

ROBOT BUILDER

The Beginner's Guide to
Building Robots



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John Baichtal

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ROBOT BUILDER

The Beginner's Guide to Building Robots

John Baichtal

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800 East 96th Street,
Indianapolis, Indiana 46240 USA

Robot Builder: The Beginner's Guide to Building Robots

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ISBN-13: 978-0-7897-5149-2

ISBN-10: 0-7897-5149-6

Library of Congress Control Number: 2014944096

Printed in the United States of America

First Printing: November 2014

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About the Author

John Baichtal writes books about toys, tools, robots, and hobby electronics. He is the co-author of *The Cult of LEGO* (No Starch Press) and author of *Hack This: 24 Incredible Hackerspace Projects from the DIY Movement*; *Basic Robot Building with LEGO Mindstorms NXT 2.0*; and *Arduino for Beginners* (all from Que Publishing). Most recently he wrote *Make: Lego and Arduino Projects for MAKE*, collaborating with Adam Wolf and Matthew Beckler, and he is the author of the upcoming Que book, *Building Your Own Drones: The Beginner's Guide to UAVs and ROVs*. He lives in Minneapolis, MN, with his wife and three children.

Dedication

To my grandmother, Marion Lillie, for her continued inspiration and support.

To my wife Elise and kids Eileen Arden, Rosemary, and Jack, for putting up with and participating in a lot of nerdy stuff.

Finally, to my cousins Sean Fields and Will Fields, the next generation of robot builders. I hope this book intrigues you!

Acknowledgments

Thanks to (in no particular order) Jude Dornisch, Steven Anderson, Adam Wolf, Michael Friert, John Wilson, Susan Solarz, Akiba, Mark Frauenfelder, Chris Berger, Michael Krampus, Alex Dyba, Brian Jepson, Becca Steffen, Dave Bryan, Actobotics, Eric Wang, Mike Hord, Makeblock, Pat Arneson, Erin Kennedy, uFactory, Windell H. Oskay, Creative Robotics, Johngineer, Matthew Beckler, Riley Harrison, Limor & Phil @ Adafruit, Tyler Cooper, Beatty Robotics, Arcbotics, David Lang, Trammell Hudson, Pete Prodoehl, Daniele Benedettelli, Bruce Shapiro, Alex Allmont, John Edgar Park, Miguel Valenzuela, Pete McKenna, Steve Norris, and, well, obviously, Rick Kughen.

A special thanks to my mother Barbara for assembling the Glossary, and for all her support. And to my gaming group, without whom I might not be sane: Big Ryan, Little Ryan, Drew, Gabe, Ned, Dave, Graham, and Jess.

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INTRODUCTION

Robots are incredible machines. The more complicated ones are entrusted with building cars and digging tunnels, projects that require lots of moving and lifting power but also precision. You may even have heard of experimental robots that are used for surgical procedures and can sew sutures or make incisions.

It's almost a science-fiction phenomenon in a way—how could anyone actually *build* one of those contraptions? It's not science fiction, of course. Robots are built by people, and you're a person—so let's make a robot! I call the first chapter of my book, “You, Robot Builder,” because that's what this book is about—showing how you can build a robot from the wheels up as you learn about motors, controllers, grippers, wheels, and everything else you need to create your first bot.

Your creation may not dig a tunnel or sew up an incision, but you will have built it, and that means you can build *any* robot, so long as you have the knowledge and parts.

What's in This Book?

The following list describes what you'll find in each chapter:

Chapter 1, “You, Robot Builder,” begins with the age-old question: What exactly *is* a robot? You'll learn about the various categories of robot and even try out a couple of absurdly simple robots that use vibration motors to move around.

Chapter 2, “Robots of the World,” shares a bunch of cool robots that other hobbyists have built around the world, with a variety of shapes and configurations.

Chapter 3, “Rolling Robots,” shows you how to build a wheeled robot, a basic platform that will serve you well through this book.

Chapter 4, “Going Solar,” teaches you about solar power. Then you use what you learn to make a spinning robot.

Chapter 5, “Controlling Your Robot,” explores two cool techniques for controlling your robot: using an Arduino microcontroller and a classic radio control rig.

Chapter 6, “Introduction to Programming,” introduces you to some basic programming techniques that delve deeper into the Arduino phenomenon.

Chapter 7, “Harnessing Infrared,” tackles two ways to use that nifty invisible light: passively, like a remote control receiver detects a signal, and actively with infrared, which uses the light to detect movement.

Chapter 8, “Building Sets,” covers those convenient modular construction sets, with multiple plastic and metal kits discussed. You'll even learn how to build a couple of robot chassis using building sets.

Chapter 9, “s/b Robot-Builder's Toolbox,” explores all the tools you need to complete your project.

Chapter 10, “Manipulators,” concludes the trio of tool chapters by exploring claws, grippers, and other manipulators robots use to interact with the outside world.

Chapter 11, “Water Robots,” tackles the subject of robot boats and shows you how to build one.

Chapter 12, “Art Bots,” takes a look at robots that draw or paint. You’ll have the opportunity to build a robot that draws with chalk.

On the Web

Chapter 13, “Web-Controlled Robots,” explores the subject of robots connected to the Internet, and you’ll build a robot that sends text messages. Chapter 13 can be downloaded for free from the Que website, www.informit.com/title/9780789751492.

I hope you find this book helpful and inspiring as you, too, become a robot builder.

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Going Solar

Why worry about batteries when we orbit around the ultimate energy source? The sun radiates vast amounts of energy, and we can use this to power our robots—and other stuff—all through the cool science of solar cells (Figure 4.1), which convert light into electricity.



FIGURE 4.1 Solar cells can be a great way to power your robot.

Your initial thought might be, “Simply add solar panels for free energy!” Not so fast. As I alluded to in Chapter 3, “Rolling Robots,” it’s not that simple. Even if you have a panel big enough to power your rig the way you like it, there’s no guarantee the sun is out. Furthermore, even if the sun is out, the earth’s orbit makes it appear to move across the sky, meaning the voltage generated will fluctuate.

All that being said, there's a lot to like about solar-powered robots. You can store them away for a couple years and they'll still work. You don't have to buy new batteries periodically. Finally, you can do some intriguing things with robotics, like create autonomous crawlers that creep around your yard like a friendly robo-insect. However, even if you do use batteries in your robot, you can have a solar panel as well, to continuously charge the batteries. The best of both worlds!

In this chapter, you'll learn about how to use these panels in your projects. Then you'll bone up on *breadboarding*, which is a cool way of temporarily constructing circuits. Finally, you'll build two sweet projects. The first is a solar-powered battery charger, and the second is a simple robot that is entirely powered by sunlight.

How Do Solar Panels Work?

Solar cells are layers of semiconductive materials (shown in Figure 4.2) that create an electrical current when exposed to light. The earliest recorded observation of the photovoltaic effect took place in 1839 when Alexandre-Edmond Becquerel's experiments with silver chloride produced voltage and current when exposed to light. By 1959, all satellites launched into space bore solar panels, and a little more than 50 years after that, we're using them to power robots.

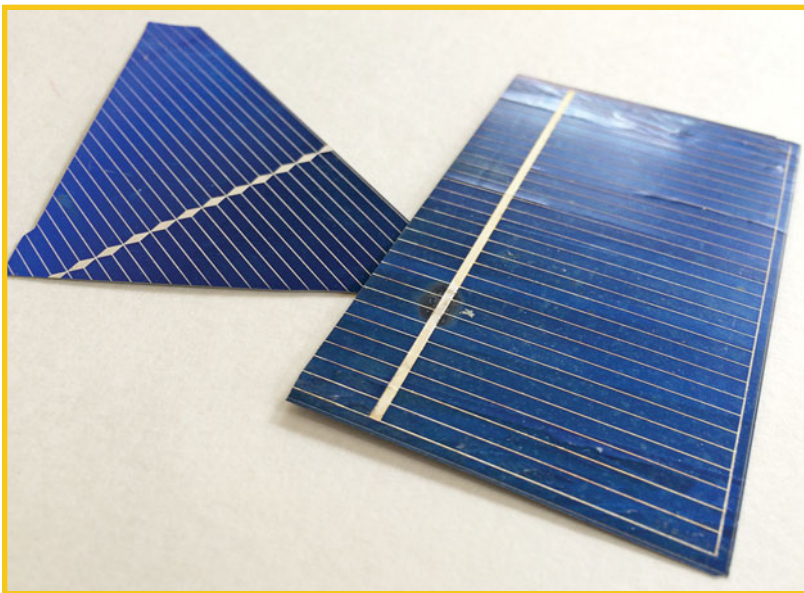


FIGURE 4.2 Silicon wafers consist of two layers of semi-conductive material.

You often hear different terms associated with solar technology. A solar cell is a piece of photovoltaic material, usually crystalline silicon. Solar cells are often connected into groups on a support structure, and these are called panels. A group of panels is an *array*.

