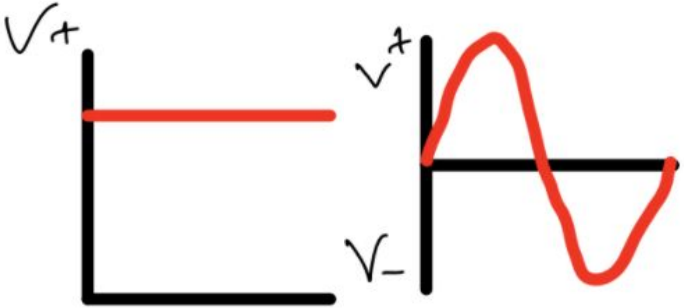
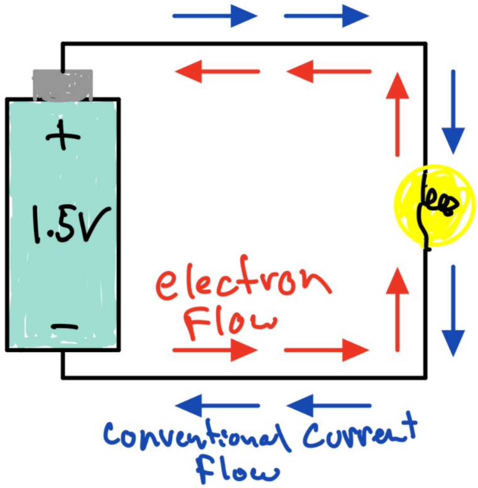
Transistors and Capacitors DC Applications

What is DC?

- Direct current is current that only flows in one direction.
- The current out of our battery or our power supply is DC.
- This is because the voltage provided by these sources is constant, thus it is always pushing the current in the same manner.
- The opposite of this would be alternating current (which we will discuss in the future)

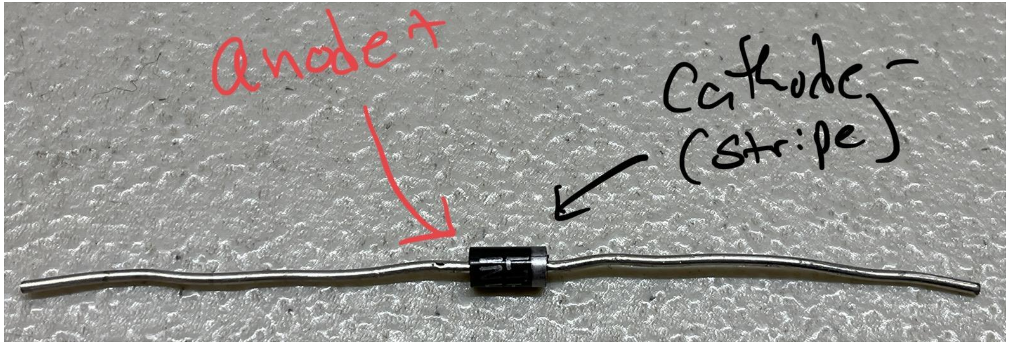


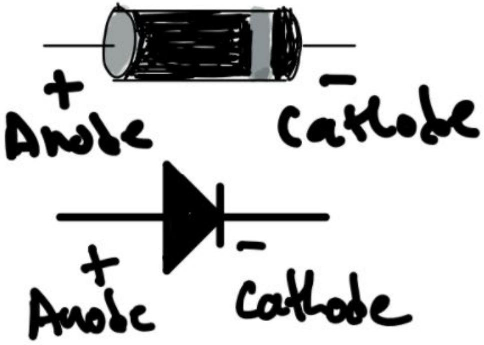


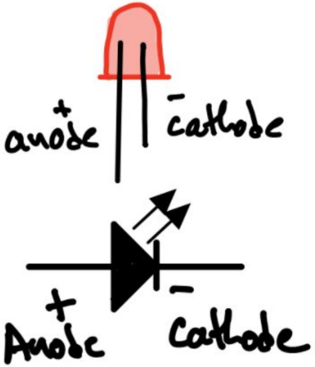
What is a Diode?

What is a Diode

- A diode is a device that allows current to flow in one direction but not in the other.
- Diodes have polarity, determined by an anode (positive) and cathode (negative).
- Most diodes allow current to flow only when positive voltage is applied to the anode.
- When a diode allows current flow, it is **forward-biased**. When a diode is **reverse-biased**, it acts as an insulator and does not permit current to flow.
- There are many different types of diodes including the Light Emitting Diode; LED!

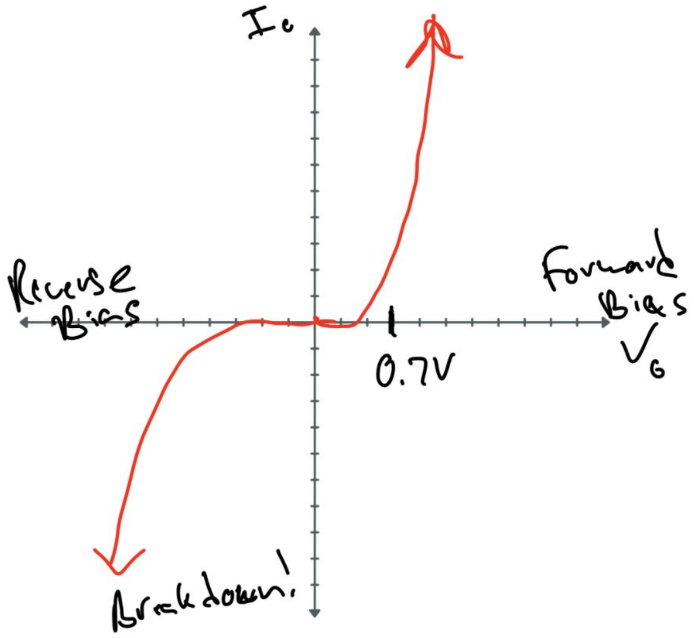






What is a Diode

- In order to have a diode allow current to flow, you must “turn on” the diode.
- Turning on a diode requires a small amount of voltage. No current will flow unless this minimum voltage is applied.
- Once this voltage is applied, current will flow. Very small increases in the voltage applied across the diode will result in large current gains!
- Diodes are NOT ohmic devices; they do not follow Ohm’s Law.
- They simply need their **forward bias voltage** applied and then a large current will flow.

