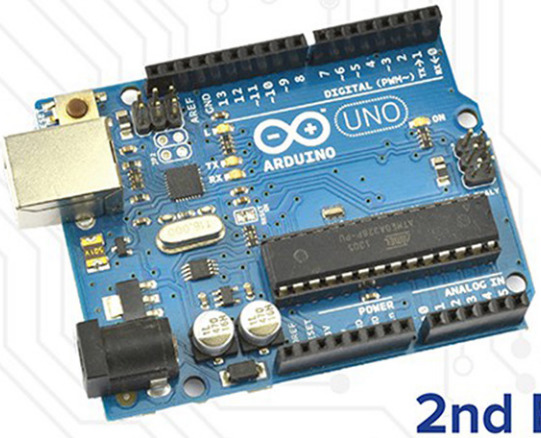

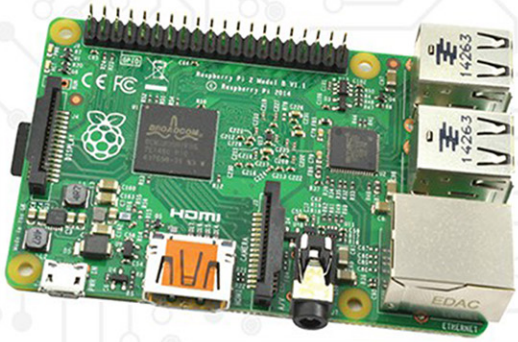

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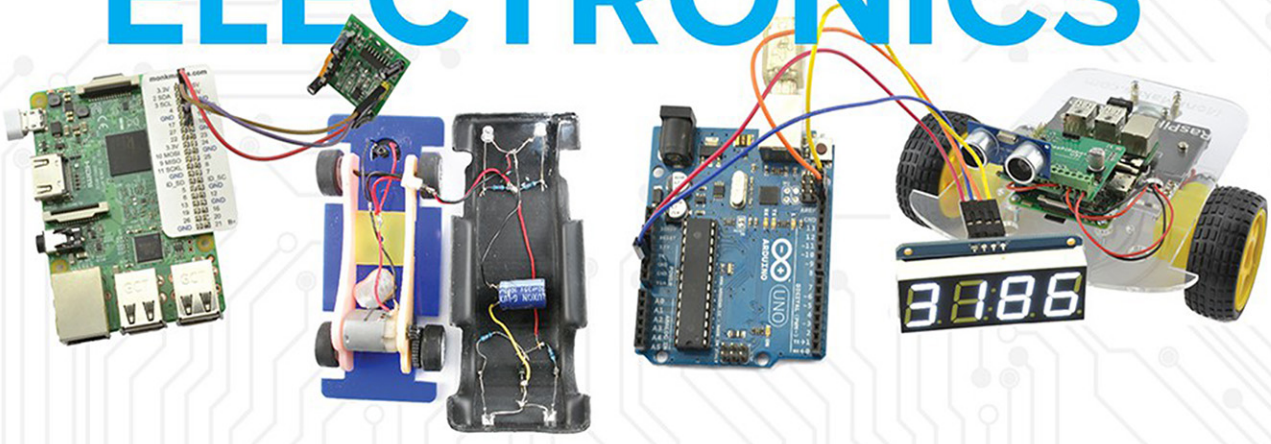
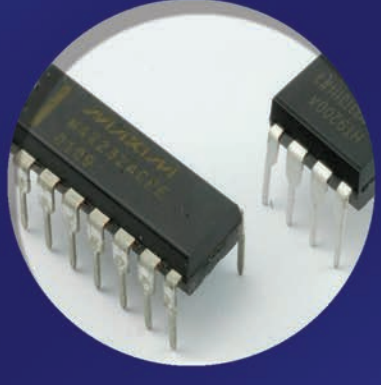
HACKING ELECTRONICS



Learning Electronics with Arduino and Raspberry Pi

SIMON MONK

HACKING ELECTRONICS



About the Author

Dr. Simon Monk (Preston, UK) has a degree in Cybernetics and Computer Science and a PhD in Software Engineering. Monk spent several years as an academic before he returned to industry, co-founding the mobile software company Momote Ltd. He has been an active electronics hobbyist since his early teens and is a full-time writer on hobby electronics and open-source hardware. Dr. Monk is the author of numerous electronics books, specializing in open-source hardware platforms, especially Arduino and Raspberry Pi. He is also co-author with Paul Scherz of *Practical Electronics for Inventors, Fourth Edition*. You can follow Simon on Twitter, where he is @simonmonk2.