Solar cells are rated for direct current (DC) output under certain test conditions—a sunny June day in San Francisco, for instance. Measurement is in watts as well as photovoltaic efficiency. Finally, because the output is DC, you'd need an inverter to run household appliances off of it.

There are two kinds of solar cells. The most common are the crystalline silicon wafers I've been describing, which are covered in glass or plastic to protect the fragile cells.

The other kind of solar cell is flexible plastic. Called thin film solar cells, or TFSC, these consist of photovoltaic material deposited on a substrate. Originally used for solar-powered watches, flexible-film solar cells are more expensive than crystalline silicon and have a lower efficiency. However, they're useful for situations where the panel needs to flex, or the weight of the panel becomes a consideration.

BEAM Robotics

One of the earliest hobbyist uses for solar cells occurred in a phenomenon called BEAM (which stands for Biology, Electronics, Aesthetics, and Mechanics); these were analog robotics designed as if they were living things. Created in the 1990s by engineer Robert Tilden, BEAM was an attempt to make robots as simple as possible—no microchips or programs ran these bots. Instead, Tilden used discrete components, such as capacitors and resistors, to create sense-act behaviors. For example, the robot in Figure 4.3 senses light and then turns a motor.



FIGURE 4.3 This solar-powered robot spins when light strikes it.

Credit: Adam Wolf

The key to creating simple BEAM bots is tiny solar cells, which generate minute amounts of electricity; with the help of capacitors and other components, they generate enough electricity to move motors and turn on LEDs.

The biology aspect of BEAM comes into play because the robots frequently emulate insects and other living organisms. The circuits mimic the activities of biological neurons, and BEAM bots' rudimentary control systems were intended to help the robots find food, just as a real being's instincts might lead it to sustenance.

Tilden came up with three golden rules for BEAM robotics:

- Make your robot as simple as possible.
- Recycle and reuse junked electronics.
- Use solar power.

BEAM aficionados use scientific terms to describe the various types of robots. For instance, photophobes are robots that retreat from the light, whereas a thermophile is attracted to heat. They also describe the beam bots by locomotion style: crawlers, jumpers, rollers, and so on.

Three Hobbyist-Friendly Solar Cells

There are many solar cells out there, but cataloging them is beyond the scope of this book. Instead, I'll describe three inexpensive cells you can easily buy.

Flexible Film

Thin, flexible, and durable, this type of solar cell is often used for curved surfaces, such as an radio control (RC) plane's wings. The cell in Figure 4.4 is from Jameco.com (P/N 227985). It measures about 1½"×2½" and is paper thin. It generates 3V and costs about \$4.

Jameco has other cells from the same manufacturer, ranging in size up to 10×6 inches. Adafruit also has a flexible solar cell, a 6V model (P/N 1485) that measures 4"×8".

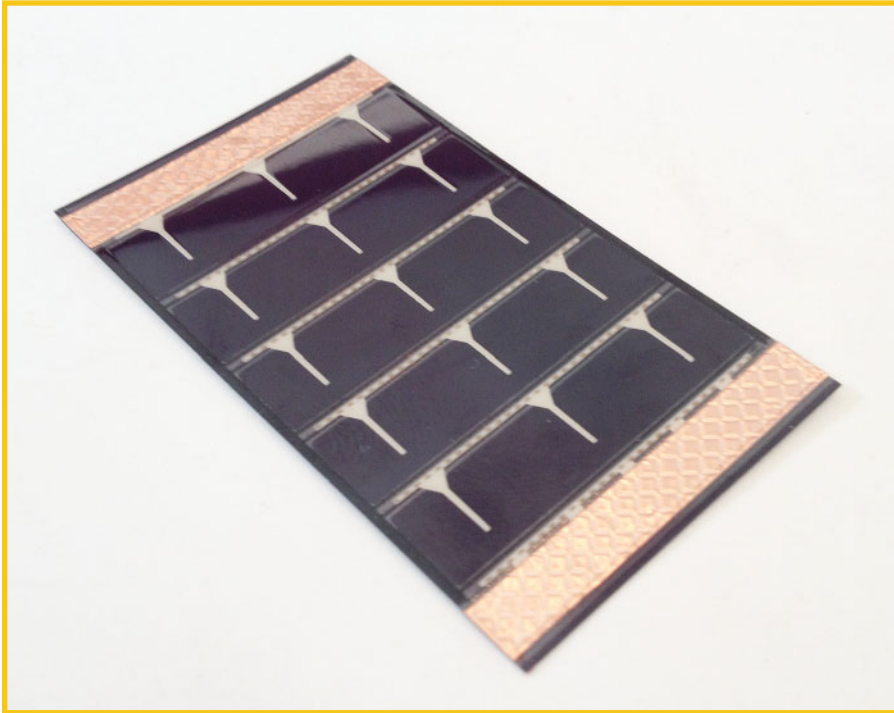


FIGURE 4.4 Flexible-film solar cells are great for attaching to curved surfaces.

Glass and Silicon

You'll often find silicon solar cells faced in glass. I'm not sure if this is to weatherproof the cell, but it sure doesn't help silicon solar cells' extreme fragility. The one in Figure 4.5 is one of those solar walkway lights. Incidentally, you can get a ton of great components from one of those, ranging from rechargeable batteries to full-color light-emitting diodes (LEDs) and, yes, solar cells.

However, you'll encounter glass panels elsewhere. For instance, the \$100 portable solar cell SunVolt (gomadic.com) is glass.

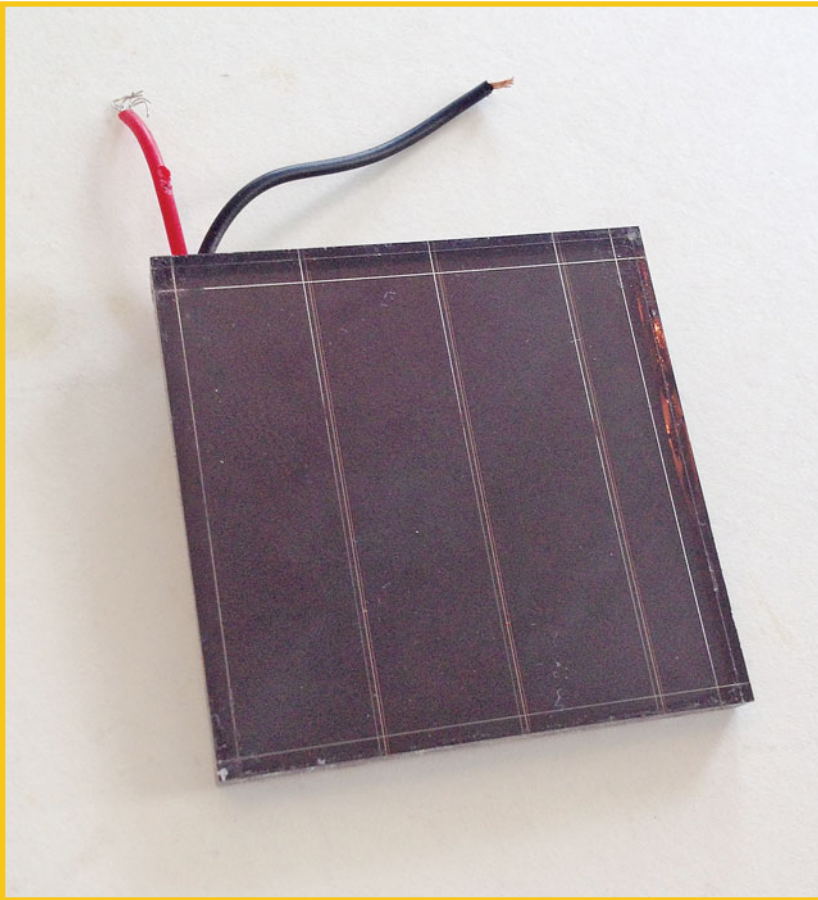


FIGURE 4.5 This solar cell came from a dismantled yard light.

Plastic and Silicon

Most of the hobbyist solar panels you'll encounter will consist of a board with one or more solar cells stuck to it and covered in clear resin. The Adafruit solar panel pictured in Figure 4.6 (P/N 417) is made up of 12 cells and delivers 6V at 3.7 watts and costs a reasonable \$30. It's pretty huge, about 7 inches on a side, but it would be great for larger projects.

I also have a smaller one, P/N YH30-18, from an unknown company. It's roughly analogous to Jameco.com P/N 2136913. It's about an inch long and has soldering points, and I've used it as a glorified light sensor in the past.