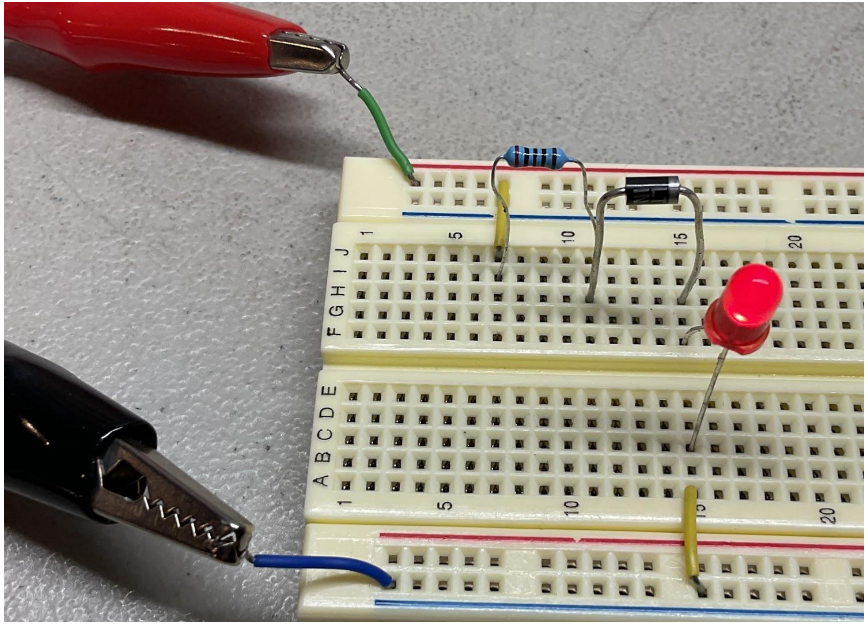


<u>Approximate Forward Bias Voltages</u>

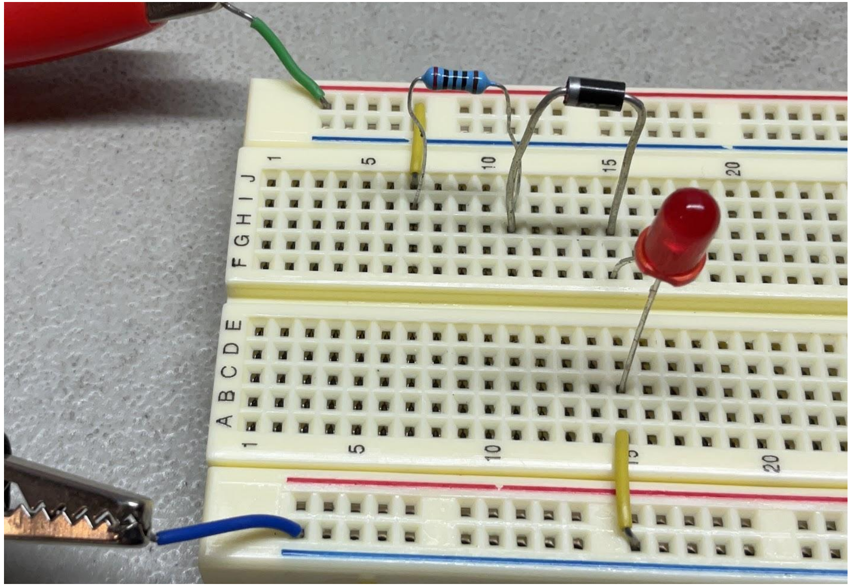
- Silicon Diodes - 0.7 volts
- Germanium Diodes - 0.3 volts
- LEDs - 1.4 volts to 4.0 volts

Diodes: Forward Bias and Reverse Bias

- Forward Bias
- Positive voltage is applied to the anode.
- Current flows!

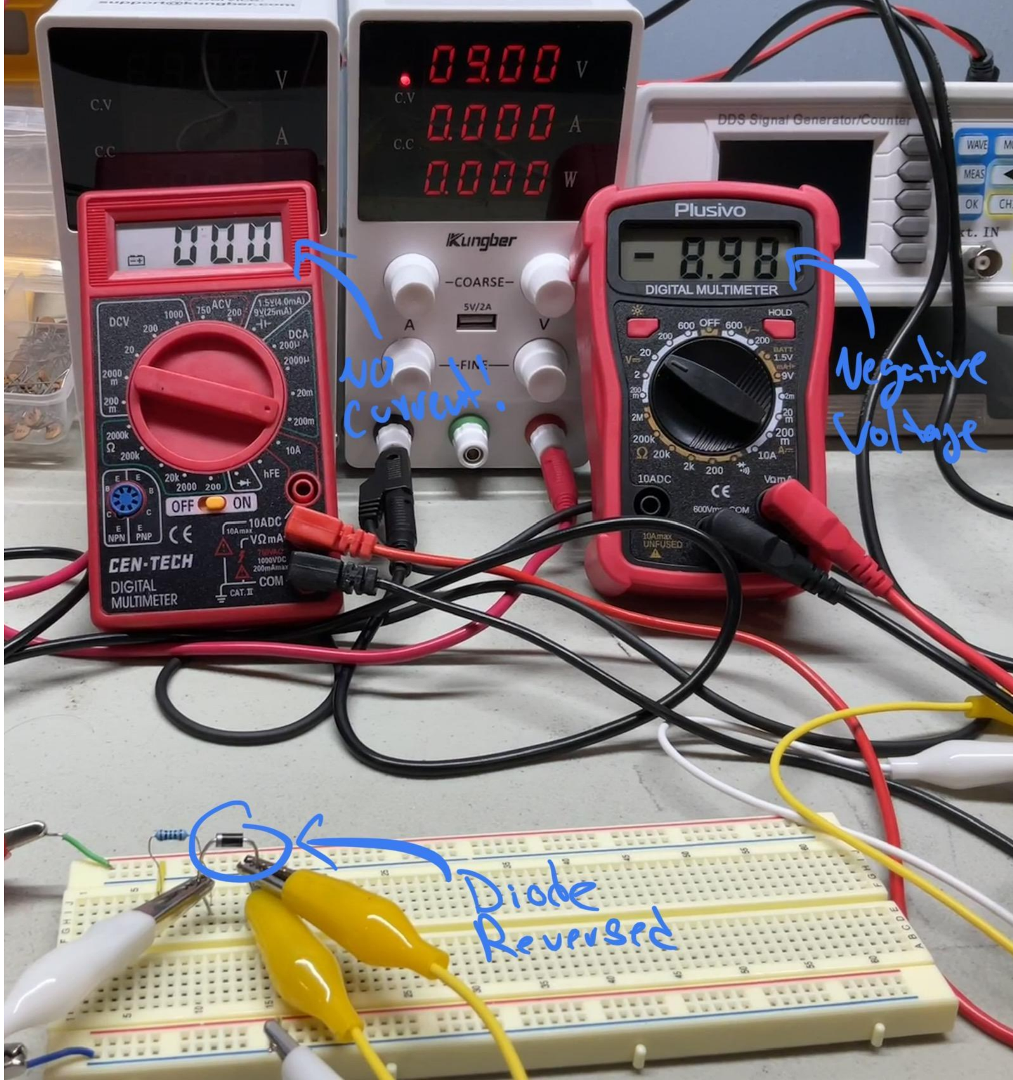


- Reverse Bias
- Positive voltage is applied to the cathode.
- No current flows!



