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

Make: Electronics

Second Edition

Charles Platt

A HANDS-ON PRIMER FOR THE NEW ELECTRONICS ENTHUSIAST

Learning by Discovery

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Make: Electronics

Learning by Discovery

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Charles Platt's first electronics project was a telephone answering machine, which he built when he was 15. He became a science-fiction writer (author of ***The Silicon Man***), taught classes in computer graphics, and was a senior writer at Wired, but he has retained his lifelong love for hobby electronics. He is currently a contributing editor to ***Make:*** magazine.

"This is teaching at its best!"—Hans Camenzind, inventor of the 555 timer

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SECOND EDITION

Make: Electronics

Charles Platt

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by Charles Platt

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[TI]

Dedication

To readers of the first edition of *Make: Electronics* who contributed many ideas and suggestions for this second edition. In particular: Jeremy Frank, Russ Sprouse, Darral Teeples, Andrew Shaw, Brian Good, Behram Patel, Brian Smith, Gary White, Tom Malone, Joe Everhart, Don Girvin, Marshall Magee, Albert Qin, Vida John, Mark Jones, Chris Silva, and Warren Smith. Several of them also volunteered to review the text for errors. Feedback from my readers continues to be an amazing resource.

Acknowledgments

I discovered electronics with my school friends. We were nerds before the word existed. Patrick Fagg, Hugh Levinson, Graham Rogers, and John Witty showed me some of the possibilities.

It was Mark Frauenfelder who nudged me back into the habit of making things. Gareth Branwyn facilitated *Make: Electronics*, and Brian Jepson enabled the sequel and this new edition. They are three of the best editors I have known, and they are also three of my favorite people. Most writers are not so fortunate.

I am also grateful to Dale Dougherty for starting something that I never imagined could become so significant, and for welcoming me as a participant.

Russ Sprouse and Anthony Golin built and tested the circuits. Technical fact checking was provided by Philipp Marek, Fredrik Jansson, and Steve Conklin. Don't blame them if there are still any errors in this book. It's much easier for me to make an error than it is for someone else to find it.

Table of Contents

What's New in the Second Edition

All of the text from the first edition of this book has been rewritten, and most of the photographs and schematics have been replaced.

Single-bus breadboards are now used throughout (as in *Make: More Electronics*) to reduce the risk of wiring errors. This change entailed rebuilding the circuits, but I believe it was worthwhile.

Diagrams showing component placement are now used instead of photographs of breadboarded circuits. I think the diagrams are clearer.

Internal views of breadboard connections have been redrawn to match the revisions noted above.

New photographs of tools and supplies have been included. For small items, I have used a ruled background to indicate the scale.

Where possible, I have substituted components that cost less. I have also reduced the range that you need to buy.

Three experiments have been completely revised:

- The Nice Dice project that used LS-series 74xx chips in the first edition now uses 74HCxx chips, to be consistent with the rest of the book and with modern usage.
- The project using a unijunction transistor has been replaced with an astable multivibrator circuit using two bipolar transistors.
- The section on microcontrollers now recognizes that the Arduino has become the most popular choice in the Maker community.

New Component Kits

Many of these improvements were suggested by my readers, and all of them have made this a better book. Unfortunately, the changes have created a compatibility problem: component kits that were marketed for the first edition are not compatible with the second edition.

To obtain kits that match this edition of the book, see Chapter 6 for instructions. Please be careful not to buy old kits that may still be offered for sale from third parties on eBay or Amazon. Some kits that were made by Radio Shack, in particular, are being resold by individuals. I regret that I have no control over this. Just be aware that if a kit doesn't refer specifically to the second edition of this book, it is probably not compatible.

Other Changes

In addition, two projects involving workshop fabrication using ABS plastic have been omitted, as many readers did not seem to find them useful.

All the page layouts have been changed to make them easily adaptable for handheld devices. The formatting is controlled by a plaintext markup language, so that future revisions will be simpler and quicker. We want the book to remain relevant and useful for many more years to come.

--Charles Platt, 2015

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.

You may feel that you don't need to know. You can drive a car without understanding the workings of an internal combustion engine, so why should you learn about electricity and electronics?

I think there are 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. It is also very affordable.
- 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 by using definitions and theory to explain some fundamental concepts. Circuits are included to demonstrate what you have been told.

