounted power jack, 103
perforated board, 101
pliers, 1
potentiometer, 42
power supply/universal AC adapter, 39
project boxes, 102
resistors, 4
solder, 100
soldering iron, 96
soldering stand, 98
transistor, 42
wire cutters, 2

reactance, 246
reference sources, 233–235
  books, 234–235
  online, 233
relay-driven LEDs (see Experiment 7: Relay-Driven LEDs)
relay oscillator (see Experiment 8: A Relay Oscillator)
relays, 42, 56–58
  coil voltage, 58
  inside, 58
  latching, 151
  nonpolarized, 58
  self-locking relay, 131–132
  set voltage, 58
  switching capacity, 58
  transistors and, 79
reset voltage, 156
resistance, 25, 246
  discovery of, 8
  larger, 10
  measuring, 6
  (see also Experiment 1: Taste the Power!)
resistors, 4, 43
  decoding, 14–15
  hot, 247
  in parallel, 25
  in series, 25
  power assessments, 31
  schematics, 52
  (see also Experiment 3: Your First Current)
Rice, Chester, 243
Richards, Keith, 260
robotics, 227
  (see Experiments 32 and 33)
Rolling Stones, 260

## S

saw, miniature, 99
schematics, 50–54
  4026 chip, 171
  batteries, 53
  coil, 238
  combination lock circuit, 198, 201
  diodes, 134
  dots, 51
  Experiment 20: A Powerful Combination, 198–199
  Experiment 30: Fuzz, 258
  incandescent lightbulb, 53
  LEDs, 53, 54
  potentiometer, 53
  PUTs, 83
  resistors, 52
  switches, 51
  symbols, 51
  wires, 52
Scitoys Catalog, 265
screwdriver set, miniature, 98
screws, 102
  tamper-proof, 203
Scribner, Charles E., 49
Sears, 321
  deburring tool, 99
self-inductance, 246
self-locking relay, 131–132
servo motor, 280
  PICAXE, 310
set voltage, 58
Shannon, Claude, 184
Shockley, William, 78, 152
short circuits, 9
Siemens, Ernst, 243
signal diodes, 134
sine wave, 255
single inline sockets and headers, 103
single-pole, double-throw switch (SPDT), 46
single-pole, single-throw switch (SPST), 46
single-pole switch, 42
single-throw switches, 46
sockets, 49
solder, 100
soldering
  alternatives, 106
  desoldering, 109
  errors, 107
  myths, 106
  switches, 143–144
  theory, 109
  (see also Experiment 12: Joining Two Wires Together)
soldering irons, 96
  warning, 104
soldering stand, 98
solder pump, 98
sound into electricity, 244–245
SparkFun Electronics, 321
sparking, 48
SPDT toggle switch, 103
square wave, 258
Stanley, 321
  pick and hook set, 99
  wire cutters, 2
stepper motors
  inside, 288–289
  (see also Experiment 33: Moving in Steps)
STMicroelectronics, 321
  integrated circuit chips, 150
  logic chips, 150
  transistor, 42
stomp-box origins, 260–261
storage containers, 229
switch bounce, 174
switches, 42, 46–48
  checking, 48
  double-pole switches, 46
  double-throw switch, 46
  early systems, 49
  installing for alarm, 142–143
  limit, 278
  magnetic sensor switches, 128
  options for toggle switches and pushbuttons, 47
  relays and, 103
  schematics, 51
  simple (see Experiment 6: Very Simple Switching)
  single-pole, double-throw switch (SPDT), 46
  single-pole, single-throw switch (SPST), 46
  single-throw switches, 46
  soldering, 143–144
  sparking, 48
  tactile, 151
switching capacity, 58
switching transistors (see Experiment 10: Transistor Switching)