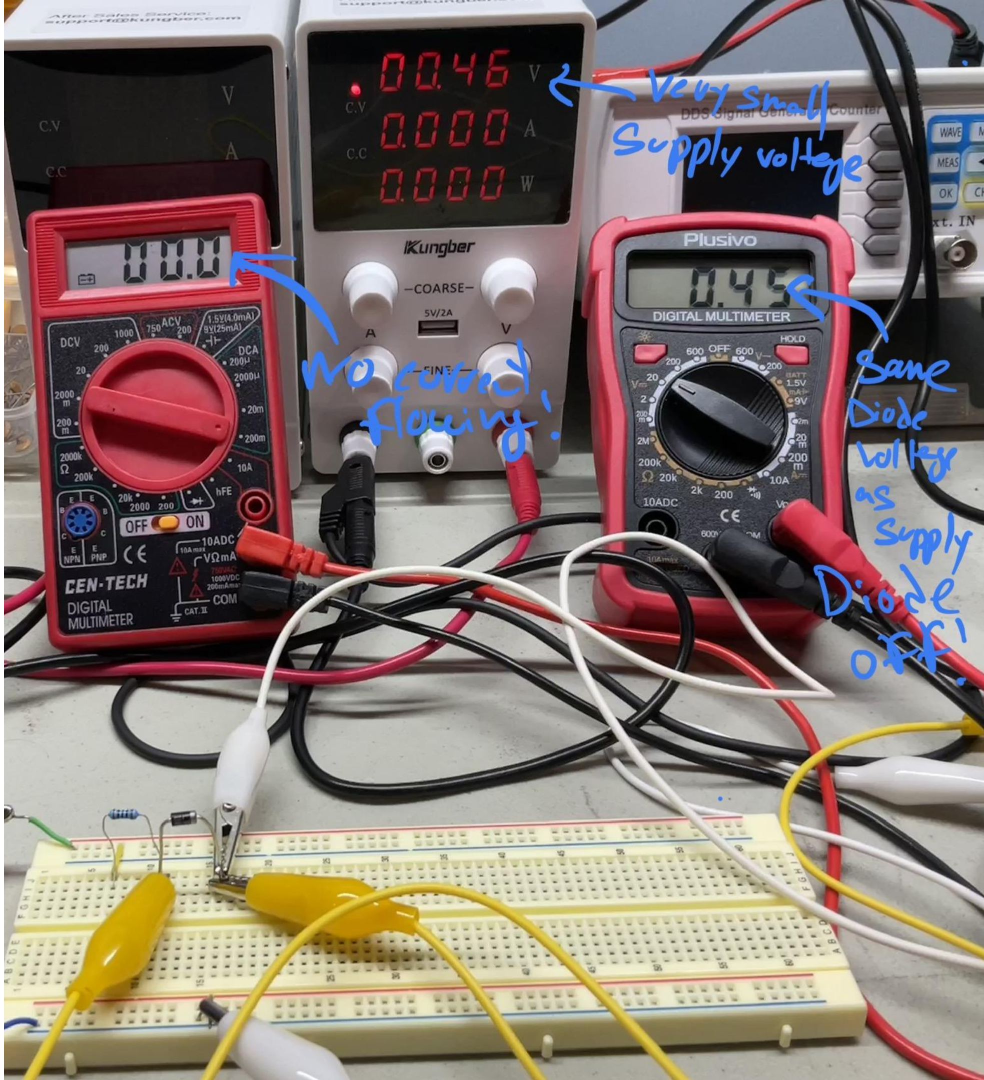
Diode: Reverse Bias Off

- When a diode is reverse biased, no current will flow regardless of the voltage across the diode.



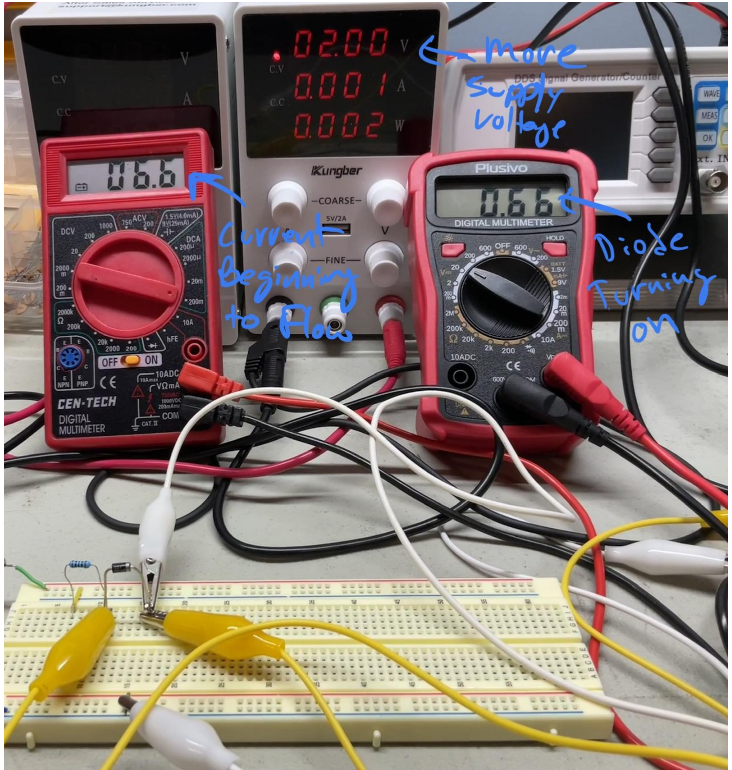
Diode: Forward Bias Off

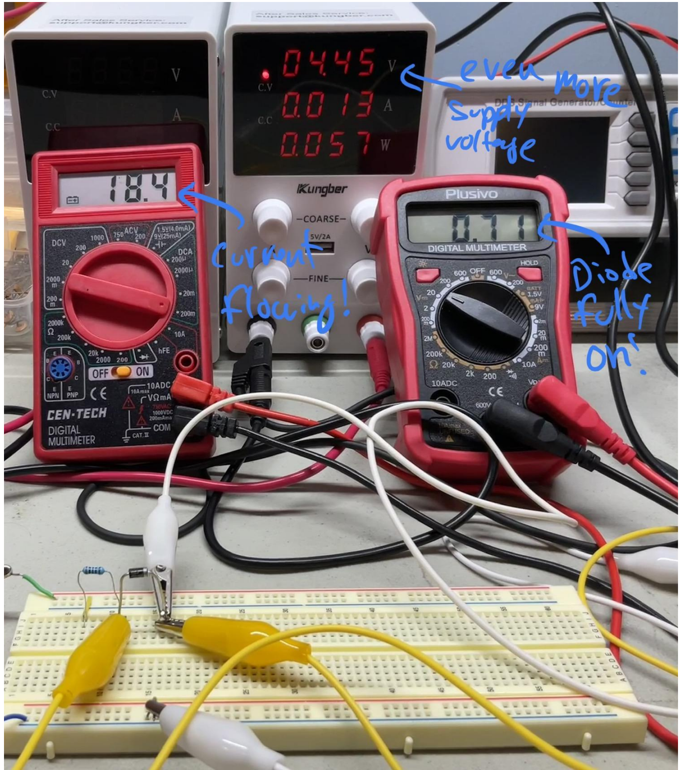
- If we assume the forward bias voltage of the diode is roughly 0.7 volts, then no current will flow until the diode turns on with a voltage drop of 0.7 volts.
- Since we have no current flowing, the total supply voltage of 0.46 volts is being dropped across the diode.
- Not enough to turn the diode on!