Science education in schools often follows a similar plan. I think of this as *learning by explanation*.

This book works the other way around. I want you to dive right in and start putting components together without necessarily knowing what to expect. As you see what happens, you will figure out what's going on. This is *Learning by Discovery*, which I believe is more fun, more interesting, and more memorable.

Working on an exploratory basis, you run the risk of making mistakes. But I don't see this as a bad thing, because mistakes are a valuable way to learn. I want you to burn things out and mess things up, to see for yourself the behavior and limitations of the parts that you are dealing with. The very low voltages used throughout this book may damage sensitive components, but will not damage you.

The key requirement of Learning by Discovery is that it has to be hands-on. You can derive some value from this book merely by reading it, but you will enjoy a much more valuable experience if you perform the experiments yourself.

Fortunately, the tools and components that you need are inexpensive. Hobby electronics should not cost significantly more than a recreation such as needlepoint, and you don't need a workshop. Everything can be done on a tabletop.

Will It Be Difficult?

I assume that you're beginning with no prior knowledge. Consequently, the first few experiments will be extremely simple, and you won't even use prototyping boards or a soldering iron.

I don't believe that the concepts will be hard to understand. Of course, if you want to study electronics more formally and do your own circuit design, that can be challenging. But in this book I have kept theory to a minimum, and the only math you'll need will be addition, subtraction, multiplication, and division. You may also find it helpful (but not absolutely necessary) if you can move decimal points from one position to another.

How This Book Is Organized

An introductory book can present information in two ways: in tutorials or in reference sections. I decided to use both of these methods.

You'll find the *tutorials* in sections headed as follows:

- Experiments
- What You Will Need
- Cautions

Experiments are the heart of the book, and they have been sequenced so that the knowledge you gain at the beginning can be applied to subsequent projects. I suggest that you perform the experiments in numerical order, skipping as few as possible.

You'll find *reference sections* under the following headings:

- Fundamentals
- Theory
- Background

I think the reference sections are important (otherwise, I would not have included them), but if you're impatient, you can dip into them at random or skip them and come back to them later.

If Something Doesn't Work

Usually there is only one way to build a circuit that works, while there are hundreds of ways to make mistakes that will prevent it from working. Therefore the odds are against you, unless you proceed in a really careful and methodical manner.

I know how frustrating it is when components just sit there doing nothing, but if you build a circuit that doesn't work, please begin by following the fault-tracing procedure that I have recommended (see "Fundamentals: Fault Tracing" on page 73). I will do my best to answer emails from readers who run into problems, but it's only fair for you to try to solve your problems first.

Writer–Reader Communication

There are three situations where you and I may want to communicate with each other.

- I may want to tell you if it turns out that the book contains a mistake which will prevent you from building a project successfully. I may also want to tell you if a parts kit, sold in association with the book, has something wrong with it. This is *me-informing-you* feedback.
- You may want to tell me if you think you found an error in the book, or in a parts kit. This is *you-informing-me* feedback.
- You may be having trouble making something work, and you don't know whether I made a mistake or you made a mistake. You would like some help. This is *you-asking-me* feedback.

I will explain how to deal with each of these situations.

Me Informing You

If you already registered with me in connection with *Make: More Electronics*, you don't need to register again for updates relating to *Make: Electronics*. But if you have not already registered, here's how it works.

I can't notify you if there's an error in the book or in a parts kit unless I have your contact information. Therefore I am asking you to send me your email address for the following purposes. Your email will not be used or abused for any other purpose.

- I will notify you if any significant errors are found in this book or in its successor, *Make: More Electronics*, and I will provide a workaround.
- I will notify you of any errors or problems relating to kits of components sold in association with this book or in *Make: More Electronics*.
- I will notify you if there is a completely new edition of this book, or of *Make: More Electronics*, or of my other books. These notifications will be very rare.

We've all seen registration cards that promise to enter you for a prize drawing. I'm going to offer you a much better deal. If you submit your email address, which may only be used for the three purposes listed above, I will send you an unpublished electronics project with complete construction plans as a two-page PDF. It will be fun, it will be unique, and it will be relatively easy. You won't be able to get this in any other way.

The reason I am encouraging you to participate is that if an error is found, and I have no way to tell you, and you discover it later on your own, you're likely to get annoyed. This will be bad for my reputation and the reputation of my work. It is very much in my interest to avoid a situation where you have a complaint.