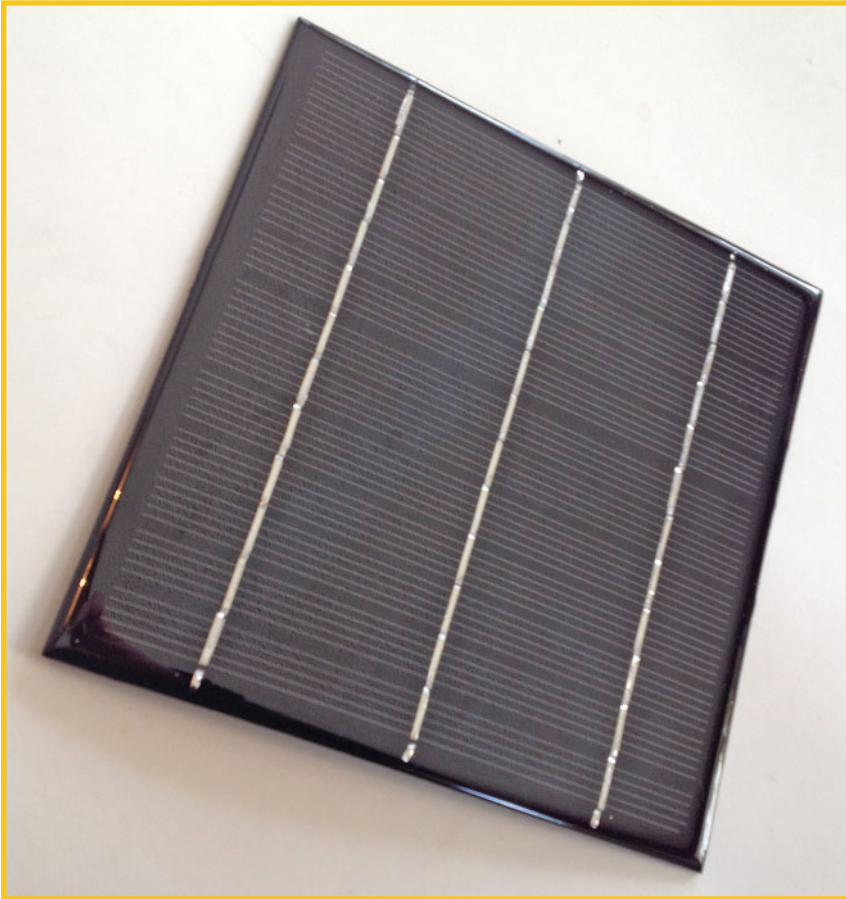


FIGURE 4.6 The most durable type of solar cells are made of plastic and silicon.

Prototyping Circuits

To use solar cells, you need to level up your skills in laying out circuits. After a certain point, you need a way to connect and organize the wires and components. This section offers two ways; the first is using a solderless breadboard, which is a quick and easy way to prototype circuits. I'll also show you how to solder, which uses conductive metal to stick components together. It's fun!

How to Breadboard

As you can see in Figure 4.7, the breadboard consists of a grid of wire holes. What you can't see is that conductors are hidden in the plastic, so some of the rows of holes are linked together and some aren't. So, without ado, let's examine a breadboard's architecture:

- **A. Ground bus**—The ground bus is the strip of holes marked with a blue or black line. All the holes in this strip are linked together and typically are used for ground connections. Simply plug in the bus to your Arduino's ground pin or the negative terminal of a battery pack.
- **B. Power bus**—The power bus is configured the same as the ground bus and marked with a red line on most breadboards. Plug your power supply here and then connect components as needed to power them.
- **C. Terminal strips**—These rows of holes are connected in groups of five, as marked in Figure 4.7. The various holes are given letters and numbers to help you organize your circuits.
- **D. Notch**—The notch in the center of the breadboard separates the two sides—none of the hidden conductors cross the notch. If you want to connect the two sides, you'll need to use wires! When breadboard projects involve integrated circuits or microchips (ICs), the chip is usually positioned to straddle the notch, and this provides limited air cooling.

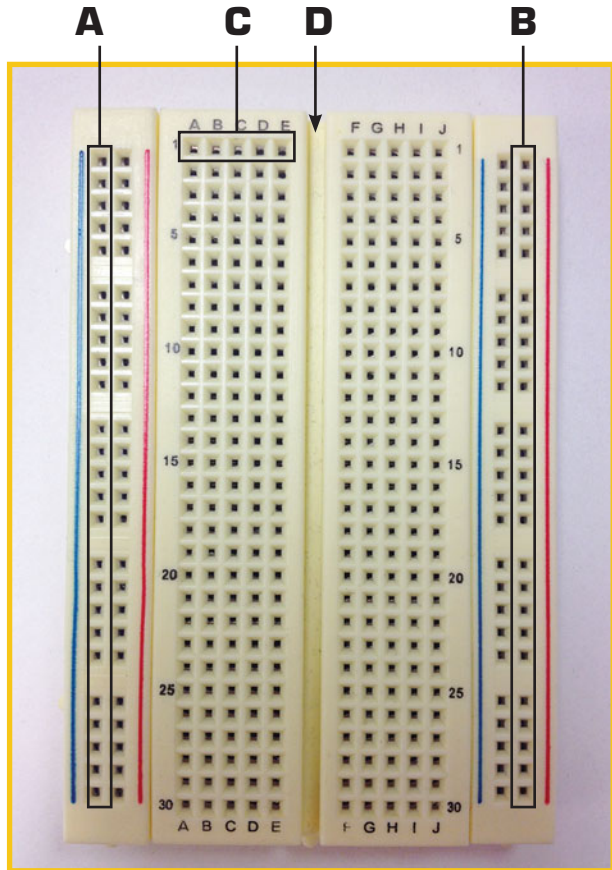


FIGURE 4.7 A solderless breadboard is a convenient prototyping platform.

Here's an example of a simple breadboard project. Look at Figure 4.8 and follow along:

- 1. Plug in a resistor from the power bus to one of the terminal strips. I used a 10,000-ohm resistor (known as a 10K, Sparkfun P/N COM-11508). It doesn't matter which wire goes where.
- 2. Plug in an LED. I used one of Sparkfun's violet LEDs (P/N COM-12704) and it ended up rather dim. You might try swapping in a lower value of resistor. LEDs are polarized, meaning that one lead is positive and one is negative, and if you put it in backward, the LED won't light up. Put the long lead of the LED (positive) in the same terminal strip as the resistor. The short end (negative) plugs into the ground bus.
- 3. Attach a 9V battery to a battery clip (Jameco P/N 109154), with the red lead plugged into the power bus and the black lead plugged into the ground bus. The LED should light up!

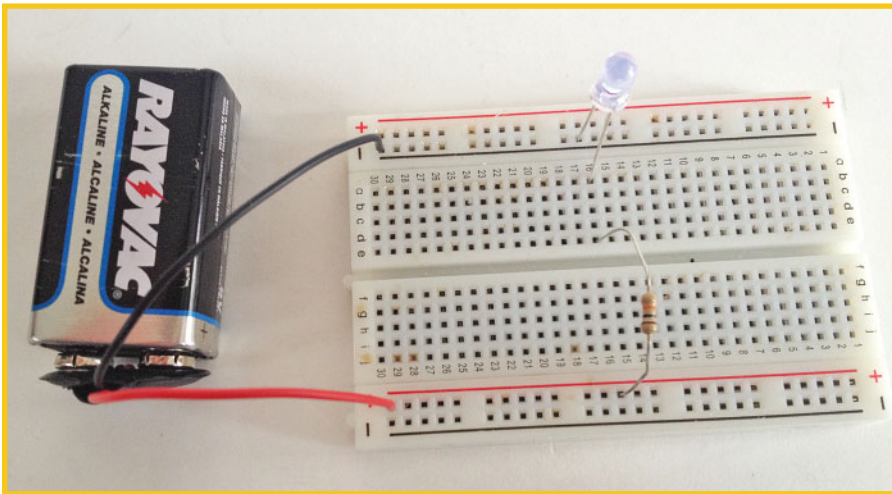


FIGURE 4.8 This simple project will show you how to use a breadboard.

How to Solder

Breadboarding is well and good, but the best way to connect wires and components—assuming everything is working the way you expect—is to solder them. In this section, I'll take you through a very quick but thorough guide to soldering.