Diode: Forward Bias On

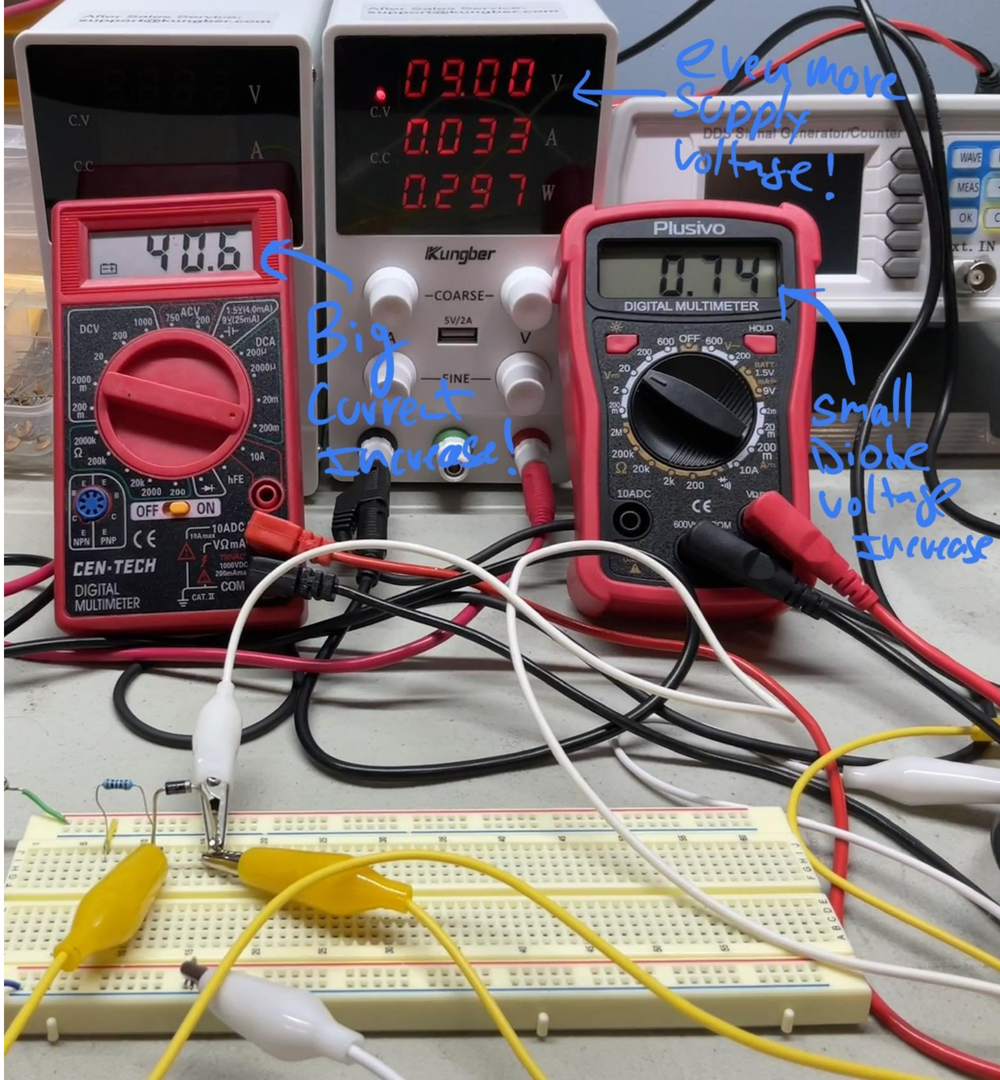
- As the supply voltage increases, the voltage drop across the diode approaches the forward bias voltage (0.7 volts) and the diode turns on.
- The diode starts to allow current to flow.
- A small increase in diode voltage results in a large increase in current.





Diode: Forward Bias On

- Now that the diode is on and forward biased, very small increases in diode voltage results in large current gains.
- The diode is allowing 40.6 mA of current to flow.
- By increasing diode voltage by only .03 volts, we increased current by 22.2 mA.



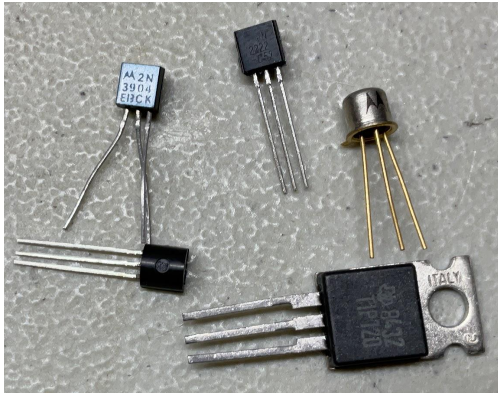
Transistor Switches

What is a Transistor

A transistor is a three terminal electronic component that can do two different jobs. It can work either as an amplifier or a switch:

- When it works as an **amplifier**, it takes in a tiny electric current at one end (an input current) and produces a much bigger electric current (an output current) at the other.
- When it works as a **switch,** it takes a tiny electric current flowing through one part of a transistor and makes a much bigger current flow through another part of it. In other words, the small current switches on the larger one.

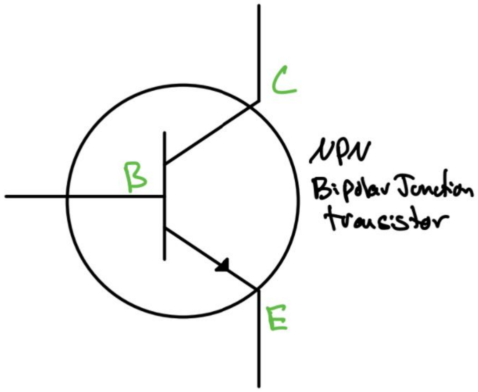
There are many different types of transistors….

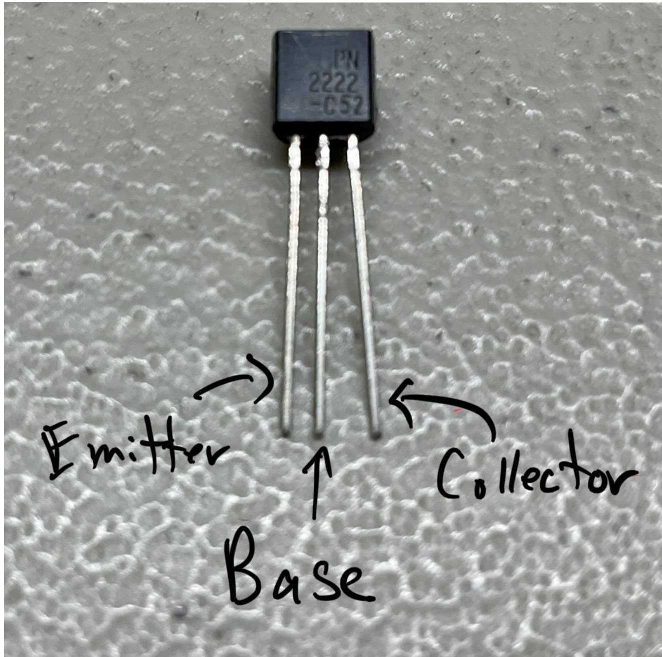


What is a Transistor

- I will be using the **PN2222** transistor which is an general purpose NPN bipolar junction transistor.