- Simply send a blank email (or include some comments in it, if you like) to *make.electronics@gmail.com*. Please put REGISTER in the subject line.

You Informing Me

If you only want to notify me of an error that you have found, it's really better to use the "errata" system maintained by my publisher. The publisher uses the "errata" information to fix the error in updates of the book.

If you are sure that you found an error, please visit:

http://shop.oreilly.com/category/customer-service/faq-errata.do

The web page will tell you how to submit errata.

You Asking Me

My time is obviously limited, but if you attach a photograph of a project that doesn't work, I may have a suggestion. The photograph is essential.

You can use *make.electronics@gmail.com* for this purpose. Please put the word HELP in the subject line.

Going Public

There are dozens of forums online where you can discuss this book and mention any problems you are having, but please be aware of the power that you have as a reader, and use it fairly. A single negative review can create a bigger effect than you may realize. It can certainly outweigh half-a-dozen positive reviews.

The responses that I receive are generally very positive, but in a couple of cases people have been annoyed over small issues such as being unable to find a part online. I would have been happy to help these people if they had asked me.

I do read my reviews on Amazon about once each month, and will always provide a response if necessary.

Of course, if you simply don't like the way in which I have written this book, you should feel free to say so.

Going Further

After you work your way through this book, you will have grasped many of the basic principles in electronics. I like to think that if you want to know more, my own *Make: More Electronics* is the ideal next step. It is slightly more difficult, but uses the same "Learning by Discovery" method that I have used here. My intention is that you will end up with what I consider an "intermediate" understanding of electronics.

I am not qualified to write an "advanced" guide, and consequently I don't expect to create a third book with a title such as "Make: Even More Electronics."

If you want to know more electrical theory, *Practical Electronics for Inventors* by Paul Scherz is still the book that I recommend most often. You don't have to be an inventor to find it useful.

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The Basics

1

Chapter One of this book contains Experiments 1 through 5.

In Experiment 1, I want you to get a taste for electricity—literally! You'll experience electric current and discover the nature of electrical resistance, not just in wires and components but in the world around you.

Experiments 2 through 5 will show you how to measure and understand the pressure and flow of electricity—and finally, how to generate electricity with everyday items on a tabletop.

Even if you have prior knowledge of electronics, I encourage you to try these experiments before venturing into subsequent parts of the book. They're fun, and they clarify some basic concepts.

Necessary Items for Chapter One

Each chapter of this book begins with pictures and descriptions of the tools, equipment, components, and supplies that will be required. After you have learned about them, you can flip to the back of the book where your buying options are summarized for quick reference.

- To buy tools and equipment, see "Buying Tools and Equipment" on page 324.
- For components, see "Components" on page 317.
- For supplies, see "Supplies" on page 316.
- If you prefer to get a prepackaged set of the components that you need, you have a choice of kits. See "Kits" on page 311 for more information.

I classify *tools and equipment* as items that should be useful indefinitely. They range from pliers to a multimeter. *Supplies*, such as wire and solder, will gradually be consumed in a variety of projects, but the quantities that I am recommending should be sufficient for all the experiments in the book. *Components* will be listed for individual projects, and will become part of those projects.

The Multimeter

Figure 1-1 *This kind of analog meter is inadequate for your purposes. You need a digital meter.*

I'm beginning my instructional overview of tools and equipment with the multimeter, because I consider it the most essential piece of equipment. It will tell you how much voltage exists between any two points in a circuit, or how much current is passing through the circuit. It will help you to find a wiring error, and can also evaluate a component to determine its electrical resistance—or its capacitance, which is the ability to store an electrical charge.

If you're starting with little or no knowledge, these terms may seem confusing, and you may feel that a multimeter looks complicated and difficult to use. This is not the case. It makes the learning process easier, because it reveals what you cannot see.

Before I discuss which meter to buy, I can tell you what not to buy. You don't want an old-school meter with a needle that moves across a scale, as shown in Figure 1-1. That is an *analog* meter.

You want a *digital* meter that displays values numerically—and to give you an idea of the equipment available, I have selected four examples.