Soldering Toolkit

You'll need the following supplies to solder:

- **Soldering iron**—These come in many shapes and price points. You don't have to spend a lot of money to get a quality iron, but the Radio Shack cheap one is not the solution. The two irons I use are a Weller WES51 (just Google that P/N to find one) and an Xytronic XY-258 iron (Adafruit P/N 180) that I keep in my toolbox.
- **Solder**—Solder comes in a great number of formulations and gauges. Here's a great solder and I use it for all of my projects: 0.31" gauge, rosin-core, 60/40 lead solder. You can buy it anywhere (Adafruit has it, P/N 145).
- **Sponge or tip cleaner**—It's important to keep your iron's tip clear of residue, such as melted jumper insulation and baked-on flux. Some irons, like the aforementioned WES51, have a sponge that comes with it, but many soldering pros swear by tip cleaners like the Hakko 599B (Adafruit P/N 1172), which features a tangle of brass foil that cleans your iron without the need for a wet sponge.
- **Vise**—Small tabletop vises like the Panavise Jr. (Sparkfun P/N TOL-10410) help keep the printed circuit board (PCB) secure while you solder. Often they have suction cups or mounting holes for added security. You can usually hold the PCB in your hand or keep it on the table, so a vise is optional.
- **Solder sucker**—This is a tool for sucking up molten solder. Sparkfun has a cheap one (P/N TOL-00082), and Adafruit has a much nicer model that costs more (P/N 1597).
- **Diagonal cutters**—Use this for clipping off leads after you're done soldering. Sparkfun has an inexpensive pair (P/N TOL-08794), and Adafruit has a nicer set made in Italy (P/N 152).
- **Fume extractor**—Soldering releases some toxic fumes. An ordinary desk fan or a specialized fan called a fume extractor (Jameco P/N 2171786) will keep those noxious gases away from your respiratory tissues.

Anatomy of a PCB

Electronic projects usually include a printed circuit board, or PCB. These typically consist of a sheet of laminate embedded with traces (wires) and solder pads, which are the tiny plates onto which the components are soldered. There are also instructions screen-printed on the material. Let's take a closer look at the typical circuit board in Figure 4.9:

- A. Circuit board
- B. Screen-printed information
- C. Solder pads
- D. Traces

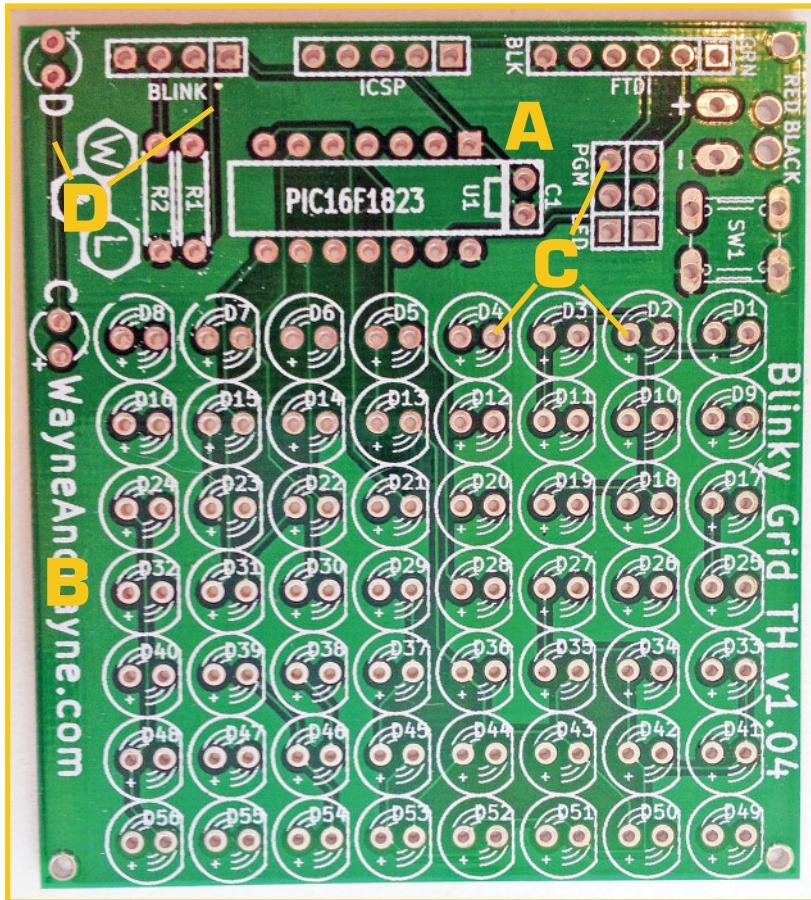


FIGURE 4.9 Screen-printed labels show you how to assemble the PCB.

Safety

Although soldering may seem dangerous—hot irons and lead poisoning!—I’m happy to say that it’s actually quite safe, as long as you follow some basic guidelines:

- Beware of what your soldering iron’s tip is touching. The tip is upwards of 600 degrees and can start fires and burn skin. However, tip burns are part of the soldering experience and can be treated as you would any burn.
- It’s suggested that you wear eye protection when clipping leads. These are the wires sticking out of electronic components, and they can go flying when clipped, potentially injuring you in the eyes. Better not to risk it.

- Solder is made out of lead, and that means that you shouldn't ingest it. You should make a point to clean your hands and workspace after soldering. The latter can be cleaned up with ordinary household spray cleaner to make sure you've collected as much lead particulate as you can.
- The fumes are also toxic. You should solder in a well-ventilated room or use a fan or fume extractor to keep those fumes away from your face.

Let's Solder!

If you have all the stuff you need, you're ready to solder! I'm illustrating the process by assembling a Blinky Grid kit from Wayne & Layne (wayneandlayne.com or Adafruit P/N 549), so if you're intrigued, you know where to find one.

Follow along with the simple steps outlined in the following sections:

STEP 1 Set Up the Work Area

You usually want your soldering iron close at hand, as well as a nice work surface. If you want accessories like a fume extractor or vise, now is the time to grab them (Figure 4.10).

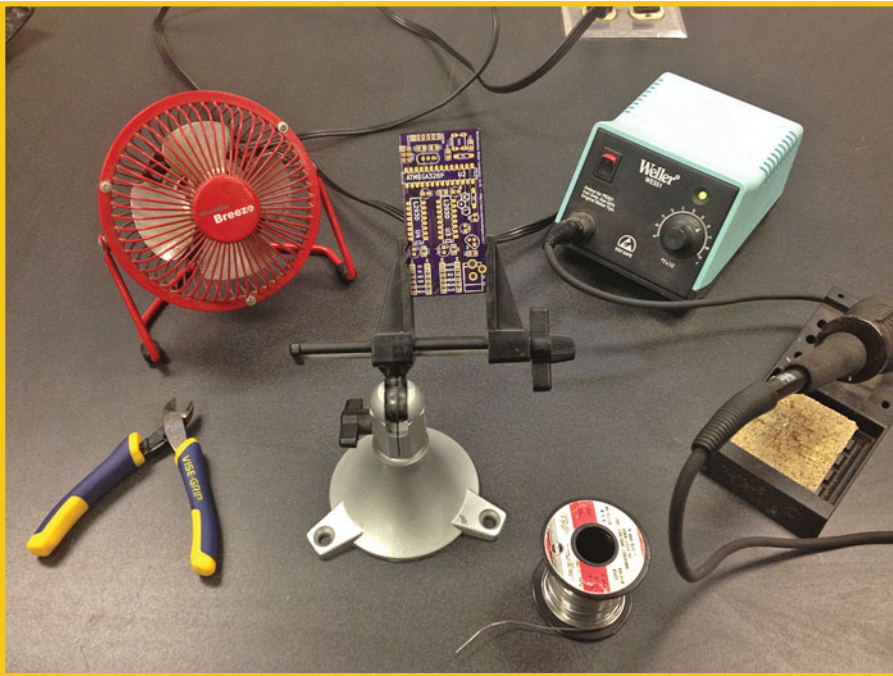


FIGURE 4.10 Want to solder? Gather all your tools together.

**STEP 2** Heat Up the Iron

Some irons don't have an "on" switch; you just plug them in. If it's got a switch, turn it on. Often an iron will have a temperature selector; if it does, set it to about 650 degrees, as you can see in Figure 4.11.

FIGURE 4.11 Plug in your iron and heat it up!**STEP 3** Tin the Tip

The first word in soldering iron maintenance is to "tin" the tip—basically, coating it in solder. This helps transmit heat, and if you tin your tip early and often, you will be rewarded with a hotter iron. Just touch the iron to a piece of solder and turn the iron around until the tip is coated, as you can see in Figure 4.12.

FIGURE 4.12 Coat the tip of your iron with solder.

STEP 4 Insert the Component

This is fairly self-evident. Components have wires sticking out of them, called leads. The circuit board normally indicates if a component is polarized. This means the leads have to be inserted in a certain way on the PCB. Also on the circuit board are little metal disks pierced with holes. These are the solder pads. Slide the component's leads through the holes in the solder pads, just like in Figure 4.13.

