Lecture 4

Solar Cells, Motors, and Nodal Analysis

Reading For This Lecture

- Reader, Chapter 3

- How a motor works
  - https://learn.sparkfun.com/tutorials/motors-and-selecting-the-right-one

- A&L
  - 3.1 3.2 – Node voltages
  - 3.3 3.3.1 – Nodal analysis

Introduction

We need to talk a little more about the solar cell in the solar charger, and the we will have covered everything except the magical DC-DC converter that converts the 3.7V of the battery to 5V. At the end of the class we will come back to look at how that devices does that magic. For this project we just want to know how efficient it is in its job.

Now we know all the devices, we will go back to the circuit to try to find a way to determine the voltages and currents we should see in the circuit, and to try to understand why the components are there, and what they do. To do this we need a general method of solving for currents and voltages in a collection of devices. This is generally called nodal analysis.

Learning Objectives

- Understand how a solar cell works
  - When light strikes a silicon diode it generates a current
    - This current is generated in parallel to the diode
    - Positive current flow out of the positive terminal of the diode
  - And how to measure the max current, and the max voltage
    - Larger max voltages require stacked diodes

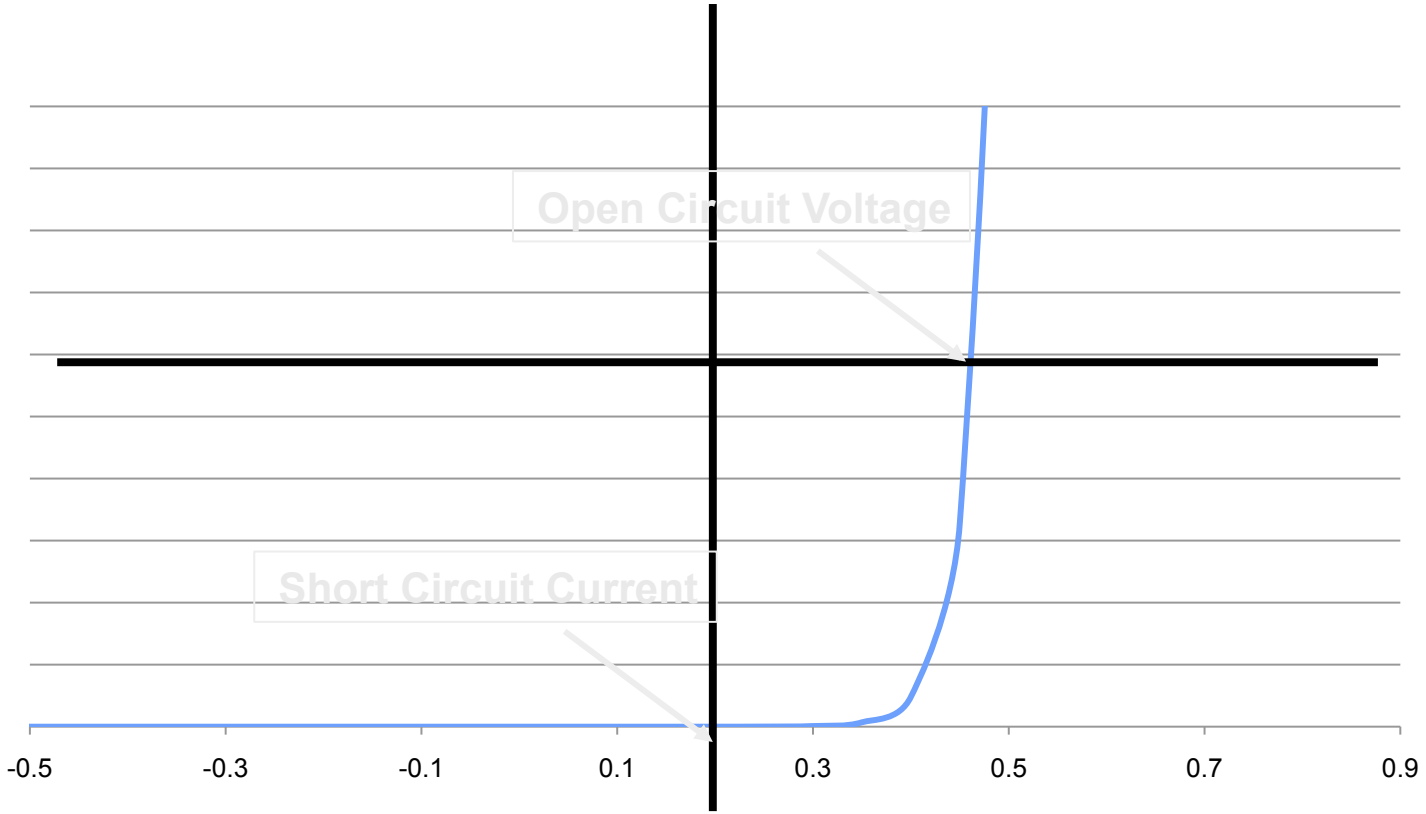
- Understand how to define nodal voltages for a circuit
  - Need to define a reference node, often called gnd.
  - And how to convert them to device voltages

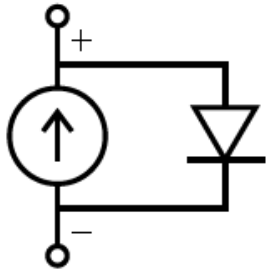
- Understand how to perform nodal analysis
  - Write KCL equations at each nodal voltage
  - Solving those equations should define all the nodal voltages