Figure 1-2 shows the cheapest digital meter that I could find, costing less than a paperback novel or a six-pack of soda. It cannot measure very high resistances or very low voltages, its accuracy is poor, and it does not measure capacitance at all. However, if your budget is very tight, it will probably see you through the experiments in this book.

Figure 1-2 *The cheapest meter that I could find.*

The meter in Figure 1-3 offers more accuracy and more features. This meter, or one similar to it, is a good basic choice while you are learning electronics.

Figure 1-3 *Any meter similar to this one is a good basic choice.*

The example in Figure 1-4 is slightly more expensive but much better made. This particular model has been discontinued, but you can find many like it, probably costing two to three times as much as the NT brand in Figure 1-3. Extech is a well-established company trying to maintain its standards in the face of cut-price competitors.

Figure 1-4 *A better-made meter at a somewhat higher price.*

Figure 1-5 shows my personal preferred meter at the time of writing. It is physically rugged, has all the features I could want, and measures a wide range of values with extremely good accuracy. However, it costs more than twenty times as much as the lowest-priced, bargain-basement product. I regard it as a long-term investment.

Figure 1-5 *A high-quality product.*

How do you decide which meter to buy? Well, if you were learning to drive, you wouldn't necessarily need a high-priced car. Similarly, you don't need a high-priced meter while you are learning electronics. On the other hand, the absolute cheapest meter may have some drawbacks, such as an internal fuse that is not easily replaceable, or a rotary switch with contacts that wear out quickly. So here's a rule of thumb if you want something that I would regard as inexpensive but acceptable:

- Search eBay for the absolute cheapest model you can find, then double the price, and use that as your guideline.

Regardless of how much you spend, the following attributes and capabilities are important.

Ranging

A meter can measure so many values, it has to have a way to narrow the range. Some meters have *manual ranging*, meaning that you turn a dial to choose a ballpark for the quantity that interests you. A range could be from 2 to 20 volts, for instance.

Other meters have *autoranging*, which is more convenient, because you just connect the meter and wait for it to figure everything out. The key word, however, is "wait." Every time you make a measurement with an autoranging meter, you will wait a couple of seconds while it performs an internal evaluation. Personally I tend to be impatient, so I prefer manual meters.

Another problem with autoranging is that because you have not selected a range yourself, you must pay attention to little letters in the display where the meter is telling you which units it has decided to use. For example, the difference between a "K" or an "M" when measuring electrical resistance is a factor of 1,000. This leads me to my personal recommendation:

- I suggest you use a manual-ranging meter for your initial adventures. You'll have fewer chances to make errors, and it should cost slightly less.

A vendor's description of a meter should say whether it uses manual ranging or autoranging, but if not, you can tell by looking at a photograph of its selector dial. If you don't see any numbers around the dial, it's an autoranging meter. The meter in Figure 1-4 does autoranging. The others that I pictured do not.

Values

The dial will also reveal what types of measurements are possible. At the very least, you should expect:

Volts, amps, and ohms, often abbreviated with the letter V, the letter A, and the ohm symbol, which is the Greek letter omega, shown in Figure 1-6. You may not know what these attributes mean right now, but they are fundamental.

Your meter should also be capable of measuring milliamps (abbreviated *mA*) and millivolts (abbreviated *mV*). This may not be immediately clear from the dial on the meter, but will be listed in its specification.

Figure 1-6 *Three samples of the Greek symbol omega, used to represent electrical resistance.*

DC/AC, meaning direct current and alternating current. These options may be selected with a DC/AC pushbutton, or they may be chosen on the main selector dial. A pushbutton is probably more convenient.

Continuity testing. This useful feature enables you to check for bad connections or breaks in an electrical circuit. Ideally it should create an audible alert, in which case it will be represented symbolically with a little dot that has semicircular lines radiating from it, as shown in Figure 1-7.

Figure 1-7 *This symbol indicates the option to test a circuit for continuity, with audible feedback. It's a very useful feature.*

For a small additional sum, you should be able to buy a meter that makes the following measurements. In order of importance:

Capacitance. Capacitors are small components that are needed in the majority of electronic circuits. Because small ones usually don't have their values printed on them, the ability to measure their values can be important, especially if some of them get mixed up or (worse) fall on the floor. Very cheap meters usually cannot measure capacitance. When the feature exists, it is usually indicated with a letter F, meaning farads, which are the units of measurement. The abbreviation CAP may also be used.