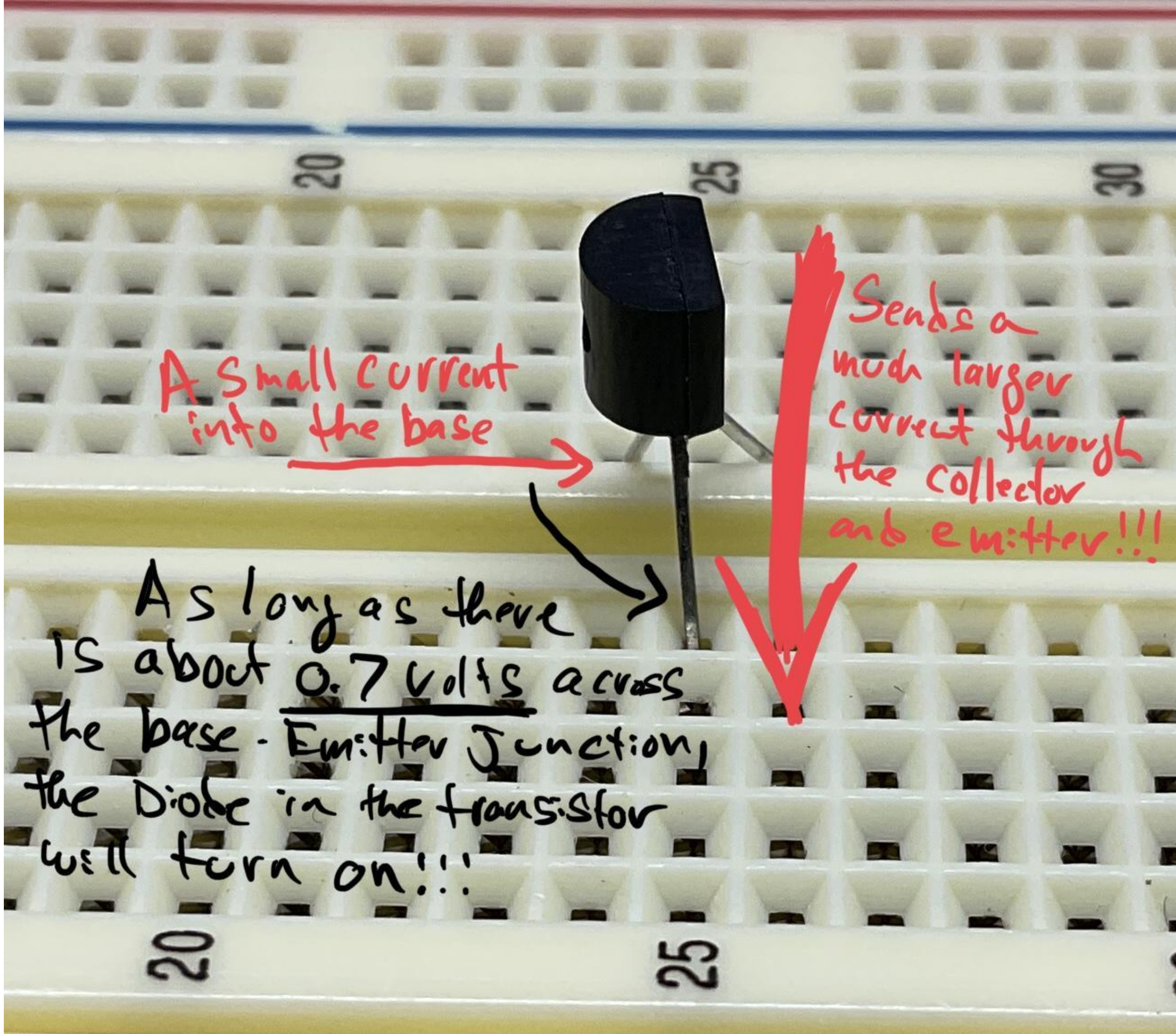
- In an NPN Bipolar Junction Transistor the three terminals are called the collector, base, and emitter.
- There is essentially a diode between the base and emitter. Just like the diode, you have to forward bias a transistor to “turn it on”.
- If you supply a minimum 0.7 volts to the base of the transistor it will “turn on”.