PREVIOUSLY IN E40M

Photo Generated Current

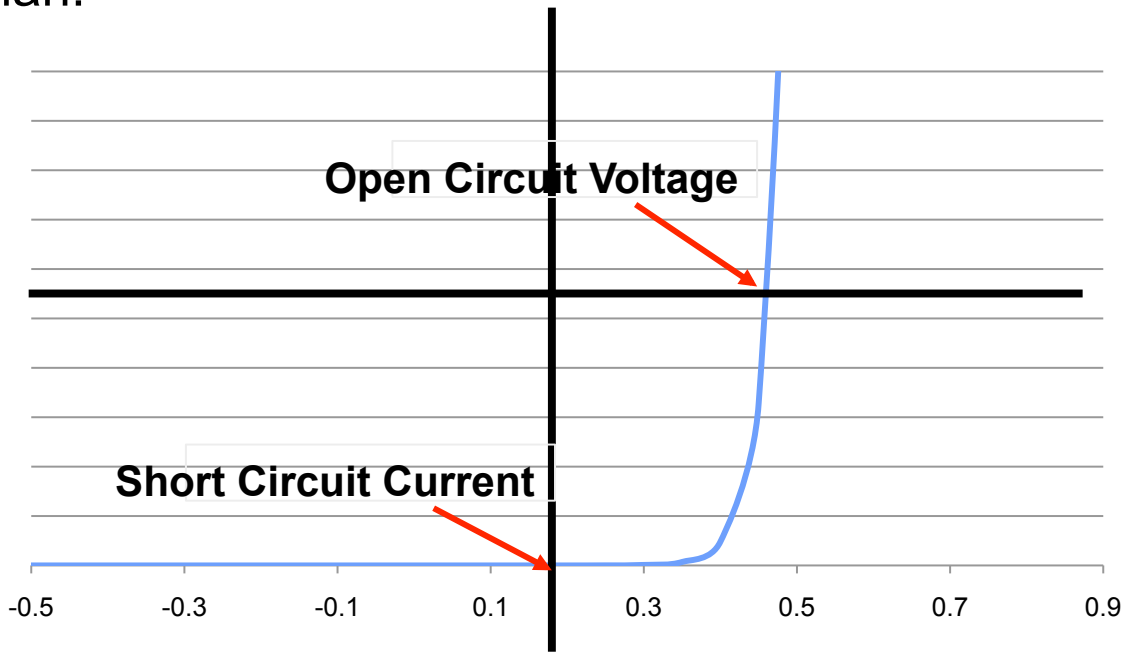
- Using standard reference direction for current
  - What does the i-V curve look like when light is shining?





Extracting Power from a Diode

- Power is iV
  - So in neither of these cases we get power from diode
- Power will be less than:
  - $V_{open} * i_{short}$



Solar Cell was Spec'd 6V and 1W

- What did you measure?

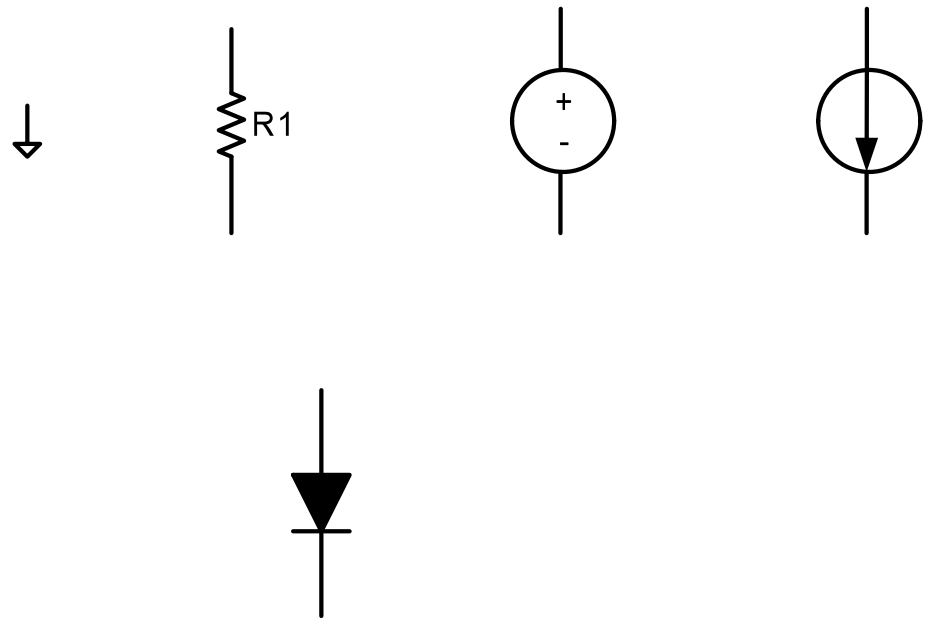
- How did they get a diode with such a large voltage?
  - They didn't, look closely at the solar cell

Learning Objectives

- Understand the device i-V curve of a resistor
- Understand the device i-V curve of a current source
- Understand the operation of a diode, and its symbol
- Be comfortable using your DMM to measure voltage and current
- Be prepared to solder next week in lab

Devices You Should Know

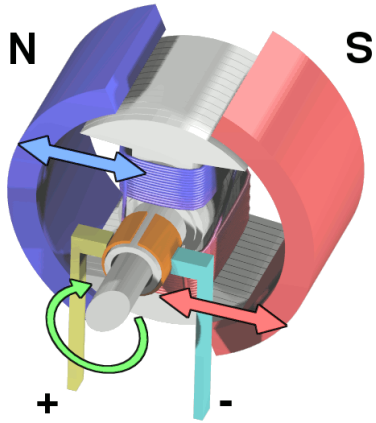
- And symbols you should recognize



IN CLASS ACTIVITY & BREAKING BREAK

A Motor

- There are many types of motors
  - See the tutorial in reading for lecture
- You have a DC brush motor (most common)
  - It is another two terminal device
  - But also has a mechanical output
  - This output affects the voltage current
- The voltage across a motor sets it speed
  - In revolutions per minute
  - What sets the current?



The Power of Power

- If the motor is connected to something (even its gears)
  - It needs to do mechanical work to turn (force * distance)
  - The larger the load, the more work it must do
- But remember that energy is conserved
  - So the energy to do the work must come from somewhere
- Motor current is proportional to the motor mechanical load
  - Larger load, requires more current

Experiment With Your Motor

- Connect your motor to your battery
  - Measure the current it takes with your DMM
- Then hold on to the output of the motor
  - Try to slow it down
  - Measure the current it takes now.
    - It should be larger

Another Experiment w/ Your Motor

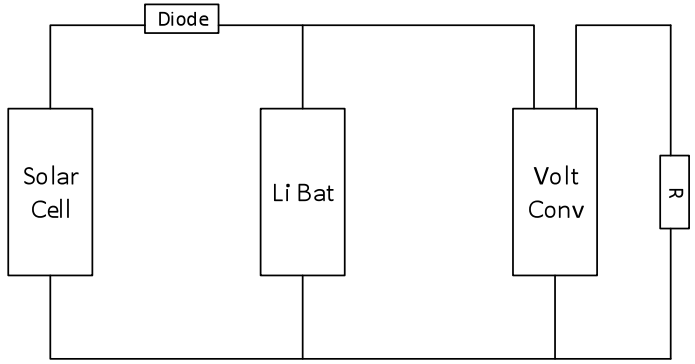
(possibly do at home)

- Find your motor
  - Find the wheel that goes on it
- Now connect it to your DMM and not a battery
  - Turn the wheel and measure the voltage output
- Now put the meter on current and set to the amp range
  - Turn the wheel again
    - Is it easier or harder to turn
  - What happened? Why?