Transistor testing, indicated by little holes labeled E, B, C, and E. You plug the transistor into the holes. This enables you to verify which way up the transistor should be placed in a circuit, or if you have burned it out.

Frequency, abbreviated Hz. This is unimportant in the experiments in this book, but may be useful if you go further.

Any features beyond these are not significant.

If you still feel unsure about which meter to buy, read ahead a little to get an idea of how you will be using a meter in Experiments 1, 2, 3, and 4.

Safety Glasses

For Experiment 2, you may want to use safety glasses. The cheapest plastic type is satisfactory for this little adventure, as the risk of a battery bursting is almost nonexistent, and probably would not occur with much force.

Regular eyeglasses would be an acceptable substitute, or you could view the experiment through a little piece of transparent plastic (for instance, you can cut out a piece of a water bottle).

Batteries and Connectors

Because batteries and connectors become part of a circuit, I am categorizing them as components. See "Other Components" on page 319 for details about ordering these parts.

Almost all the experiments in this book will use a power source of 9 volts. You can obtain this from a basic nine-volt battery sold in supermarkets and convenience stores. Later I'll suggest an upgrade to an AC adapter, but you don't need that right now.

For Experiment 2, you will need a couple of 1.5-volt AA batteries. These have to be the alkaline type. You must not perform this experiment with any kind of rechargeable battery.

To transfer the power from a battery into a circuit, you need a connector for the 9-volt battery, as shown in Figure 1-8, and a carrier for a single AA battery, as shown in Figure 1-9. One carrier will be enough, but I suggest you get at least three 9-volt connectors for future use.

Figure 1-8 *Connector to deliver power from a 9-volt battery.*

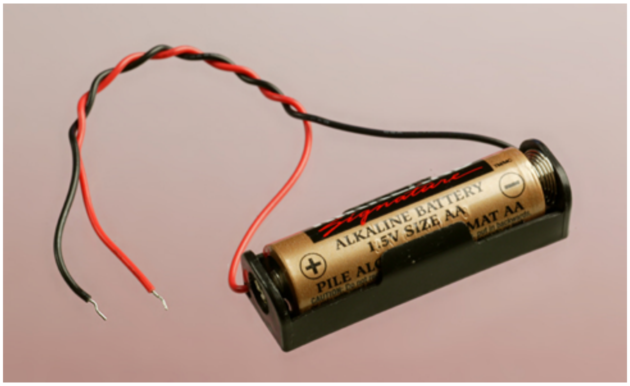

Figure 1-9 *You need a carrier like this for a single AA battery. Don't buy the type of carrier that holds two batteries (or three, or four).*

Test Leads

You will use test leads (pronounced "leeds") to connect components with each other in the first few experiments. The type of leads I mean are *double-ended*. Surely, any piece of wire has two ends, so why should it be called "double-ended"? The term usually means that each end is fitted with an *alligator clip* as shown in Figure 1-10. Each clip can make a connection by grabbing something and gripping it securely, freeing you to use your hands elsewhere.

You don't want the kind of test leads that have a plug at each end. Those are sometimes known as *jumper wires*.

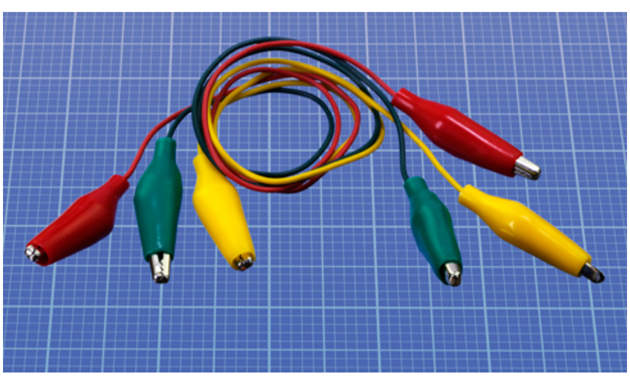

Figure 1-10 *Double-ended test leads with an alligator clip at each end.*

Test leads are classified as equipment for the purposes of this book. See "Buying Tools and Equipment" on page 324 for more information.