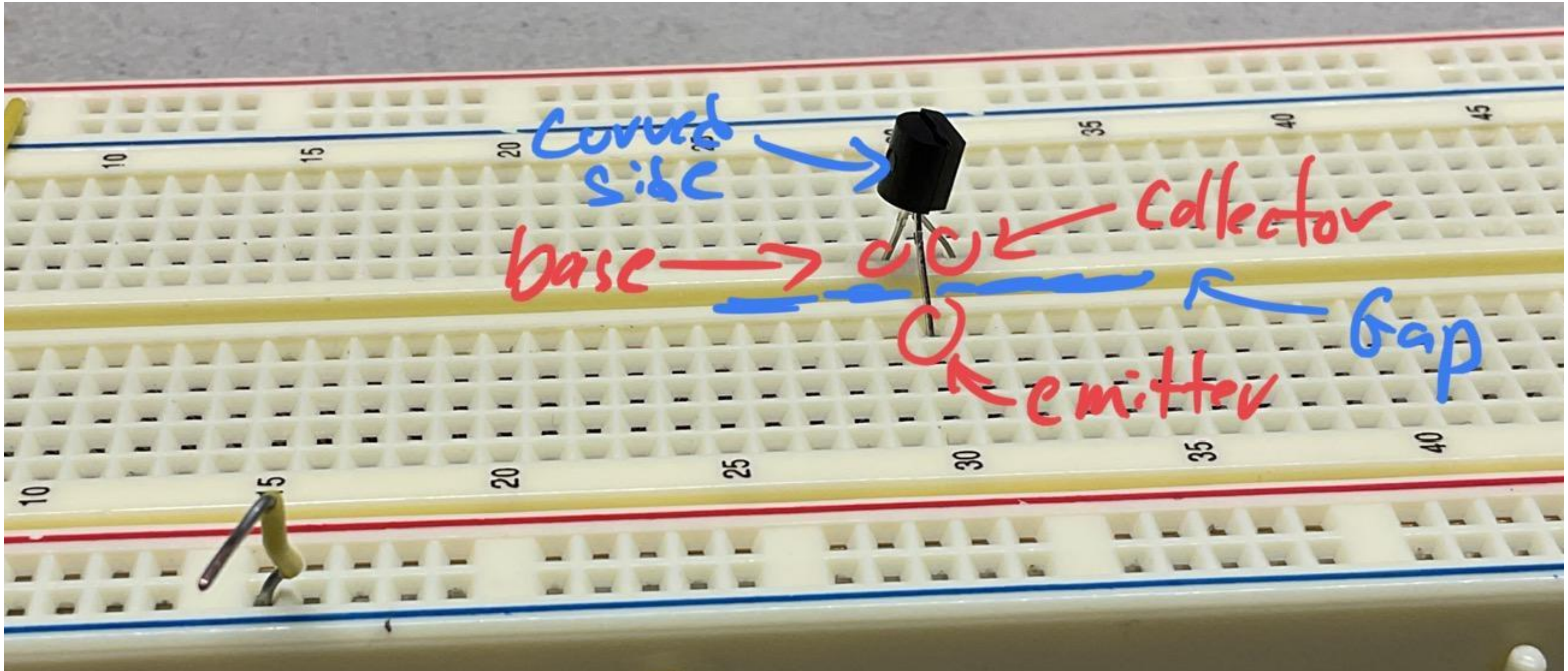
What is a Transistor

- As long as the there is about 0.7 volts across the diode between the base and emitter junction then the transistor will be “on”.
- A very small current sent to the base of the transistor will close a “switch” between the collector and emitter.
- When this “switch” closes a large current can flow from collector to emitter.
- Essentially, a very small current can be used to switch on/off a much larger current.



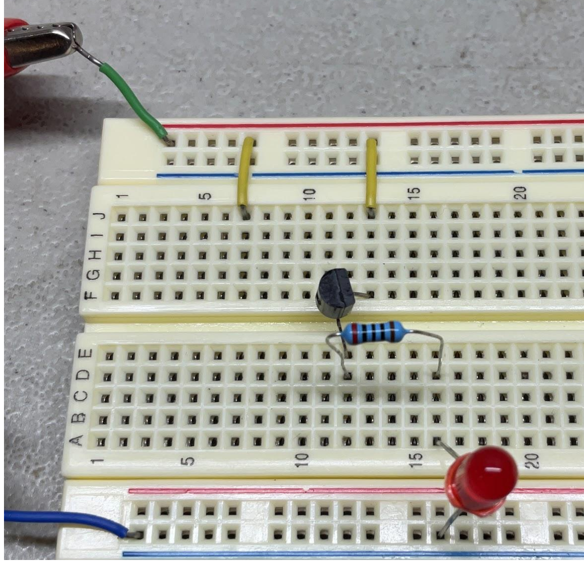
Putting a Transistor in the Bread Board

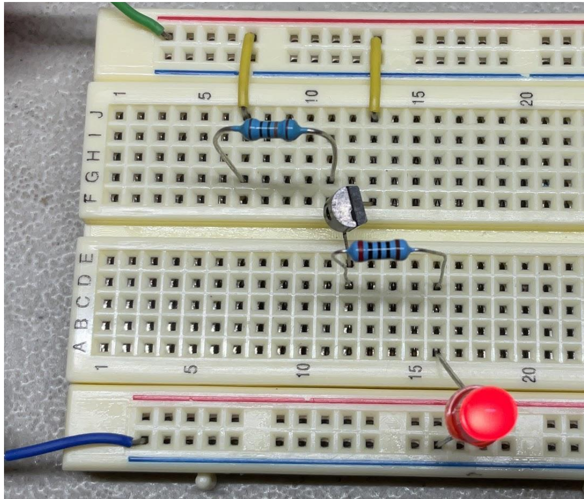
- I normally jump the gap with a transistor. Carefully turn the legs of the transistor so that the curved side is facing left. The emitter will be on the bottom of the breadboard with access to your ground rail.



Transistor Switch - Emitter Side

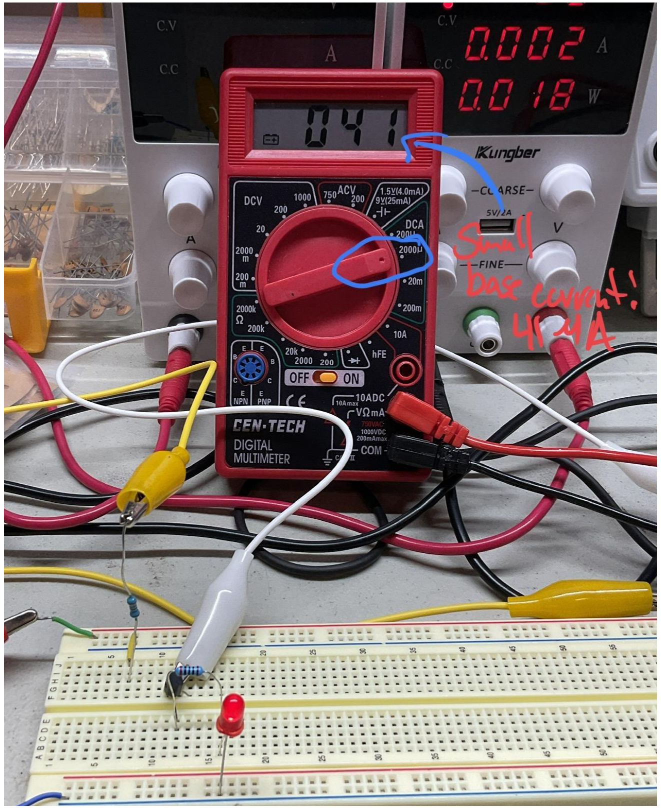
- Place a transistor in the board.
- Use a jumper to hook the collector to Vcc
- Off the emitter use a 200 ohm (red, black, black, black) resistor to an LED to ground.
- The transistor is off because there is no current flowing into the base/there is not 0.7 volts.
- Put a 100K (brown, black, black, orange) resistor from Vcc to the base.
- This should provide the required voltage/current to turn the transistor on.
- One shortcoming of this is that the base must be 0.7 volts higher than the emitter in order for the diode to turn on…Here we have to be 0.7 volts higher than the required voltage drop across the resistor and LED.