NODAL VOLTAGES

Solving For Voltages and Currents

- Given a circuit, and device models
  - Want to solve for device voltages and currents



- Be we are ~~lazy~~ efficient
  - With the least work possible

- KVL means
  - Not all device voltages are independent
  - Can we formulate the problem differently
    - Reduce the number of variable we need to deal with?

Avoid KVL Redundancy

- KVL forces the voltage across a device
  - Not to depend on the path you take
- So
  - We can make any node a reference
  - And measure the voltages of other nodes
    - Relative to this reference
  - Device voltages
    - Difference of the node voltages

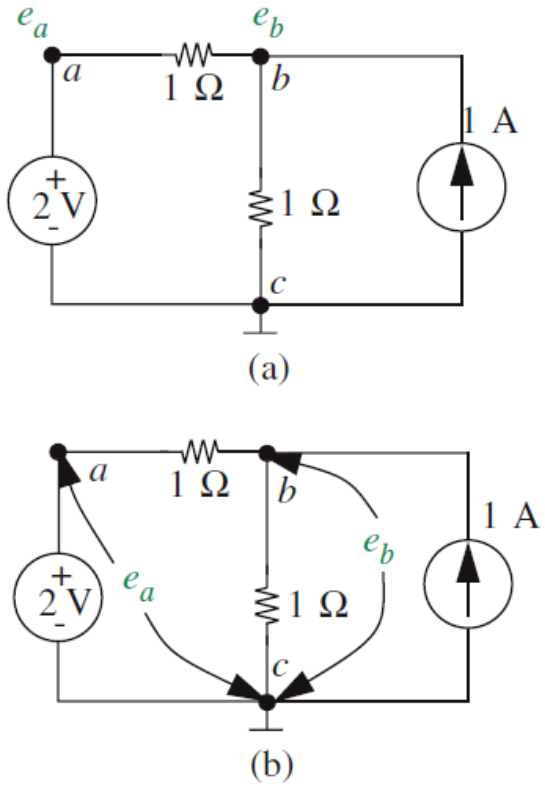
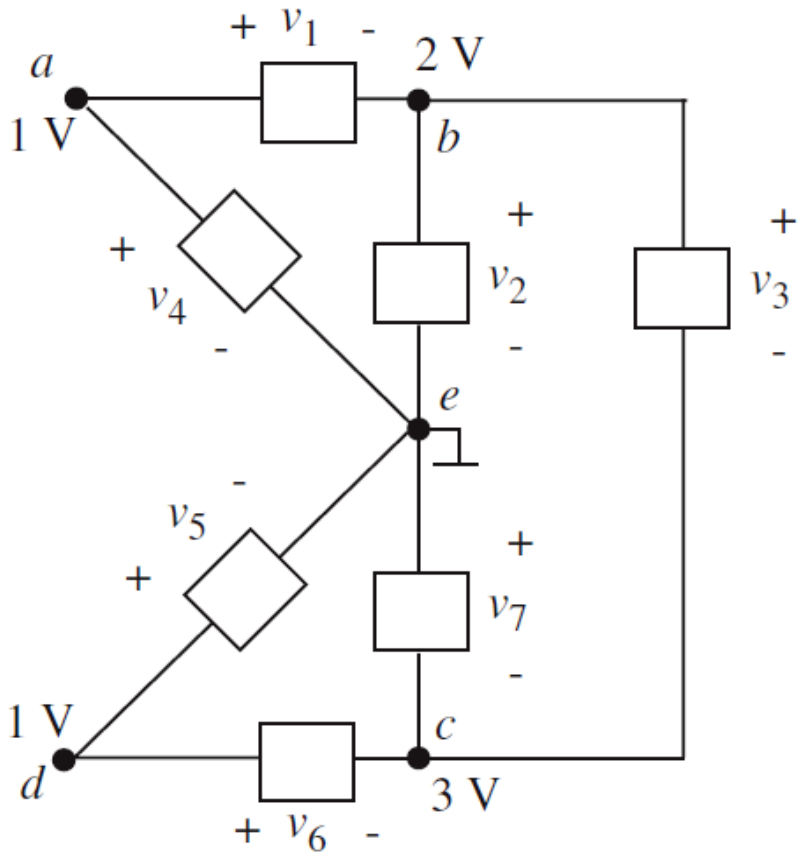


FIGURE 3.1 Ground node and node voltages.

What are the Device Voltages?

- Why doesn't "e" have a voltage



Beware of Gnd (Ground)

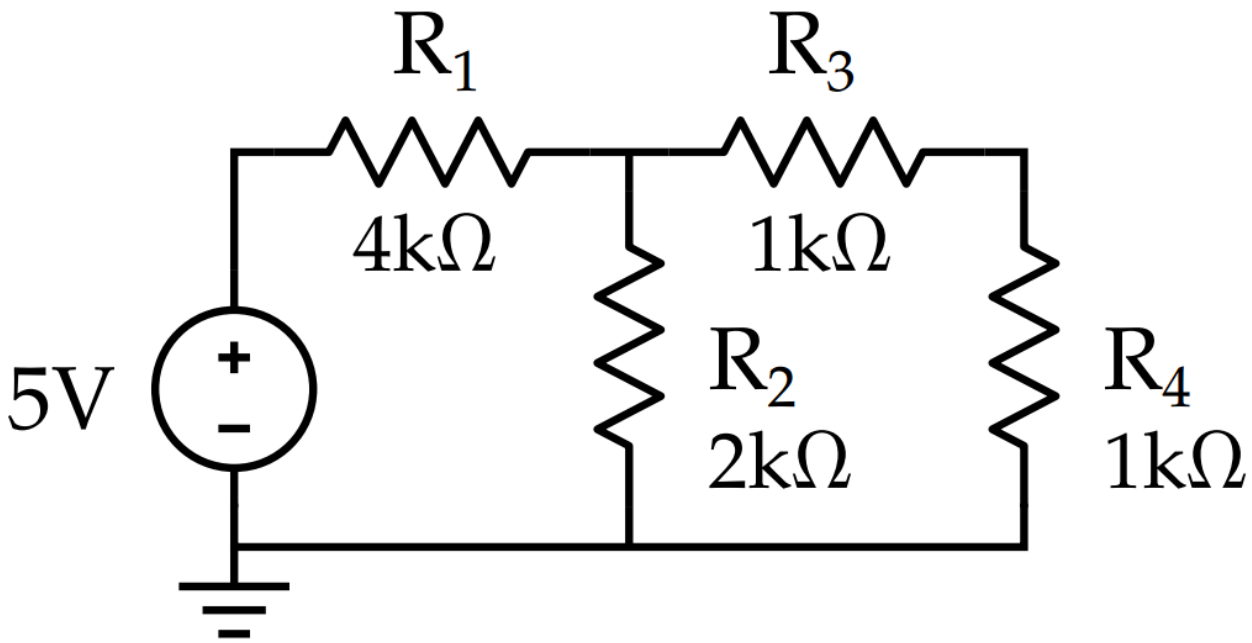
- Since voltages are all relative
  - Often designs will declare one voltage to be the reference
  - We generally call this voltage ground (gnd)