Potentiometer

A potentiometer functions like the volume control on an old-fashioned stereo. The kinds shown in Figure 1-11 are considered large by modern standards, but large is what you need, because you'll be gripping the terminals with the alligator clips on your test leads. A 1" diameter potentiometer is preferred. Its resistance should be listed as 1K. If you are buying your own, see "Other Components" on page 319 for details.

Figure 1-11 *Potentiometers of the general type required for your first experiments.*

Fuse

A fuse interrupts a circuit if too much electricity passes through it. Ideally you'll buy the type of 3-amp automotive fuse shown in Figure 1-12, which is easy to grip with test leads, and clearly reveals the element inside it. Automotive fuses are sold in a variety of physical sizes, but so long as you use one rated for 3 amps, the dimensions don't matter. Buy three to allow for destroying them intentionally or accidentally. If you don't want to use an auto parts supplier, a 2AG-size 3-amp glass cartridge fuse of the kind shown in Figure 1-13 will be available from electronics component suppliers, although it is not quite so easy to use.

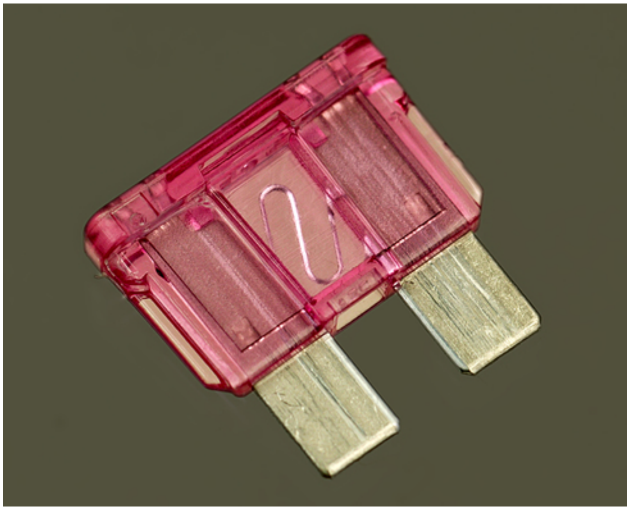

Figure 1-12 *This type of automotive fuse is easier to handle than the cartridge fuses used in electronics hardware.*

Figure 1-13 *You can use a cartridge fuse like this, although your alligator clips won't grip it so easily.*

Light-Emitting Diodes

More commonly known as *LEDs*, they come in various shapes and forms. The ones we will be using are properly known as *LED indicators*, and are often described as *standard through-hole LEDs* in catalogs. A sample in Figure 1-14 is 5mm in diameter, but 3mm is sometimes easier to fit into a circuit when space is limited. Either will do.

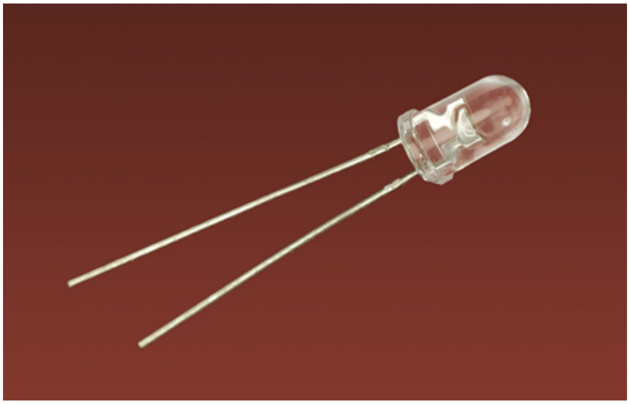

Figure 1-14 *A light-emitting diode (LED) approximately 5mm in diameter.*

Throughout this book I will refer to *generic LEDs*, by which I mean the cheapest ones that don't emit a high-intensity light and are commonly available in red, yellow, or green. They are often sold in bulk quantities, and are used in so many applications that I suggest you buy at least a dozen of each color.

Some generic LEDs are encapsulated in "water clear" plastic or resin, but emit a color when power is applied. Other LEDs are encapsulated in plastic or resin tinted with the same color that they will display. Either type is acceptable.

In a few experiments, *low-current LEDs* are preferred. They cost slightly more, but are more sensitive. For example, in Experiment 5, where you will generate a small amount of current with an improvised battery, you'll get better results with a low-current LED. See "Other Components" on page 319 for additional guidance, if you are not using components that were supplied in a kit.