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Second Edition

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To Roger, for making it possible for me to turn a hobby into an occupation.

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Contents at a Glance

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Contents

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And last but not least, thanks once again to Linda, for her patience and generosity in giving me space to do this.

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Introduction

This is a book about "hacking" electronics. It is not a formal, theory-based book about electronics. Its sole aim is to equip the reader with the skills he or she needs to use electronics to make something, whether it's starting from scratch, connecting together modules, or adapting existing electronic devices for some new use.

You will learn how to experiment and get your ideas into some kind of order, so that what you make will work. Along the way, you'll gain an appreciation for why things work and the limits of what they can do, and learn how to make prototypes on solderless breadboard, how to solder components directly to each other, and how to use protoboard to make more complex soldered circuits.

You will also learn how to use the popular Arduino microcontroller board, which has become one of the most important tools available to the electronics hacker. There are over 20 examples of how to use an Arduino with electronics in this book.

You will also learn how to use the Raspberry Pi (a tiny Linux computer) as a tool for electronics hacking.

Electronics has changed. This is a modern book that avoids theory you will likely never use and instead concentrates on how you can build things using readymade modules when they are available. There is, after all, no point in reinventing the wheel.

Some of the things explained and described in the book include

- Using LEDs, including high-power Lumileds and Addressable LED strips (Neopixels)
- Using LiPo battery packs and buck-boost power supply modules
- Using sensors to measure light, temperature, acceleration, sound level, and color
- Interfacing the Raspberry Pi and Arduino with external electronics
- Using servo motors

Some of the things described in the book that you can make along the way include

- A smartcard RFID tag reader
- An Internet-controlled hacked electric toy
- A device for measuring color
- An ultrasonic rangefinder
- A remote control robotic rover
- An accelerometer-based version of the “egg and spoon” race
- An audio amplifier
- A bug made from a hacked MP3 FM transmitter
- Working brakes and head lights that can be added to a slot car
- A smart-card reader/spoofer

You Will Need

This is a very practical, hands-on type of book. You will therefore need some tools and components to get the most out of it.

As far as tools go, you will need little more than a multimeter and soldering equipment.

You should also have a Raspberry Pi, or Arduino or both, as quite a few of the projects use these handy boards.

Every component used in this book is listed in the Appendix, along with sources where it can be obtained. The majority of the components can be found in a starter kit from SparkFun, but most electronic starter kits will provide a lot of what you will need.

In many of the “how-tos,” there will be a You Will Need section. This will refer to a code in the Appendix that explains where to get the component.

How to Use This Book

The book contains the following chapters:

Chapter	Title	Description
Chapter 1	Getting Started	The book starts off by telling you where you can buy equipment and components, as well as things to hack. This chapter also deals with the basics of soldering and focuses on a project to hack an old computer fan to make a fume extractor for use while soldering.
Chapter 2	Components	This chapter introduces electronic components—or at least the ones you are likely to use—and explains how to identify them and describes what they do. It also introduces a small amount of essential theory, which you will use over and over again.
Chapter 3	Basic Hacks	This chapter contains a set of fairly basic "hacking" how-tos, introducing concepts like using transistors with example projects. It includes hacking a "push light" to make it automatically turn on when it gets dark and how to control a motor using power MOSFETs.
Chapter 4	LEDs	In addition to discussing regular LEDs and how to use them and make them flash and so on, this chapter also looks at using constant current drivers for LEDs and how to power large numbers of LEDs and laser diode modules.
Chapter 5	Batteries and Power	This chapter discusses the various types of battery, both single use and rechargeable. It also covers how to charge batteries including LiPos. Automatic battery backup, voltage regulation, and solar charging are also explained.
Chapter 6	Hacking Arduino	The Arduino has become the microcontroller board of choice for electronics hackers. Its open-source hardware design makes using a complex device like a microcontroller very straightforward. The chapter gets you started with the Arduino and includes a few simple how-tos, like controlling a relay, playing sounds, and controlling servo motors from an Arduino. It also covers the use of Arduino expansion shields.
Chapter 7	Hacking with Raspberry Pi	The Raspberry Pi single board computer is great for hacking together electronic projects that require a bit more power than an Arduino can provide, or that need a network connection or large display. In this chapter you will learn how to set up and use a Raspberry Pi, as well as connect electronics to its GPIO pins.