- There is also something called earth ground
  - And this is the voltage of a pipe running through the earth
  - This is the round prong on 3 point plugs

- Not all nodes labeled gnd are connected to earth gnd
  - And not all earth gnds are at the same potential

Nodal Voltages

- Measure the voltage of every node in the circuit
  - Relative to the same reference node



NODAL ANALYSIS

The General Solution Method

- Write the KCL equations for every node but the reference (Gnd)
  - Sum of the device currents at each node must be zero
- Write the equations for each device's current
  - Find out the current as a function of the node voltages
- Solve the resulting equations

An Example

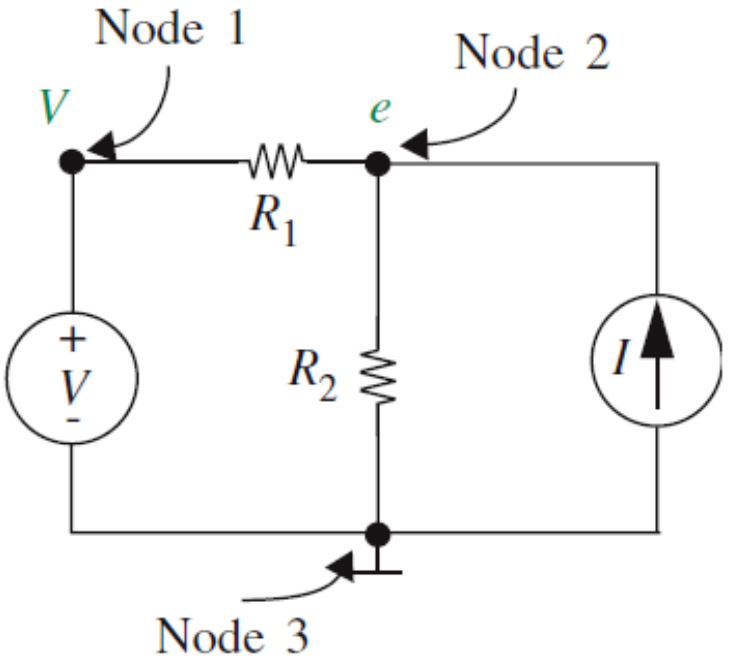
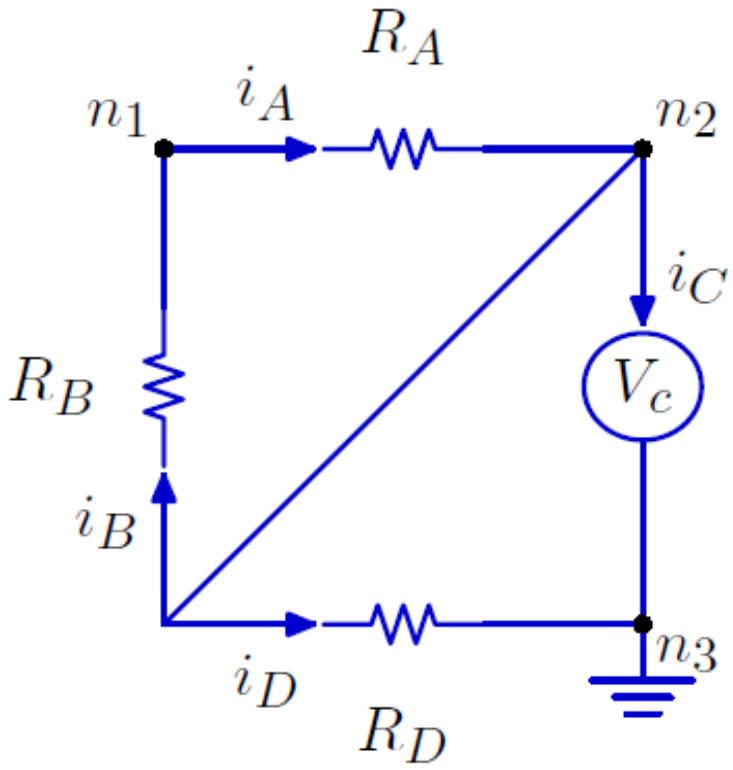
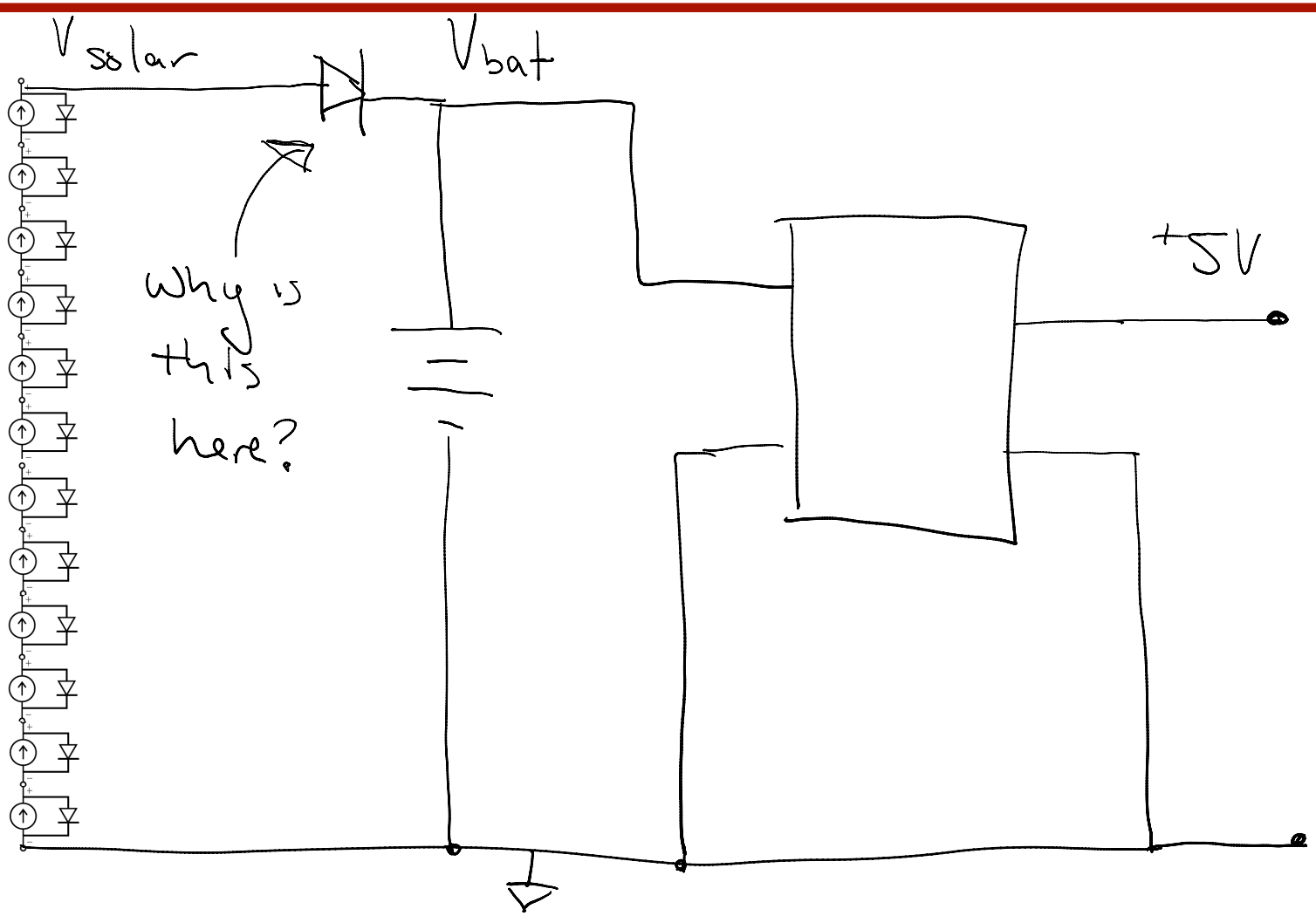