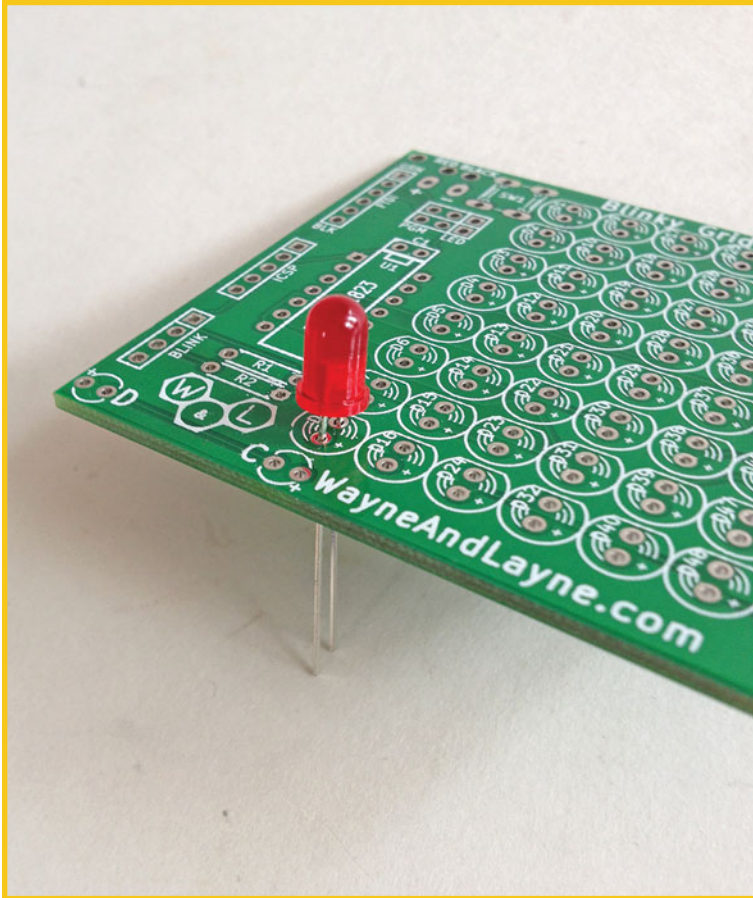


FIGURE 4.13 Insert the component, making sure you got the polarity right.

STEP 5 Bend Back the Leads

Turn the PCB around so you're looking at the back. Bend the leads of the component (as you can see in Figure 4.14) so it won't fall out when you solder.

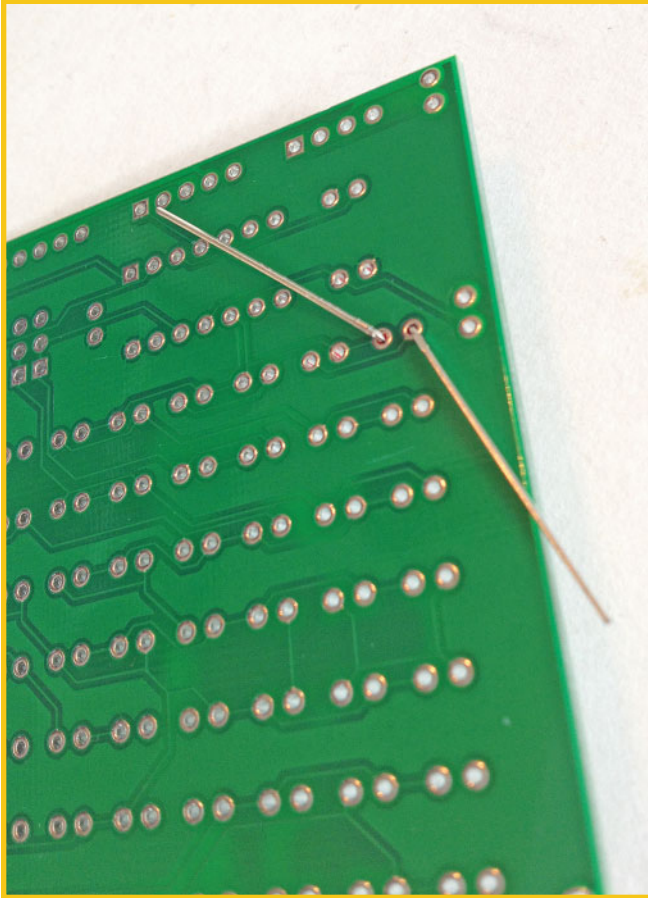
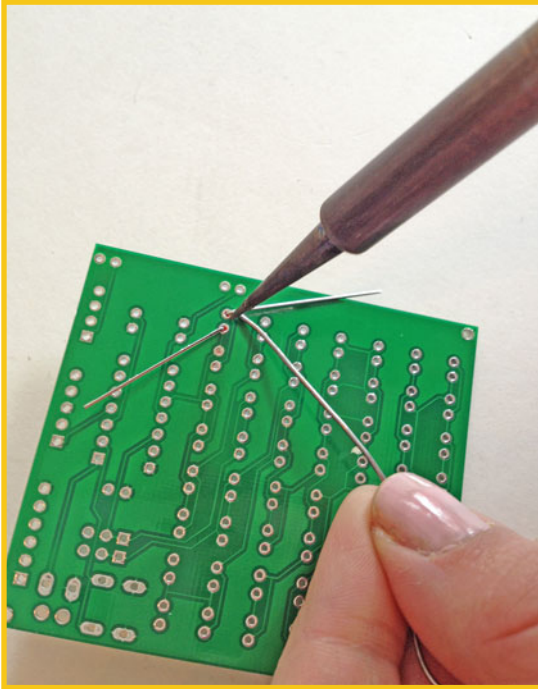
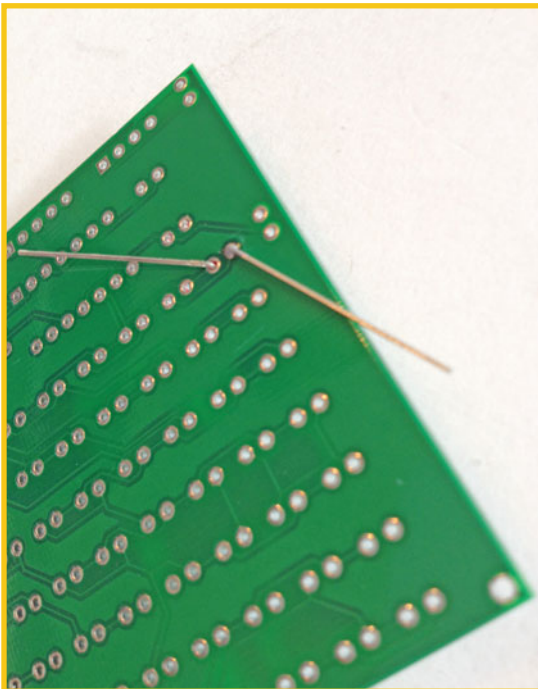


FIGURE 4.14 Bend the leads back to keep the component from falling out.

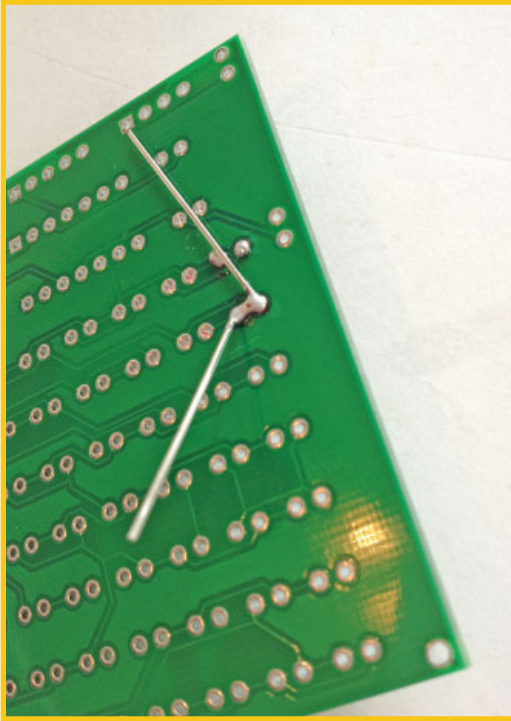
**STEP 6** Solder the Joint

Touch the iron's tip to the lead and the solder pad for three seconds (Figure 4.15) and insert the end of a piece of solder. The solder should flow into the hole and rise into an even little hill.

FIGURE 4.15 Just add solder!**STEP 7** Examine the Joint

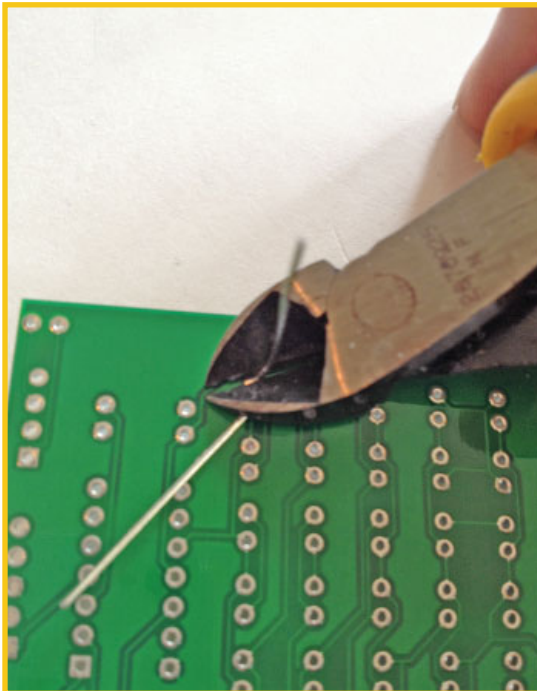
Before you move on, take a gander at the connection. It should be a neat little hill, like in Figure 4.16.