Resistors

You'll need a variety of resistors to restrict the voltage and current in various parts of a circuit. They should look something like the ones in Figure 1-15. The color of the body of the resistor doesn't matter. Later I will explain how the colored stripes tell you the value of the component.

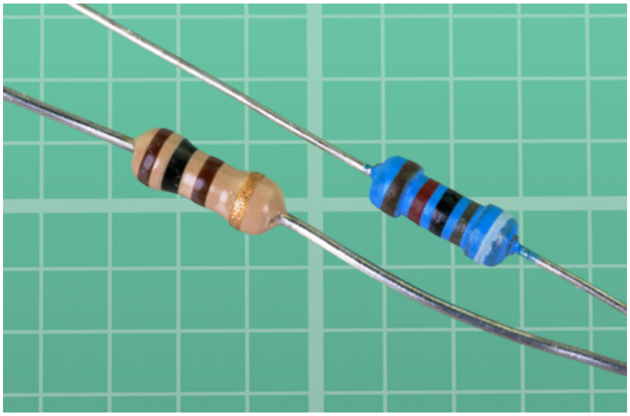

Figure 1-15 *Two resistors of the type you need, all rated for 1/4 watt.*

If you are buying your own resistors, they are so small and cheap, you would be foolish to select just the values listed in each experiment. Get a prepackaged selection in bulk from surplus or discount sources, or eBay. For more information about resistors, including a complete list of all the values used throughout this book, see "Components" on page 317.

You don't need any other components to take you through Experiments 1 through 5. So let's get started!

Experiment 1: Taste the Power!

Can you taste electricity? It feels as if you can.

What You Will Need

- 9-volt battery (1)
- Multimeter (1)

That's all!

Caution: No More than Nine Volts

This experiment should only use a 9-volt battery. *Do not* try it with a higher voltage, and *do not* use a bigger battery that can deliver more current. Also, if you have metal braces on your teeth, be careful not to touch them with the battery. Most important, never apply electric current from any size of battery through a break in your skin.

Procedure

Moisten your tongue and touch the tip of it to the metal terminals of a 9-volt battery, as shown in Figure 1-16. (Maybe your tongue isn't quite as big as the one in the picture. Mine certainly isn't. But this experiment will work regardless of how big or small your tongue may be.)

Figure 1-16 *An intrepid Maker tests the characteristics of an alkaline battery.*

Do you feel that tingle? Now set aside the battery, stick out your tongue, and dry the tip of it very thoroughly with a tissue. Touch the battery to your tongue again, and you should feel less of a tingle.

What's happening here? You can use a meter to find out.

Setting Up Your Meter

Does your meter have a battery preinstalled? Select any function with the dial, and wait to see if the display shows a number. If nothing is visible, you may have to open the meter and put in a battery before you can use it. To find out how to do this, check the instructions that came with the meter.

Meters are supplied with a red lead and a black lead. Each lead has a plug on one end, and a steel probe on the other end. You insert the plugs into the meter, then touch the probes on locations where you want to know what's going on. See Figure 1-17. The probes detect electricity; they don't emit it in significant quantities. When you are dealing with the small currents and voltages in the experiments in this book, the probes cannot hurt you (unless you poke yourself with their sharp ends).

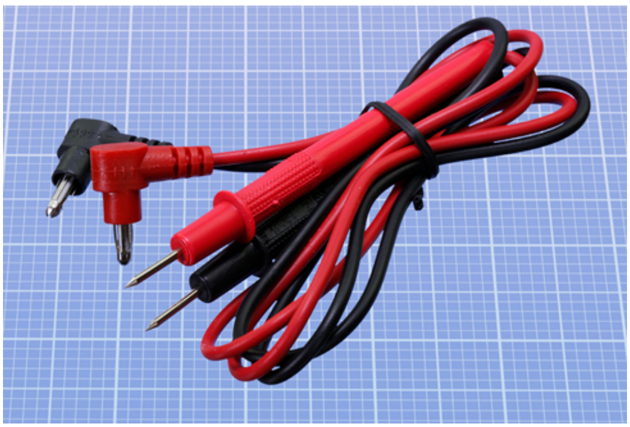

Figure 1-17 *Leads for a meter, terminating in metal probes.*

Most meters have three sockets, but some have four. See Figure 1-18, Figure 1-19, and Figure 1-20 for examples. Here are the general rules:

- One socket should be labelled COM. This is *common* to all your measurements. Plug the black lead into this socket, and leave it there.
- Another socket should be identified with the ohm (omega) symbol, and the letter V for volts. It can measure either resistance or voltage. Plug the red lead into this socket.
- The voltage/ohms socket may also be used for measuring small currents in mA (milliamps) . . . or you may see a separate socket for this, which will require you to move the red lead sometimes. We'll get to that later.
- An additional socket may be labelled 2A, 5A, 10A, 20A, or something similar, to indicate a maximum number of amps. This is used for measuring high currents. We won't be needing it for projects in this book.