FIGURE 3.10 A resistive circuit.

Another Example

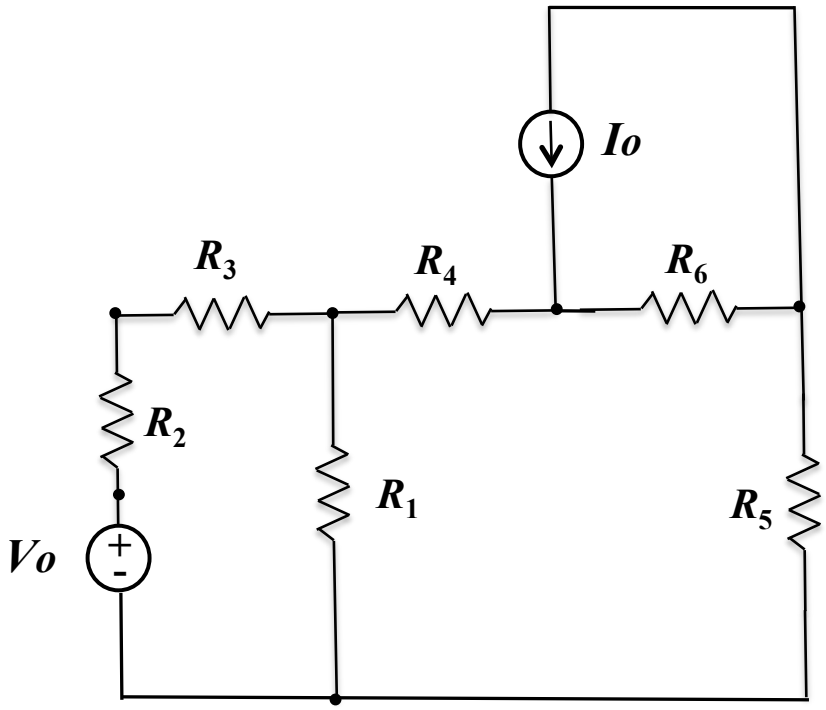


Solar Charger



Another Example

Step 1

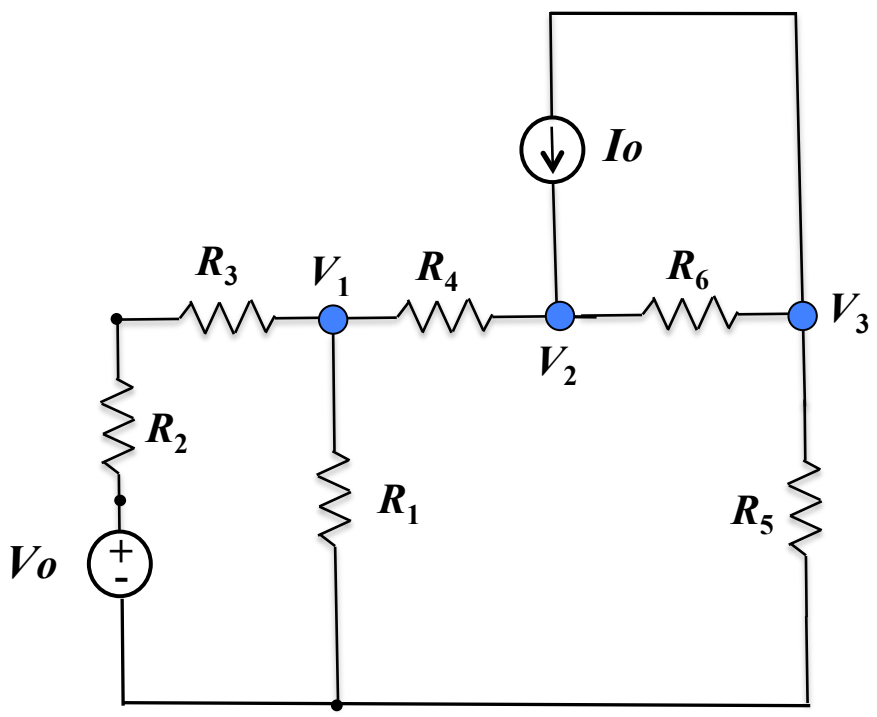


(a) Identify the nodes with at least 3 branches

(b) Select one of them as the reference node

(c) Label the rest of the nodes with voltages V_1, V_2, …

Result of Step 1

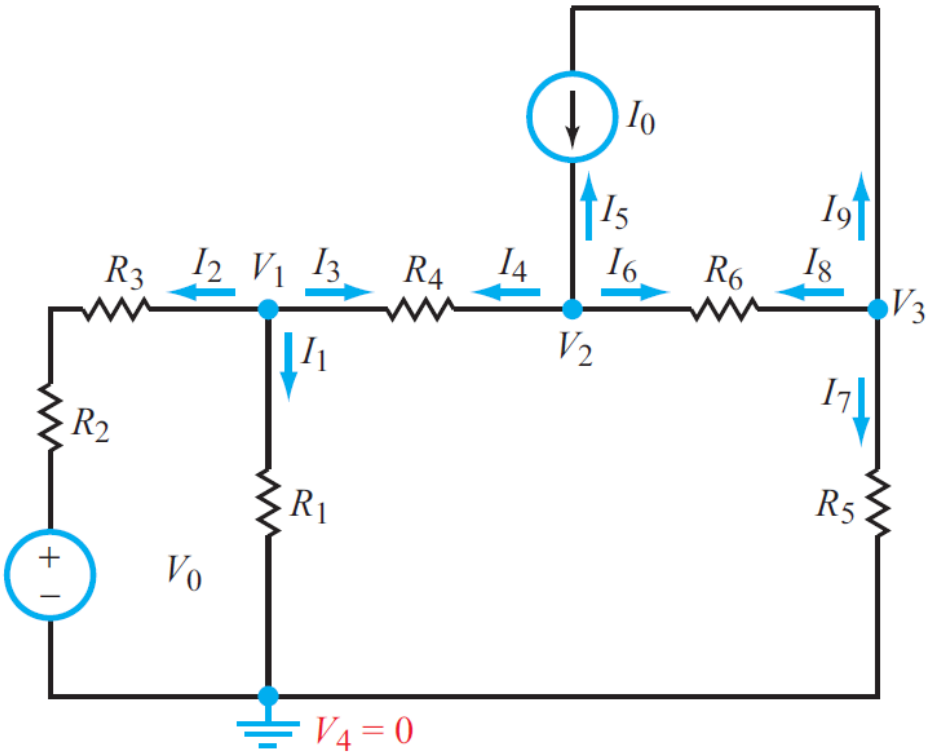


Step 2

Apply KCL at each of the nodes you labeled in step 1;

to show that reference polarities do not matter, we will define KCL in terms of currents *leaving* nodes in this example.

Result of Step 2



Node 1

$$I_1 + I_2 + I_3 = 0.$$

$$\frac{V_1}{R_1} + \frac{V_1 - V_0}{R_2 + R_3} + \frac{V_1 - V_2}{R_4} = 0 \qquad \text{(node 1)}.$$

Node 2

$$\frac{V_2 - V_1}{R_4} - I_0 + \frac{V_2 - V_3}{R_6} = 0 \qquad \text{(node 2)},$$

Node 3

$$\frac{V_3}{R_5} + \frac{V_3 - V_2}{R_6} + I_0 = 0 \qquad \text{(node 3)}.$$