FIGURE 4.16 A successfully soldered connection looks like a tiny hill!

**STEP 8** Resolder as Necessary

Suppose your solder joint looks like the one in Figure 4.17—gooping up two solder pads. Grab your solder sucker, a spring-loaded piston that sucks away melted solder. Press down the plunger, then melt the solder with your iron while holding the solder sucker close. When the solder starts to flow, press the button on the piston and it will suck the solder away.

FIGURE 4.17 Too much solder? Grab a solder sucker.

**STEP 9** Clip the Lead

When the solder joint looks the way you like it, clip the lead as close to the joint as you can manage (see Figure 4.18). Ready for the next component!

FIGURE 4.18 Clip the excess lead off. You're done!

Using Solar Power to Charge Batteries

If you've ever seen a solar yard light, you'll know that it's easy to charge batteries using solar power. Let me edit that: it's easy to charge some batteries. It's easy to charge the cheaper end of the battery spectrum. I'm talking the NiMh and NiCad batteries, found in the usual sizes and costing somewhat more.

All you need to charge one of these batteries is to connect it to an electrical source—the only caveat being you should protect the battery from the circuit reversing polarity, which can damage your batteries. To do this, you add a diode (such as 1N4001 diode, Adafruit P/N 755) between the positive lead of the solar cell and the positive lead on the battery pack, as seen in Figure 4.19.

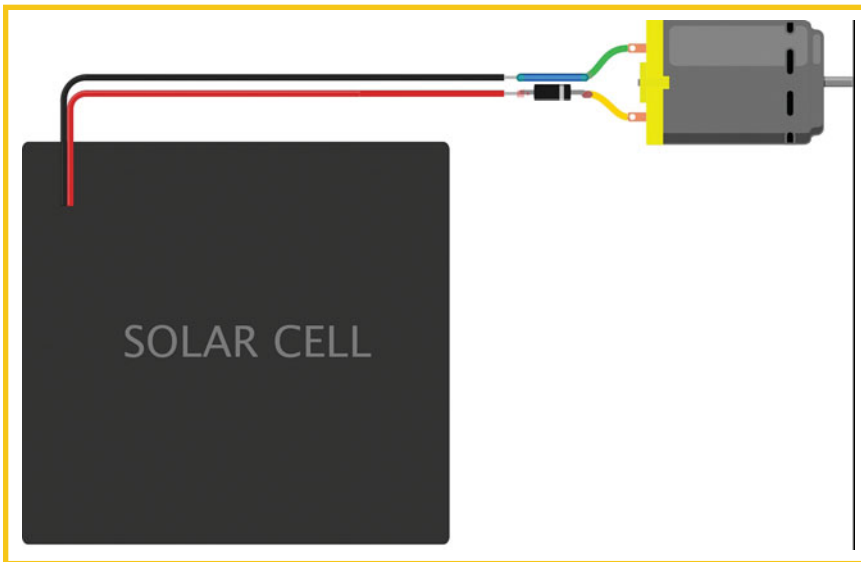


FIGURE 4.19 Protect your solar cell from energy flowing back into the battery pack.

If you want to use one of those more compact LiPoly batteries in your project, an example is Adafruit's Lithium Ion Polymer battery (P/N 1578) that delivers 3.7v at 500mAh, and they have a number of variants if that's not the configuration you want.

Adafruit also sells a solar charger (P/N 390) that goes with the battery, as well as solar panels (such as P/N 417) guaranteed to work with it. You can see this arrangement in Figure 4.20. The advantage with going with a preconfigured setup like Adafruit's is that you know it works, with no experimentation or ordering new parts when one configuration doesn't work.

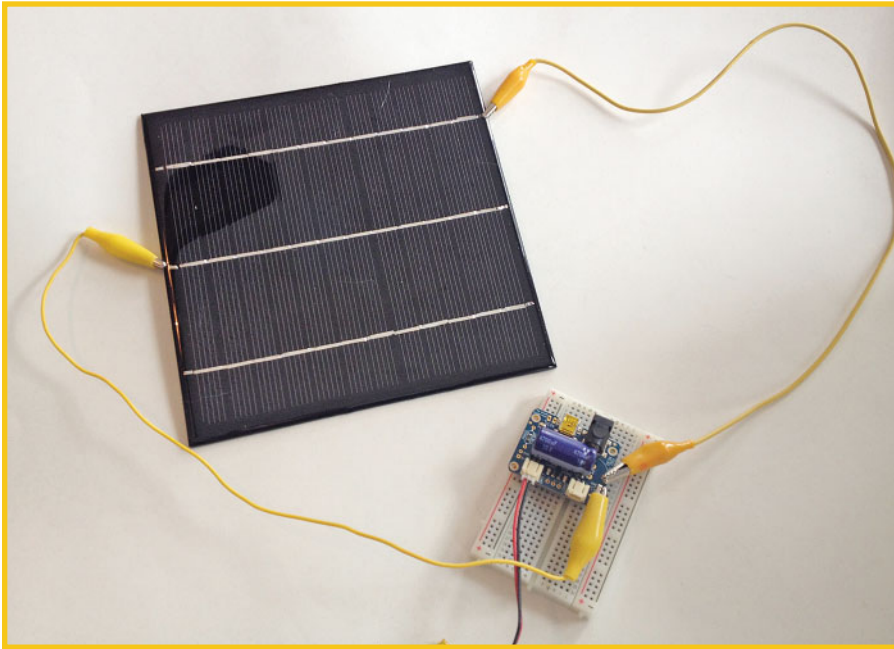


FIGURE 4.20 A LiPoly battery getting charged with a solar panel.

Project: DIY Solar Panel

One cool thing about solar panels is that you are not limited to just one. You can take a bunch of separate panels, or even fragments of panels, and solder them together to make a larger one. You can do this one of two ways. The first is to connect them in series, which means that the negative lead of one cell connects to the positive lead of the next. When a number of cells are connected this way, the voltage is the sum of the various panels and the amps remain the same. For example, two 12V 3.5-amp cells wired in series output 24V at 3.5 amps. By contrast, if you were to wire those cells in parallel, where all the positive leads are connected together and all the negative leads are connected together, you'd get an output of 12V at 7 amps.

Why would you want one over the other? It all depends on what you're using it for. Motors use a lot of amps, for instance. Go ahead and try both ways of wiring up your panels, testing each way with a multimeter. See Chapter 9, "Robot-Builder's Tool Box," to learn more about this great tool.

Parts List

To make your own multicell solar panel, you'll need the following parts. Follow along with Figure 4.21:

- Pieces of solar panel or a number of separate panels. One option is the Jameco Solar Cell Grab Bag (jameco.com, P/N 2113666), which consists of factory-extra solar cells in irregular shapes. The downside to that option is that you have to solder all the parts together. Another option is to buy individual solar panels already equipped with wires, and then manually connect them.
- Stranded hookup wire like Sparkfun P/N 11375.
- Soldering supplies (optional). If you decide to solder and need help, I teach you how to solder earlier this chapter.
- A board or other surface on which to stick the solar cells.
- Hot glue or some other kind of adhesive.

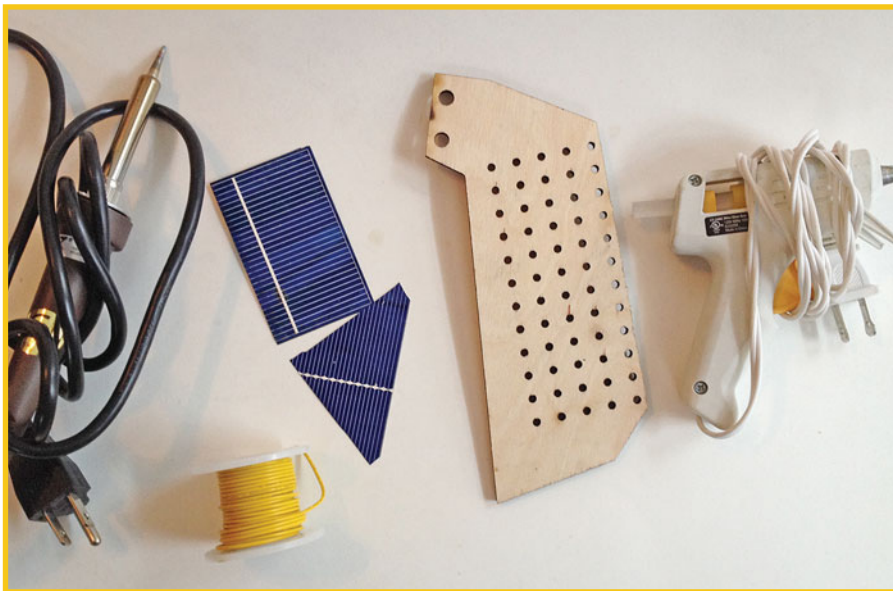


FIGURE 4.21 You'll need the following parts to make your DIY solar cells.