Chapter	Title	Description
Chapter 8	Hacking with Modules	When you want to make something, you can often use readymade modules at least for part of the project. Modules exist for all sorts of things, from wireless remotes to motor drivers.
Chapter 9	Hacking with Sensors	Sensor ICs and modules are available for sensing everything from temperature to acceleration. In this chapter, we explore a good range of them and explain how to use them and connect some of them to an Arduino.
Chapter 10	Audio Hacks	This chapter has a number of useful how-tos relating to electronics and sound. It includes making and adapting audio leads, as well as audio amplifiers, and discusses the use of microphones.
Chapter 11	Mending and Breaking Electronics	Mending electronics and scavenging useful parts from dead electronics are a worthy activity for the electronics hacker. This chapter explains how to take things apart and sometimes put them back together again.
Chapter 12	Tools	The final chapter of the book is intended as a reference to explain more about how to get the most out of tools such as multimeters and lab power supplies.

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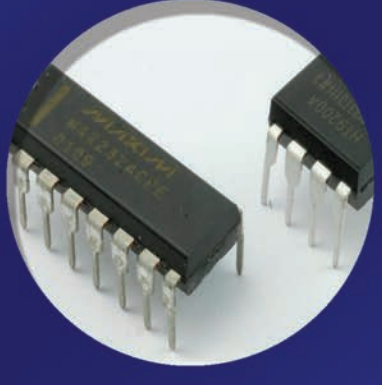
HACKING ELECTRONICS



1

Getting Started

In this first chapter, we will investigate some of the tools and techniques needed to hack electronics. We will start with a little soldering, and wire up an old computer fan to help keep the solder fumes out of our lungs.

As it says in the title, this book is all about "hacking electronics." The word "hacking" has come to mean many things. But in this book, "hacking" means "just do it!" You don't need a degree in electronic engineering to create or modify something electronic. The best way to learn is by having a go at it. You will learn as much from your mistakes as from your successes.

As you start to make things and experiment, you will likely want to understand more of the theory behind it all. Traditional electronics textbooks are pretty terrifying unless you have a good grasp of complex mathematics. This book strives to, above all else, enable you to do things first and worry about the theory later.

To get started, you will need some tools, and also find out where to get components and parts to use in your projects.

Getting Stuff

In addition to buying components and tools, there are lots of low-cost and interesting electronic consumer items that can be hacked and used for new purposes, or that can act as donors of interesting components.

Buying Components

Most component purchases happen on the Internet, although there are local electronic stores like Micro Center and Fry's (in the U.S.) and Maplin (in the UK) where you can buy components. At traditional brick-and-mortar stores like those, the product range is often limited and the prices can be on the high side. They do, after all, have a shop to pay for. These stores are invaluable, however, on the odd occasion when you need something in a hurry. Perhaps you need an LED because you accidentally destroyed one, or maybe you want to look at the enclosures they sell for

projects. Sometimes it's just nice to hold a box or look at tools for real, rather than trying to size them up from pictures on a web site.

As you get into electronics, you will likely gradually accumulate a set of components and tools that you can draw from when you start a new project. Components are relatively cheap, so when I need one of something, I generally order two or three or even five if they are cheap, enough that I have extras that can be used another time. This way, you will often find that when you start to work on something, you actually have pretty much everything you need already.

Component buying really depends on where you are in the world. In the U.S., Mouser and DigiKey are the largest suppliers of electronic components to the hobby electronics market. In fact, both of these suppliers sell worldwide. Farnell also supplies pretty much anything you could want, anywhere in the world.

When it comes to buying ready-made electronics modules for your projects, the SparkFun, Seeed Studio, Adafruit, and ITead Studio web sites can help. All have a wide range of modules, and much enjoyment can be had simply from browsing their online catalogs.

Nearly all the components used in this book have part codes for one or more of the suppliers I just mentioned. The only exceptions are for a few unusual modules that are better to buy from eBay.

There is also no end to the electronic components available on online auction sites, many coming direct from countries in the far east and often at extremely low prices. This is frequently the place to go for unusual components and things like laser modules and high-power LEDs that can be expensive in regular component suppliers. They are also very good for buying components in bulk. Sometimes these components are not grade A, however, so read the descriptions carefully and don't be disappointed if some of the items in the batch are dead-on-arrival.

Finally, a kit designed specifically for this book and designed by the author is available from MonkMakes Ltd. (https://monkmakes.com/hacking2).

Where to Buy Things to Hack

The first thing to consider, now that you are into hacking electronics, is an effect that your household and friends will have on you. You will become the recipient of dead electronics. But keep an eye open in your new role as refuse collector.