Result of Step 3

- Solve the resulting nodal equations:

$$\left(\frac{1}{R_1}+\frac{1}{R_2+R_3}+\frac{1}{R_4}\right)V_1-\left(\frac{1}{R_4}\right)V_2=\frac{V_0}{R_2+R_3} \quad (3.8a)$$

$$-\left(\frac{1}{R_4}\right)V_1+\left(\frac{1}{R_4}+\frac{1}{R_6}\right)V_2-\frac{V_3}{R_6}=I_0, \quad (3.8b)$$

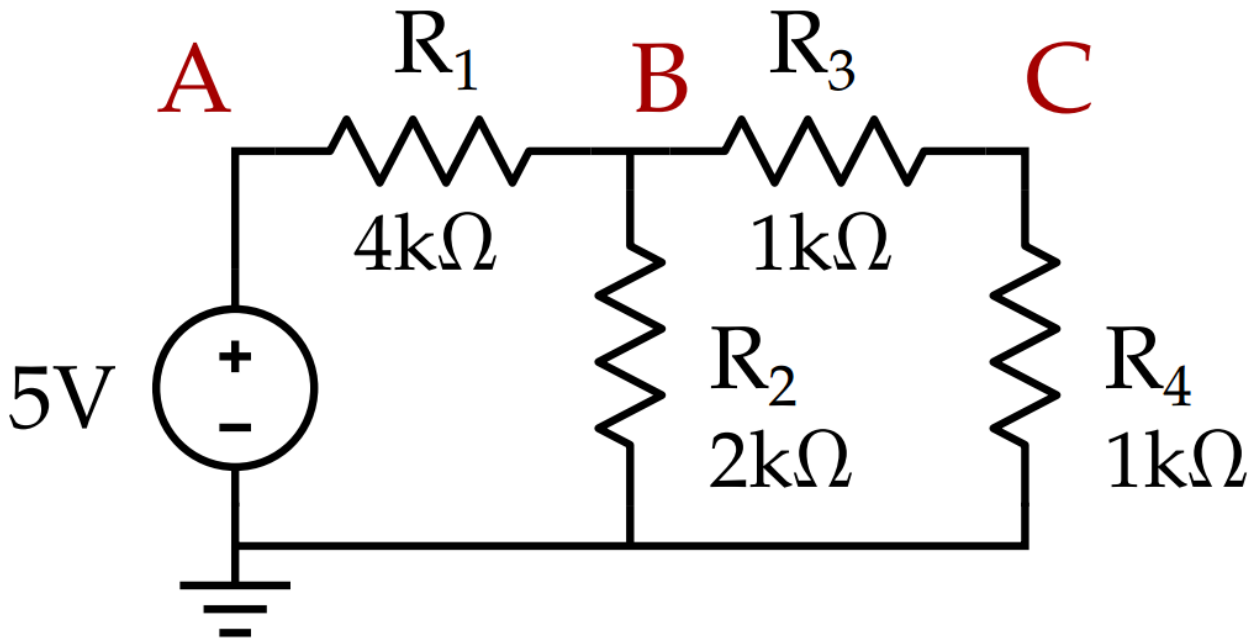
and

$$-\left(\frac{1}{R_6}\right)V_2+\left(\frac{1}{R_5}+\frac{1}{R_6}\right)V_3=-I_0. \quad (3.8c)$$

$$\begin{aligned} a_{11}V_1+a_{12}V_2+a_{13}V_3&=b_1\\ a_{21}V_1+a_{22}V_2+a_{23}V_3&=b_2\\ a_{31}V_1+a_{32}V_2+a_{33}V_3&=b_3 \end{aligned}$$

Nodal Analysis

- Write the KCL equations for every node but the reference (Gnd)
  - Sum of the device currents at each node must be zero
- Solve the resulting equations



MAKING BREAK SOLDERING

- In your prelab you are asked to watch a soldering video at https://learn.sparkfun.com/tutorials/how-to-solder---through-hole-soldering/all.