Figure 1-18 *Note the labeling of sockets on this meter.*

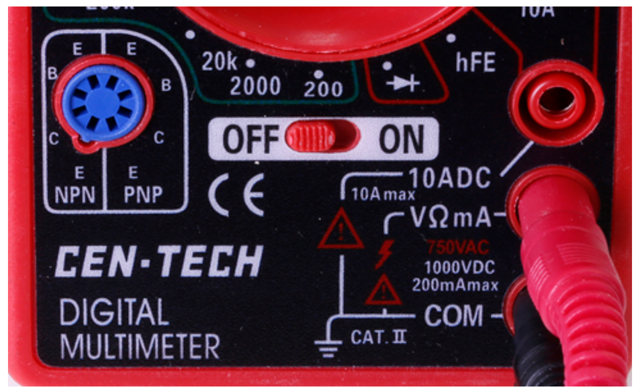

Figure 1-19 *Socket functions are split up differently on this meter.*

Figure 1-20 *Sockets on one more meter.*

Fundamentals: Ohms

You're going to evaluate the resistance of your tongue, in ohms. But what is an ohm?

We measure distance in miles or kilometers, mass in pounds or kilograms, and temperature in Fahrenheit or Centigrade. We measure electrical resistance in ohms, which is an international unit named after Georg Simon Ohm, who was an electrical pioneer.

The Greek omega symbol indicates ohms, but for resistances above 999 ohms the uppercase letter K is used, which means *kilohm*, equivalent to a thousand ohms. For example, a resistance of 1,500 ohms will be referred to as 1.5K.

Above 999,999 ohms, the uppercase letter M is used, meaning *megohm*, which is a million ohms. In everyday speech, a megohm is often referred to as a "meg." If someone is using a "two-point-two meg resistor," its value will be 2.2M.

A conversion table for ohms, kilohms, and megohms is shown in Figure 1-21.

Ohms	Kilohms	Megohms
1 Ω	0.001K	0.000001M
10 Ω	0.01K	0.00001M
100 Ω	0.1K	0.0001M
1,000 Ω	1K	0.001M
10,000 Ω	10K	0.01M
100,000 Ω	100K	0.1M
1,000,000 Ω	1,000K	1M

Figure 1-21 *Conversion table for the most common multiples of ohms.*

- In Europe, the letter R, K, or M is substituted for a decimal point, to reduce the risk of errors. Thus, 5K6 in a European circuit diagram means 5.6K, 6M8 means 6.8M, and 6R8 means 6.8 ohms. I won't be using the European style here, but you may find it in some circuit diagrams elsewhere.

A material that has very high resistance to electricity is known as an *insulator*. Most plastics, including the colored sheaths around wires, are insulators.

A material with very low resistance is a *conductor*. Metals such as copper, aluminum, silver, and gold are excellent conductors.

Measuring Your Tongue

Inspect the dial on the front of your meter, and you'll find at least one position identified with the ohm symbol. On an autoranging meter, turn the dial to point to the ohm symbol as shown in Figure 1-22, touch the probes *gently* to your tongue, and wait for the meter to choose a range automatically. Watch for the letter K in the numeric display. Never stick the probes *into* your tongue!

Figure 1-22 *On an autoranging meter, just turn the dial to the ohm (omega) symbol.*

On a manual meter, you must choose a range of values. For a tongue measurement, probably 200K (200,000 ohms) would be about right. Note that the numbers beside the dial are maximums, so 200K means "no more than 200,000 ohms" while 20K means "no more than 20,000 ohms." See the close-ups of the manual meters in Figure 1-23 and Figure 1-24.

Figure 1-23 *A manual meter requires you to select the range.*