Sometimes these “dead” items may actually be candidates for straightforward resurrection.

Another major source of useful bits is the dollar store. Find the aisle with the electronic stuff: flashlights, fans, solar toys, illuminated cooling laptop bases, and so on. It’s amazing what can be bought for a single unit of currency. Often you will find motors and arrays of LEDs for a lower price than you would the raw components from a conventional supplier.

Supermarkets are another source of cheap electronics that can be hacked. Good examples of useful gadgets are cheap powered computer speakers, mice, power supplies, radio receivers, LED flashlights, and computer keyboards.

A Basic Toolkit

Don’t think you are going to get through this chapter without doing some soldering. Given this, you will need some basic tools. These do not have to be expensive. In fact, when you are starting out on something new, it’s a good idea to learn to use things that are inexpensive, so it doesn’t matter if you spoil them. After all, you wouldn’t learn the violin on a Stradivarius. Plus, what will you have to look forward to if you buy all your high-end tools now!

Many starter toolkits are available. For our purposes, you will need a basic soldering iron, solder, a soldering iron stand, some pliers, snips, and a screwdriver or two. SparkFun sells just such a kit (SKU TOL-09465), so buy that one or look for something similar.

Figure 1-1 A digital multimeter

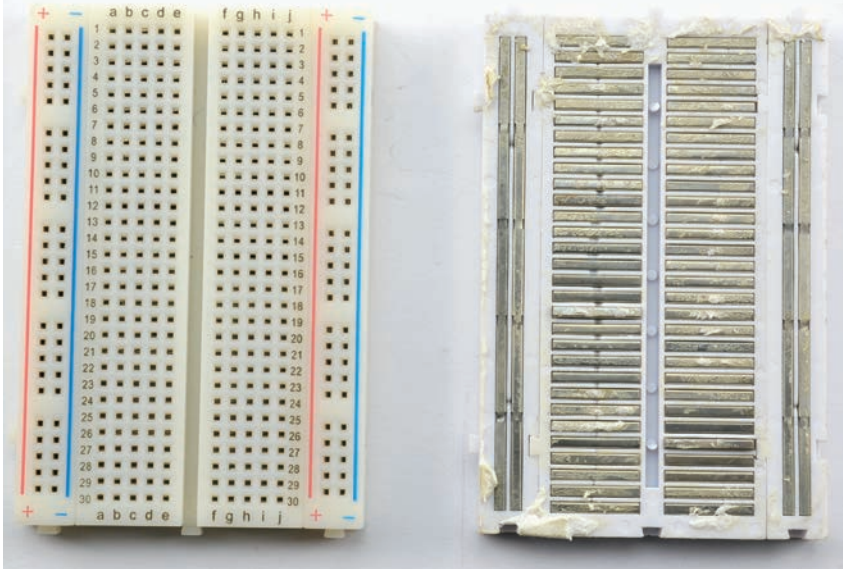
You will also need a multimeter (Figure 1-1). I would suggest a low-cost digital multimeter (don’t even think of going above USD 20). Even if you end up buying a better one, you will still end up using the other one since it’s often useful to measure more than one thing at a time. The key things you need are DC Volts, DC current, resistance, and a continuity test. Everything else is fluff that you will only need once in a blue moon. Again, look for something similar to the model shown in Figure 1-1. A multimeter like this is supplied with the MonkMakes Hacking Electronics Kit.

Test leads that end in alligator clips rather than a probe are very useful; some multimeters are supplied with such leads. If your multimeter does not include aligator-clip test leads, these are available from eBay for a few dollars.

Solderless breadboards (Figure 1-2) are very useful for quickly trying out designs before you commit them to solder. You poke the leads of components into the sockets, and metal clips behind the holes connect all the holes on a row together. They are not expensive (see T5 in the Appendix).

You will also need some solid core wire in different colors (T6) to make bridging connections on the breadboard. Another good idea is to buy special-purpose jumper wires with little plugs on the end—although these are useful, they are by no means essential.

Breadboard come in all shapes and sizes, but the most popular and the one used in this book is called "half-breadboard" or 400 point breadboard. This has 30 rows in two columns with two "supply" strips down each side (Figure 1-1). This kind of breadboard is widely available to buy and is also included in the MonkMakes Hacking Electronics Kit.



(a) (b)

Figure 1-2 Solderless breadboard

Figure 1-2b shows a breadboard that has been disassembled so that you can see the metal conductive clips behind the plastic. The long strips down each side are used for the power supply to the components. One positive and one negative. They are color-coded red and blue or black.