- Another video that you may find helpful is https://www.youtube.com/watch?v=eU4t0Yko9Uk

Physical Construction

- Need to permanently attach wires to terminals
- Do that by **soldering**
  - The soldering iron heats the tip to > 600^{o}F
  - This is hot enough to melt the alloy in the solder
  - When you remove the soldering iron
    - The solder cools and turns back into a solid
  - And you end up with a metal connection
- Just remember that the wire gets hot when it is being soldered

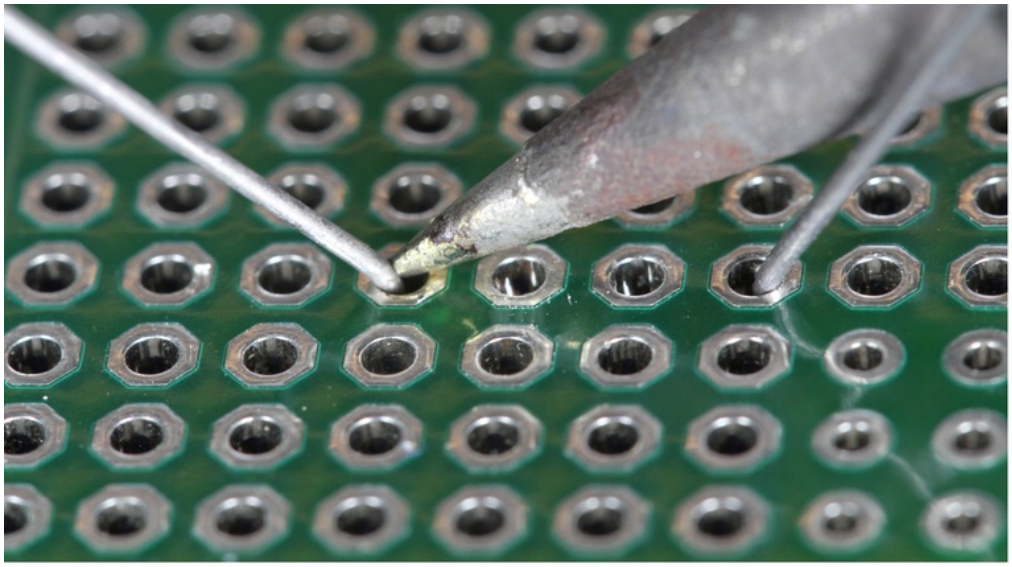
Why Does Solder Smoke?

- Most metals form a thin oxide layer in air
  - Especially when they are very hot.
- Solder won't stick to oxide
  - It wants to touch metal
  - And oxides generally don't conduct electricity
- To remove the oxide that exist and prevent it from forming
  - Solder contains rosin inside (rosin core solder)
  - The rosin melts, and then vaporizes during soldering
  - That is the smoke you see

Warning: There is also acid core solder that is used for plumbing, but should never be used for electronics. The residual acid can etch through your traces

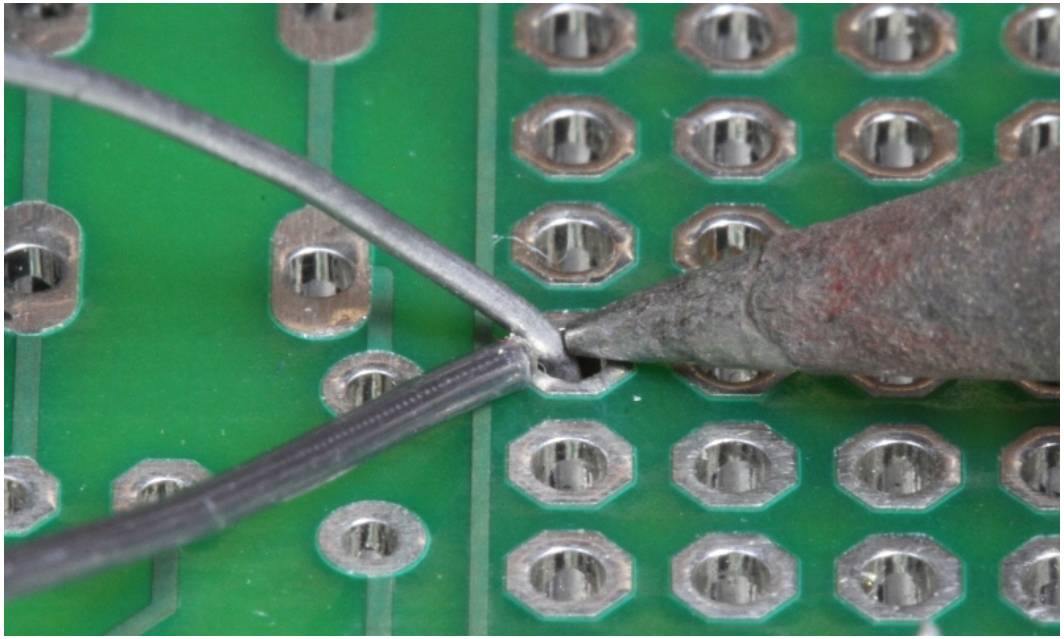
The Soldering Process

- Heating the thing to be soldered
  - In this case it is a board and a wire



http://learn.adafruit.com/adafruit-guide-excellent-soldering/making-a-good-solder-joint