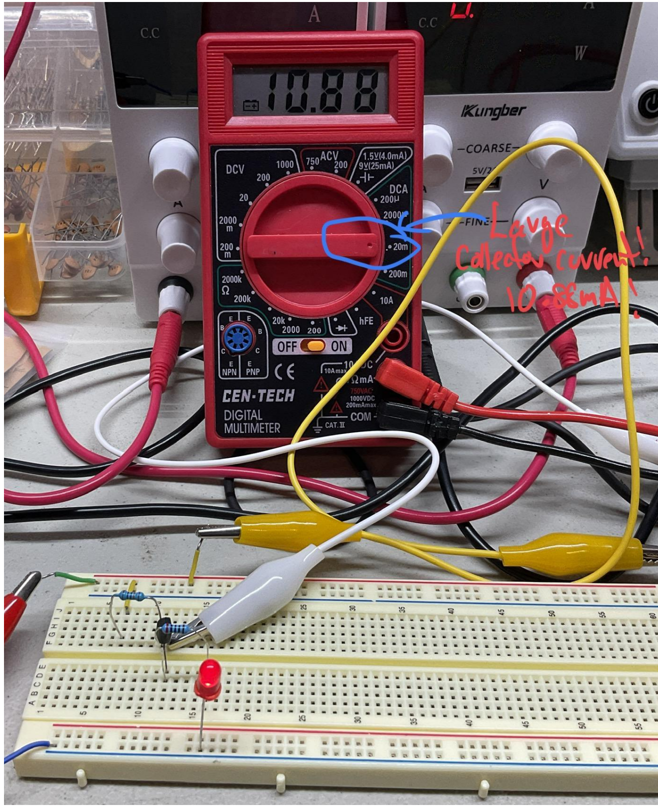




Transistor Switch - Emitter Side

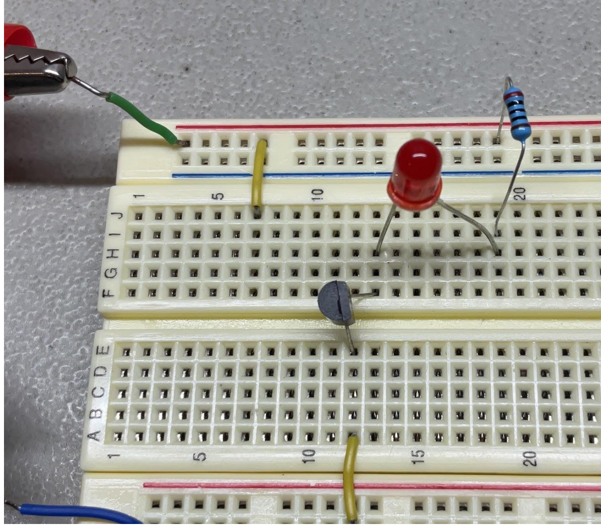
- In this setup the base current is measuring at 41 microAmps.
- The collector current is measuring at 10.88 milliAmps!
- That's roughly 265 times the current!

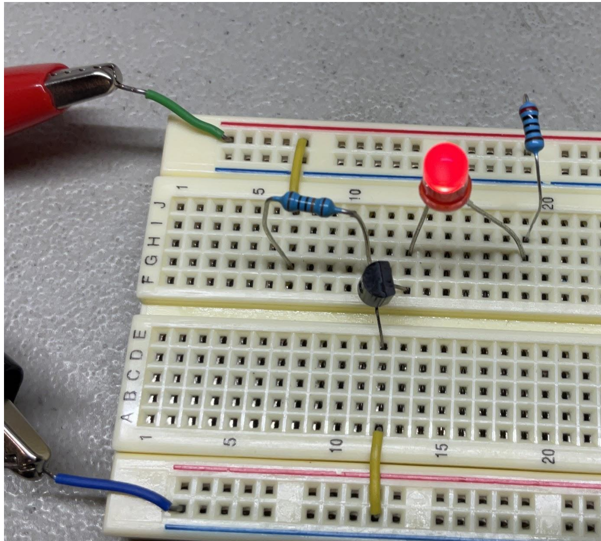




Transistor Switch - Collector Side

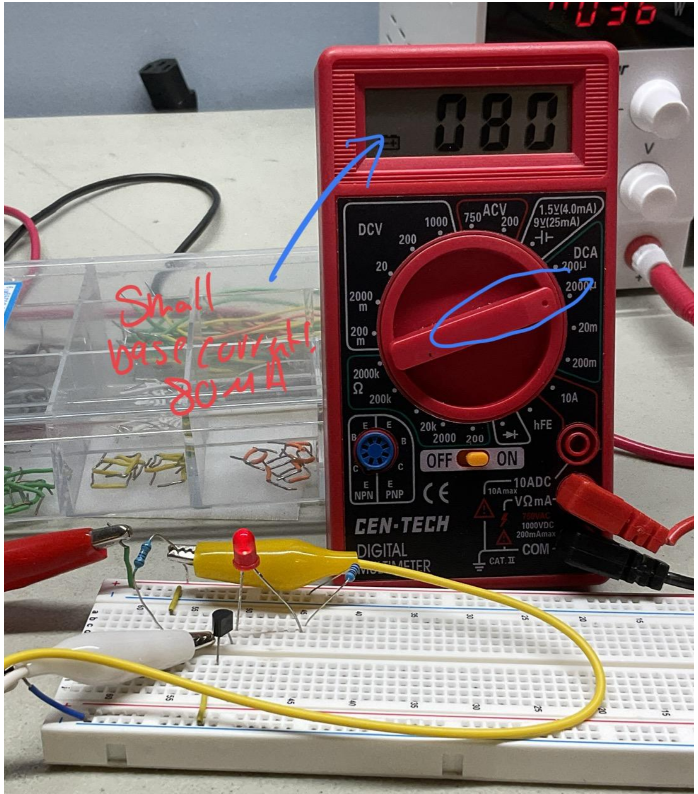
- Place a transistor in the board.
- Use a jumper to ground the emitter.
- Use a 200 ohm (red, black, black, black) resistor to an LED into the collector.
- The transistor is off because there is no current flowing into the base/there is not 0.7 volts.
- Put a 100K (brown, black, black, orange) resistor from Vcc to the base.
- This should provide the required voltage/current to turn the transistor on.
- Since the emitter is now tied to ground, our base will only require about 0.7 volts to turn the transistor on!

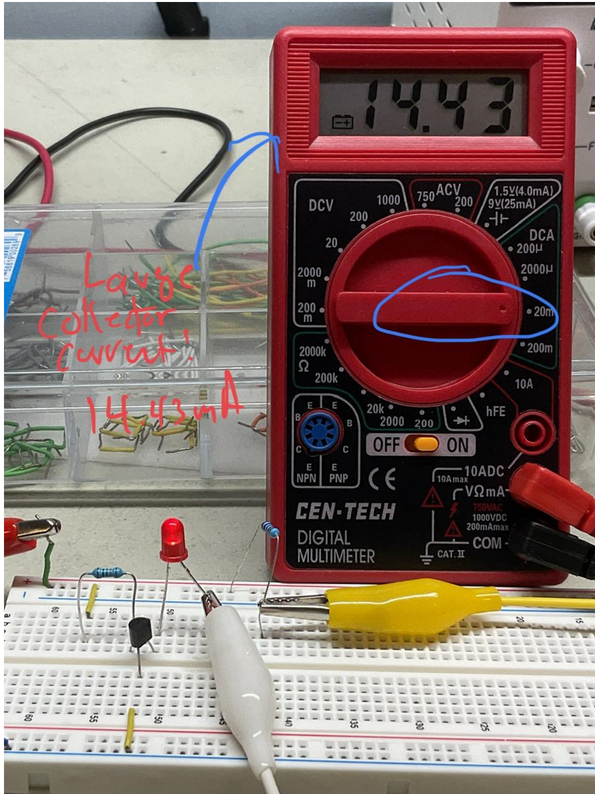




Transistor Switch - Collector Side

- In this setup the base current is measuring at 80 microAmps. (More base current!)
- The collector current is measuring at 14.43 milliAmps! (More collector current!)
- That's roughly 180 times the current!