Step-by-Steps

Follow along with these steps to build your DIY solar cells:

STEP 1 Decide how many volts and amps you want. Measure each panel's output and determine whether to go with serial or parallel. If in doubt, I suggest serial because it's easier to wire together! In Figure 4.22, I show two solar panels soldered in series, connected to a multimeter. Note that I used solid hookup wire when prototyping this project. Big mistake—the solid wire is too stiff. Stranded wire is more flexible, which is easier on fragile solder joints, and it lays flat better.

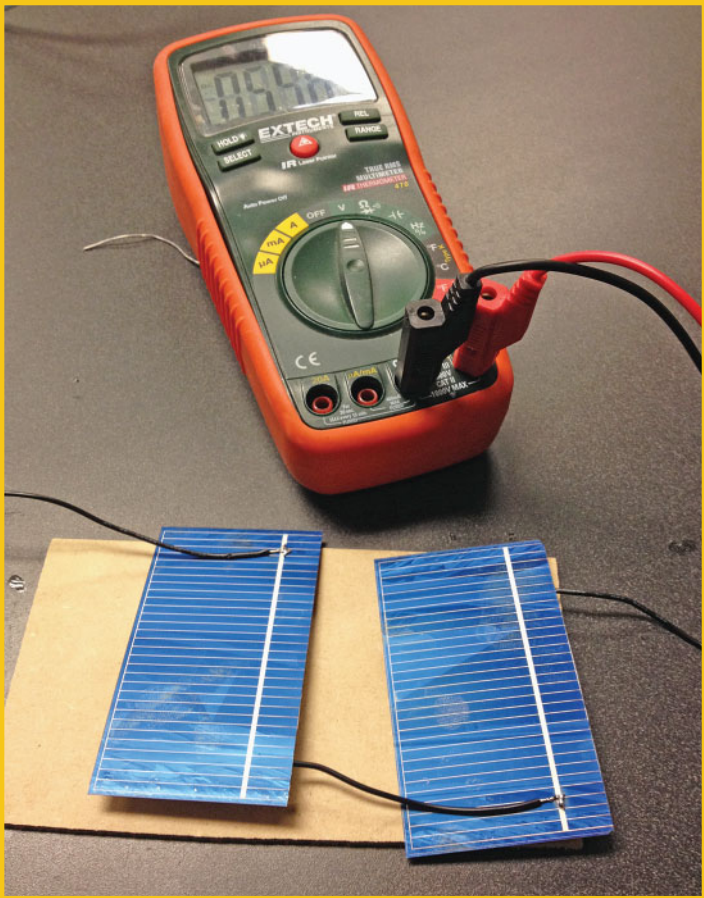


FIGURE 4.22 Connect your solar cells in series.

STEP 2 Connect the cells together in series. This means the positive wire of one cell connects to the negative wire of the next cell. On cells without wires, you will need to solder them on. The entire metallic backing of the cell is the positive lead, and the shiny strips on the front are negative, as shown in Figure 4.23. However, if your solar cells have wire leads, you don't have to bother with all that.

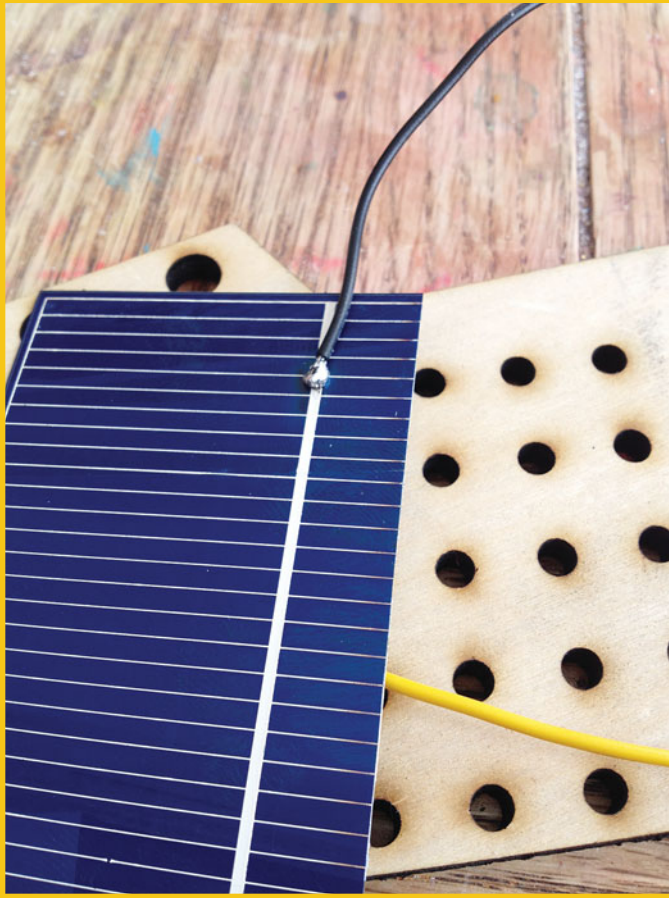
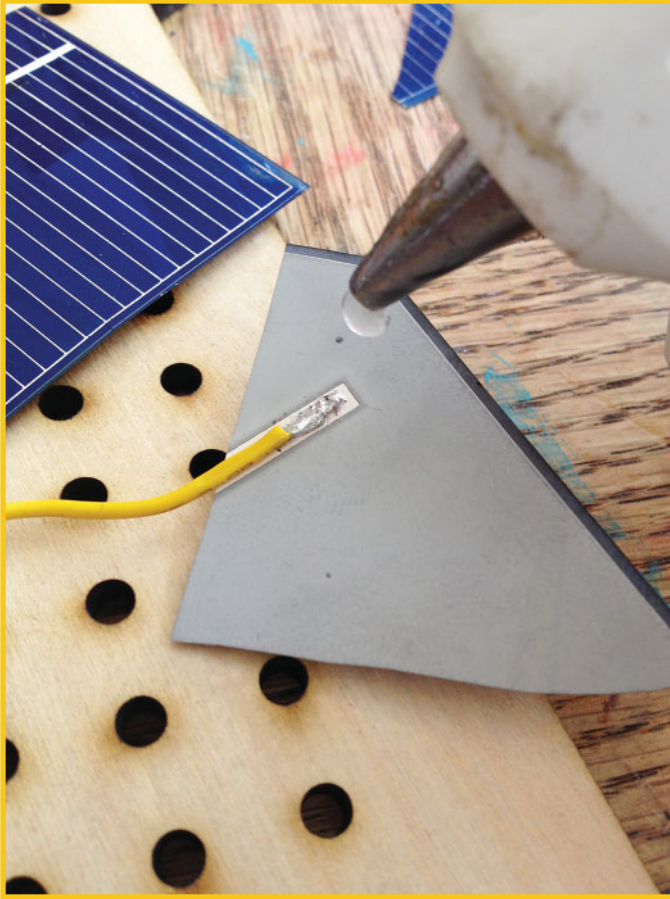


FIGURE 4.23 Solder one wire to the positive and one to the negative lead.



STEP 3 Glue the cells to the board. You may want to secure the solder joints with a little hot glue as well, as shown in Figure 4.24.

FIGURE 4.24 A little hot glue can help keep the solder joints secure.

STEP 4 Hook up the cells as shown in Figure 4.25—each positive wire is plugged into its neighbor's negative wire.

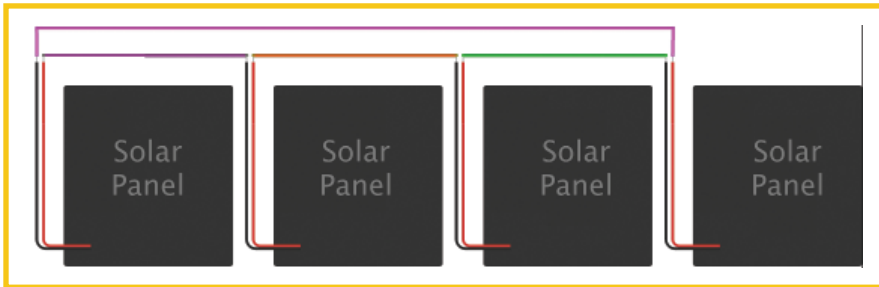


FIGURE 4.25 Hook up the solar cells in series.