# T


tactile switches, 151
tamper-proof screws, 203
tantalum capacitor, 63
Texas Instruments, 321
  4026 Decade Counter, 150
  logic chips, 150
Theory
  Alternating current concepts, 248
  Basic measurements, 36
  Binary arithmetic, 217
  Calculating voltage drop, 283–284
  Doing the math on your tongue, 30
  How radio works, 266–267
  Inductance, 237
  Inside a stepper motor, 288–289
  Inside the 555 timer: astable mode, 164–165
  Inside the 555 timer: monostable mode, 158–159
  Power assessments, 31
  See the current, 80–81
  Soldering theory, 109
  Sound, electricity, and sound, 244–245
  The nature of electricity, 33
  The time constant, 71–72
  Waveforms, 255–256
third hand, 96
Thomson, J. J., 35
time constant, 71–72
toggle switches, 42, 229
  options for toggle switches and pushbuttons, 47
Tools
  Desoldering, 109
  Eight most common soldering errors, 107
  Four most common perfboarding errors, 138
torque, 281
Tower Hobbies, 321
  miniature hand saw, 99
tracing a fault, 139
transistors, 42
  2N2222 (see Experiments 11 and 15)
  2N6027 programmable unijunction transistor (see Experiment 14: A Pulsing Glow)
  basics, 77
  beta value, 80
  break-to-make transistor circuit, 129–130
  getting a better understanding, 80–81
  NPN and PNP, 76–77
  origins, 78
  relays and, 79
  switching (see Experiment 10: Transistor Switching)
  unijunction, 82–84
Transistor-Transistor Logic (TTL), 190–192
tremolo box, 261
Trem-Trol, 261
trigger voltage, 156
TTL Cookbook, 234
tweeter, 253
Twin Industries, 321
  perforated board, 101
Tyco, 321
  relays, 42


# U


unijunction transistors, 82–84


# V


Vaughan, 321
Vectorboard, 101
Velleman keyboards, 321
Ventures, 260
VIH min, 192
VIL max, 192
vise, miniature, 99
Vishay, 321
VOH min, 192
VOL max, 192
Volta, Alessandro, 12
voltage, 10
  blocking bad voltage, 132–134
  calculating drop, 283–284
  high, 263
  how much wire consumes, 27
  measuring, 6
voltage regulators, 151, 182
  LM7805 (see Experiment 19: Learning Logic)
volts, 36
  basics, 11
Vox wow-fuzz pedal, 257


# W


Wal-Mart, 229, 321
Warnings
  Avoid Burns While Bending, 272
  Beware of Pin-Shuffling!, 161
  Blood Blisters and Dead Media, 240
  Capacitor Polarity, 63
  Cut with Care, 270
  Flying Wire Segments, 121
  Getting Zapped by Capacitors, 62
  Grounding Yourself, 172
  Heat Guns Get Hot, Too!, 110, 111
  High Voltage!, 263
  Hot Resistors, 247
  Never Use Two Hands, 74
  No Floating Pins!, 175
  No More Than 9 Volts, 5
  Pin 2 Pull-Down, 299
  Short Circuits, 9
  Soldering Irons Get Hot!, 104
  The Warranty Issue, 197
water-powered turbine, 236
wattage, history, 28
Watt, James, 28
watts, 36
  basics, 31
waveforms, 255–256
  clipping, 257
wavelength of the sound, 244
Weller, 321
Weller Therma-Boost, 96
windmill, 236
wire cutters, 2
  warning, 121
wire gauges, 282
wires, 100
  point-to-point wiring connections, 106
  schematics, 52
  soldering (see also Experiment 12: Joining Two Wires Together)
  voltage consumed by, 27

wire strippers, 40
wire wrap, 106
woofer, 253
work area, customizing, 228–232
  bench, 231
  computer, 232
  labeling, 231
  oscilloscope, 231

## X

X-Acto, 321
  miniature hand saw, 99
Xcelite, 321
  pliers, 1
Xytronic, 321
  soldering iron, 96

## Z

Zener diode, 134
zinc electrode, 33

# Colophon

The heading and cover font are BentonSans, the text font is Myriad Pro, and the code font is TheSansMonoCondensed.

# About the Author

**Charles Platt** became interested in computers when he acquired an Ohio Scientific C4P in 1979. After writing and selling software by mail order, he taught classes in BASIC programming, MS-DOS, and subsequently Adobe Illustrator and Photoshop. He wrote five computer books during the 1980s.

He has also written science-fiction novels such as *The Silicon Man* (published originally by Bantam and later by Wired Books) and *Protektor* (from Avon Books). He stopped writing science fiction when he started contributing to *Wired* in 1993, and became one of its three senior writers a couple of years later.

Charles began contributing to MAKE magazine in its third issue and is currently a contributing editor. *Make: Electronics* is his first title for Make Books. Currently he is designing and building prototypes of medical equipment in his workshop in the northern Arizona wilderness.