Stripping Wire

Let's start with some basic techniques you need to know when hacking electronics. Perhaps the most basic of these is stripping wire.

You Will Need

Quantity	Item	Appendix Code
	Wire to be stripped	T9 or scrap
1	Pliers	T1
1	Snips	T1

Whenever you hack electronics, there is likely to be some wire involved, so you need to know how to use it. Figure 1-3 shows a selection of commonly used types of wire, set beside a matchstick to give them perspective.

On the left, next to the matchstick, are three lengths of solid-core wire, sometimes called hookup wire. This is mostly used with solderless breadboard, because being made of a single core of wire inside plastic insulation, it will eventually break if it is bent. Being made of a single strand of wire does mean it is much easier to push into sockets when prototyping since it doesn't bunch up like multi-core wire.

When using it with breadboard, you can either buy already-stripped lengths of wire in various colors as a kit (see Appendix, T6) or reels of wire that you can cut to the lengths you want yourself (see Appendix, T7, T8, T9). It is useful to have at least

Figure 1-3 Common types of wire

three colors: red, yellow, and black are a good choice. It makes it easier to see how a project is connected up if you use red for the positive power supply, black for negative, and yellow for any other wires needed.

The top right of Figure 1-3 shows a length of multi-core wire, as well as some twin-strand multi-core wire. Multi-core wire is used when connecting up modules of a project. For instance, the wires to a loudspeaker from an amplifier module might use some twin, multi-core wire. It's useful to have some of this wire around. It is easily reclaimed from broken electronic devices, and relatively inexpensive to buy new (see Appendix, T10 and T11).

The wire at the bottom right of Figure 1-3 is screened wire. This is the type of wire you find in audio and headphone leads. It has an inner core of multi-core insulated wire surrounded by a screened wire on the outside. This type of wire is used where you don't want electrical noise from the environment such as mains hum (60 Hz electrical noise from 110V equipment) to influence the signal running through the central wire. The outer wire screens the inner wire from any stray signals and noise. There are variations of this where there is more than one core surrounded by the screening—for example, in a stereo audio lead.

Insulated wire is of no use to us unless we have a way of taking some of the insulation off it at the end, as this is where we will connect it to something. This is called "stripping" the wire. You can buy special-purpose wire strippers for this, which you can adjust to the diameter of the wire you want to strip. This implies that you know the width of the wire, however. If you are using some wire that you scavenged from a dead electronic appliance, you won't know the width. Having said that, with a bit of practice you will find you can strip wire just as well using a pair of pliers and some wire snips.

Wire snips and pliers are essential tools for the electronics hacker. Neither tool needs to be expensive. In fact, snips tend to get notches in them that make them annoying to use, so a cheap pair (I usually pay about USD 2) that can be replaced regularly is a good idea.

Figures 1-4a and 1-4b show how to strip a wire with pliers and snips. The pliers are used to hold things still with a firm grip, while the snips do the actual stripping.

Grip the wire in the pliers, about an inch away from the end (Figure 1-4a). Use the snips to grip the insulation where you want to take it off. Sometimes it helps to just nip the insulation all the way around before gripping it tightly with the snips, and then pull the insulation off (Figure 1-4b).

(a) (b)

FIGURE 1-4 Stripping wire

For longer lengths of wire, you can just wrap the wire around your finger a few times instead of using pliers.

This takes a bit of practice. Sometimes you will have the snips grip it too tightly and accidentally cut the wire all the way through, while other times you won't grip it hard enough with the snips and the insulation will stay in place or stretch. Before attempting anything important, practice with an old length of wire.

Joining Wires Together by Twisting

It is possible to join wires without soldering. Soldering is more permanent, but sometimes this technique is good enough.

One of the simplest ways of joining wires is to simply twist the bare ends together. This works much better for multi-core wire than the single-core variety, but if done properly with the single-core, it will still make a reliable connection.

You Will Need

To try out joining two wires by twisting (there is slightly more to it than you might expect), you will need the following.

Quantity	Item	Appendix Code
2	Wires to be joined	T10
1	Roll of PVC insulating tape	T3

If you need to strip the wires first to get at the copper, refer back to the section "How to Strip a Wire."

Figures 1-5a thru 1-5d show the sequence of events in joining two wires by twisting them.