TIP

The entire metallic backing of the solar cell is the positive lead, and the shiny strips on the front are negative.

Project: Making a Solar Spinner

Let's make the most basic solar-powered motor possible. It's not just a solar panel connected to a motor, but it's close. It's called a Solar Spinner because the entire robot, except for the base, spins in the light.

What makes the robot work is a capacitor, an electronic component that stores a small amount of voltage inside an electrical field. In a way, it works like a small battery, charging up as solar power trickles in, and then releasing the electricity when the cap is full. See Figure 4.26.

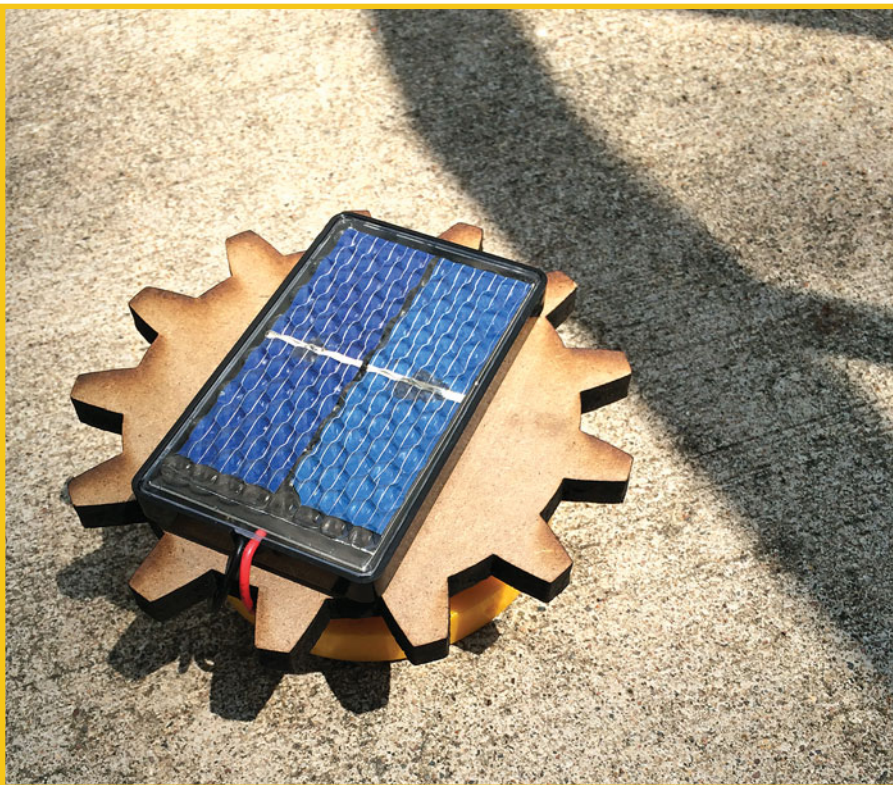


FIGURE 4.26 The Solar Spinner turns when the sun's out.

Parts List

You'll need the following parts to build your Solar Spinner (see Figure 4.27):

- **3V DC motor**—Jameco P/N 2158442.
- **A small solar panel**—Harvest one from a yard light, or Jameco has a good one, P/N 2136921.
- **Stranded wire**—Jameco P/N 2187876.
- **1-Farad, 5.5V capacitor**—Jameco P/N 142957.

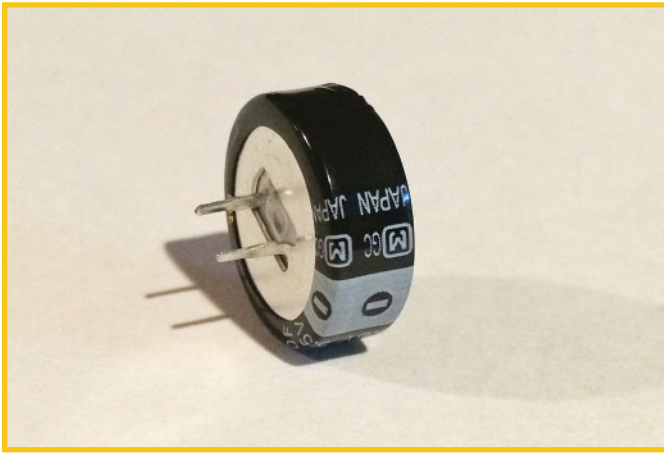


FIGURE 4.27 Grab these parts to build your Spinner.

Step-by-Steps

This is a very simple build, so let's get started!



STEP 1 Solder the negative lead of the solar panel to the negative lead of the capacitor, and then connect both to the negative port of the motor. See Figure 4.28.

FIGURE 4.28 Connect the negative leads of the three components.

STEP 2 Connect the negative lead of the solar panel to the negative lead of the capacitor, and then solder both to the negative port of the motor. See Figure 4.29.

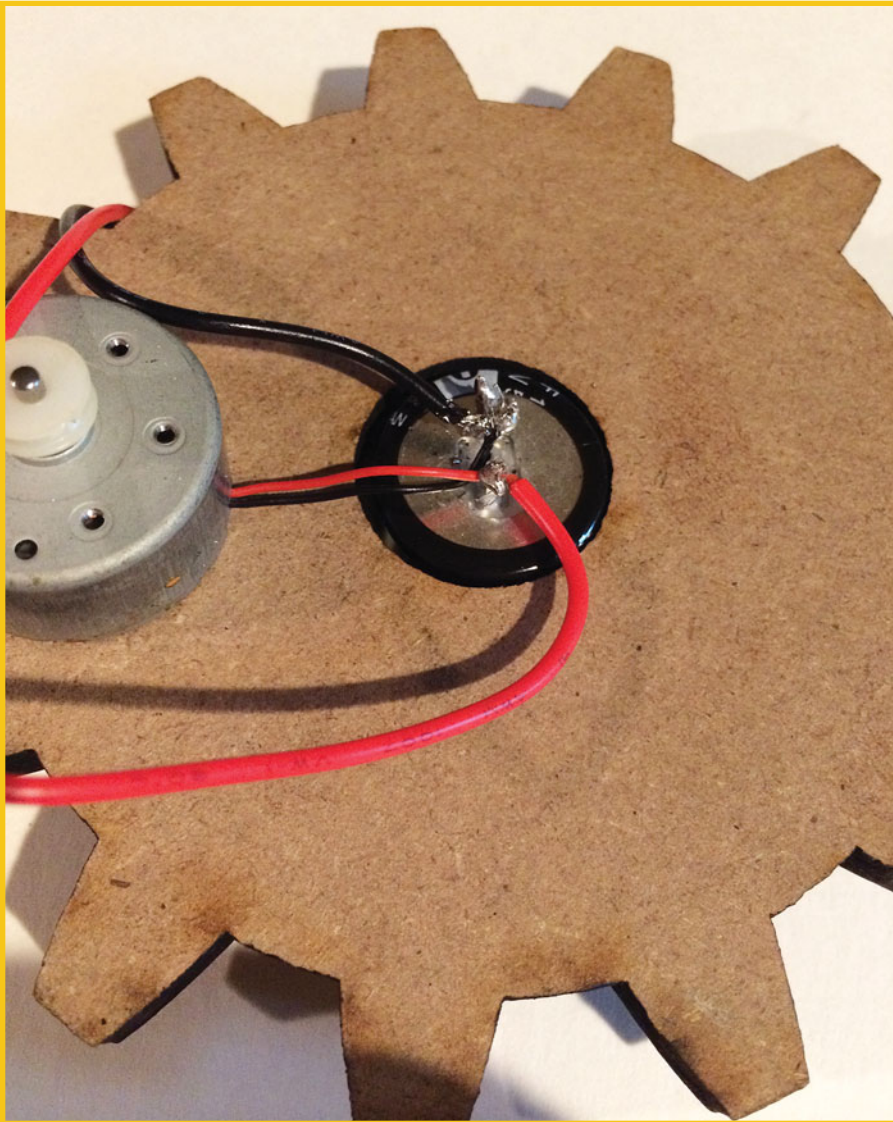


FIGURE 4.29 You guessed it—now connect the negatives.

What you basically have is a motor that turns when direct sunlight strikes the solar panel. What you do with that is up to you. Some folks have added a rubber knob to the motor, and the whole assembly rolls in circles like a one-wheeled car.

I decided to have the motor, cap, and solar panel rotate around the hub, with the hub fixed in place. You can see what I came up with in Figure 4.26.

Summary

In this chapter, you found out about solar panel technology, learned how to breadboard, and even created not one but two simple solar projects: a solar panel made up of different pieces of solar cell, and a solar spinner BEAM robot. In Chapter 5, “Controlling Your Robot,” we’ll check out four ways of controlling your robot, with techniques ranging from a classic remote control rig ranging up to an Arduino and motor control shield.

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