Apply the Solder



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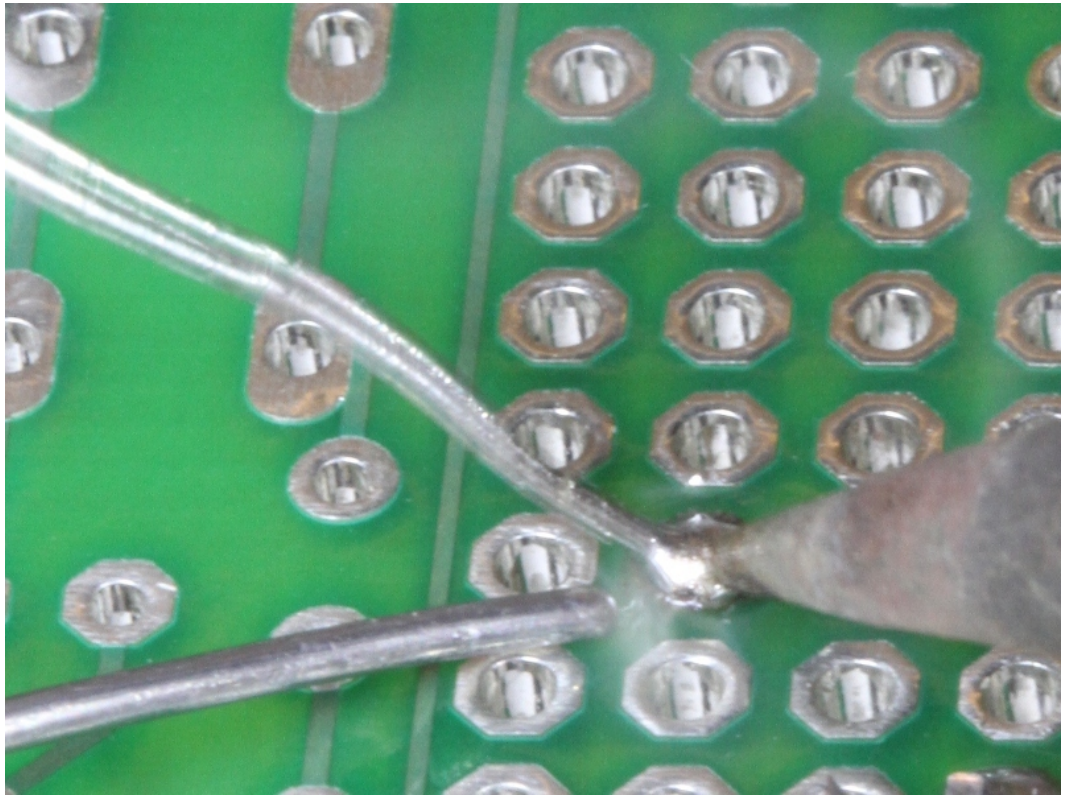
Solder Flow



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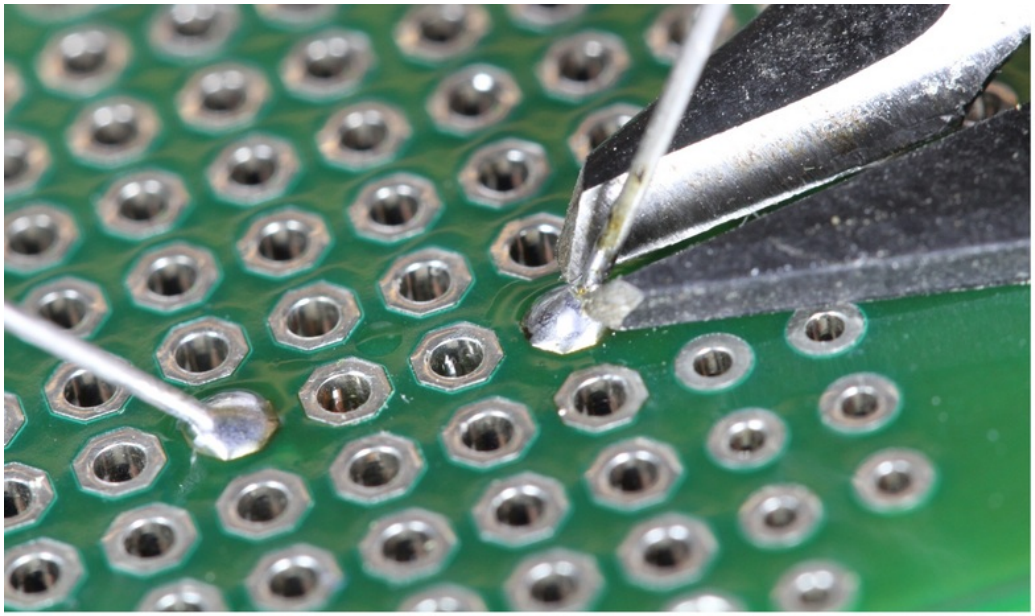
Snip



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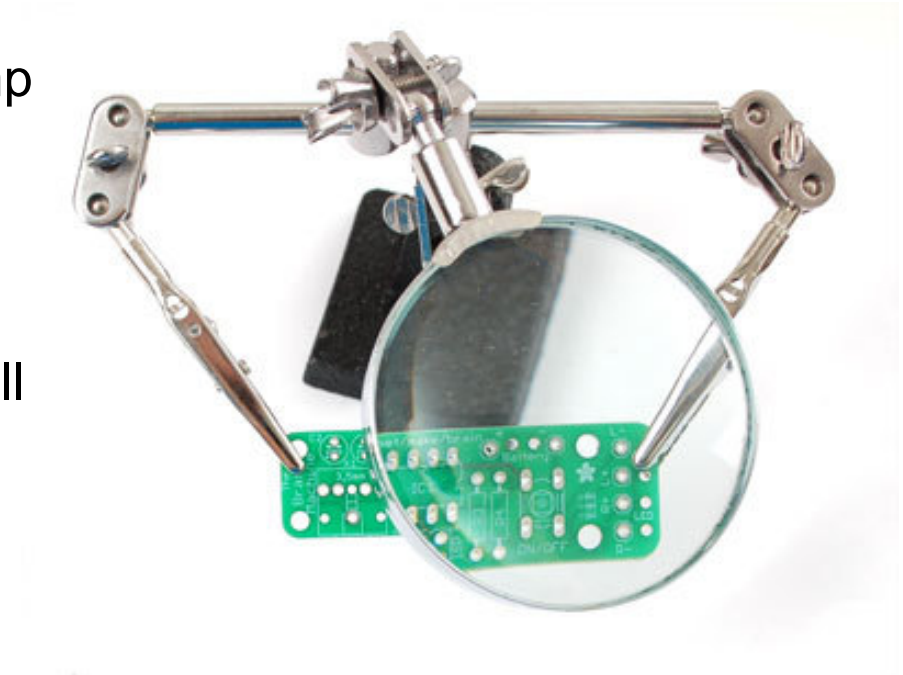
A Third Hand

- Sometimes you will need a third hand
  - Partners are helpful here
  - But we also have clamps in the lab you can use

- Put your switches in the clamp
  - Or on the table
  - They will get hot

- Solder does conduct heat well
  - It uses the heat to melt
  - So you can hold that



Crimping the Wire

- Since the wire will get hot
  - Especially close to the solder joint
  - You would like it to stay in place by itself
  - Otherwise you need to hold it with pliers

- So you generally place wires through the hole
  - In the board, switch
  - And then bend it so it stays put

Fixing Mistakes

- There are ways to remove solder if you make mistakes
- **Solder wick**

- **Solder sucker**

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