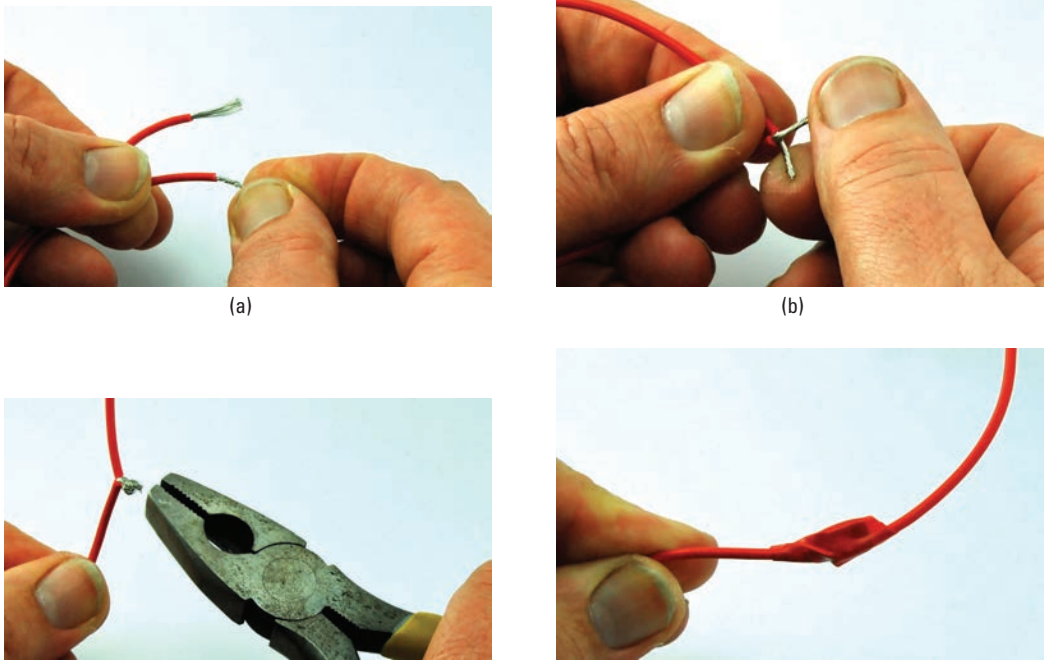


Figure 1-5 Joining wires by twisting

First, twist the strands of each wire up clockwise (Figure 1-5a). This just tidies up any straggling strands of the multi-core wire. Then, twist together the two pre-twisted wires (Figure 1-5b) so they are both twisting around each other. Try to avoid the situation where one of the wires twists around the second, while the second remains straight. If it does this, it is very easy for the first wire to just slip off the second. Next, twist the joined wires up into a neat little knot (Figure 1-5c). Note that a pair of pliers may be easier to use when making the knot, especially if the wire is on the thick side. Lastly, cover the joint with four or five turns of PVC insulating tape (Figure 1-5d).

Joining Wires by Soldering

Soldering is the main skill necessary for hacking electronics.

Safety

I don't want to put you off, but … be aware that soldering involves melting metal at very high temperatures. Not only that, but melting metal that's coupled with noxious fumes. It is a law

of nature that anyone who has a motorbike eventually falls off it, and anyone who solders will burn their fingers. So be careful and follow these safety tips:

- Always put the iron back in its stand when you are not actually soldering something. If you leave it resting on the bench, sooner or later it will roll off. Or you could catch the wires with your elbow and if it falls to the floor, your natural reflex will be to try and catch it—and chances are you will catch the hot end. If you try and juggle it in one hand, while looking for something or arranging some components ready to solder, sooner or later you will either solder your fingers or burn something precious.
- Wear safety glasses. Blobs of molten solder will sometimes flick up, especially when soldering a wire or component that is under tension. You do not want a blob of molten solder in your eye. If you are long-sighted, magnifying goggles may not look cool, but they will serve the dual purpose of protecting your eyes and letting you see what you are soldering properly.
- If you do burn yourself, run cold water over the burned skin for at least a minute. If the burn is bad, seek medical attention.
- Solder in a ventilated room, and ideally set up a little fan to draw the fumes away from you and the soldering iron. Preferably have it blowing out of a window. A fun little project to practice your wire joining skills on is making a fan using an old computer (see the section “How to Hack a Computer Fan to Keep Soldering Fumes Away”).

You Will Need

To practice joining some wires with solder, you will need the following items.

Quantity	Item	Appendix Code
2	Wires to be joined	T10
1	Roll of PVC insulating tape	T3
1	Soldering kit	T1
1	Magic hands (optional)	T4
1	Coffee mug (essential)	