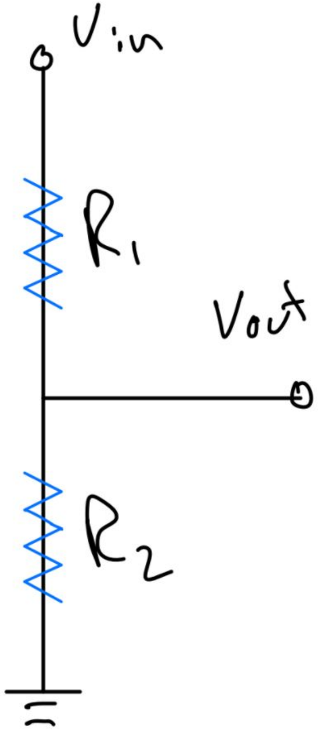




Voltage Dividers

The Most Important Circuit: The Voltage Divider

- Right now, we still have to manually interact with our transistors to use them as switches because we have fixed voltages.
- We won't always have fixed voltages though as we begin to move into AC.
- For now, we can vary our voltages by learning how to use a voltage divider!

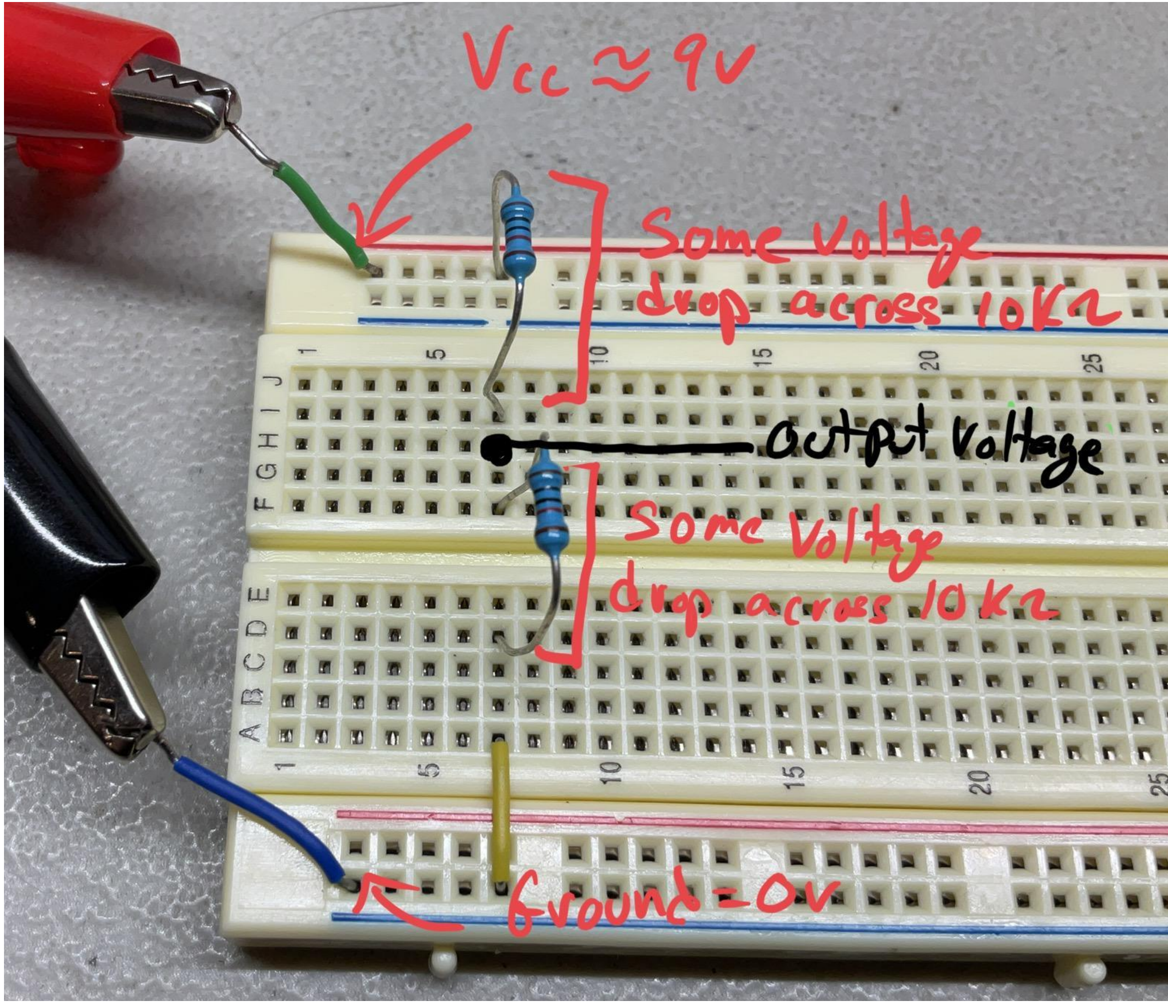


Voltage/Potential Divider

$$V_{out} = \frac{R2}{R1 + R2} V_{in}$$

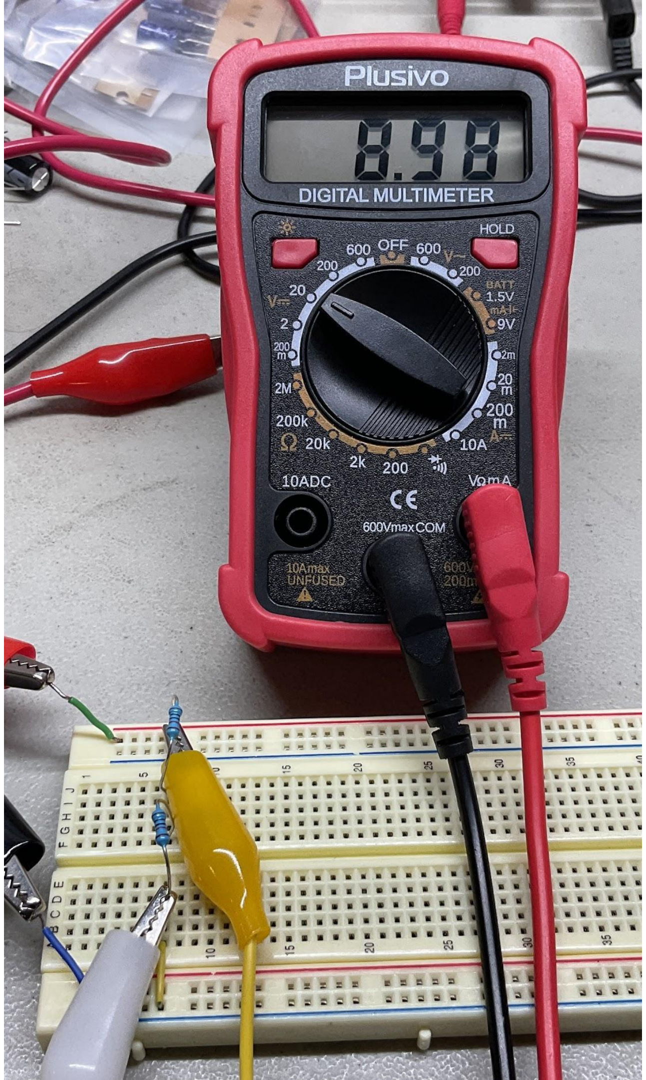
Voltage Divider

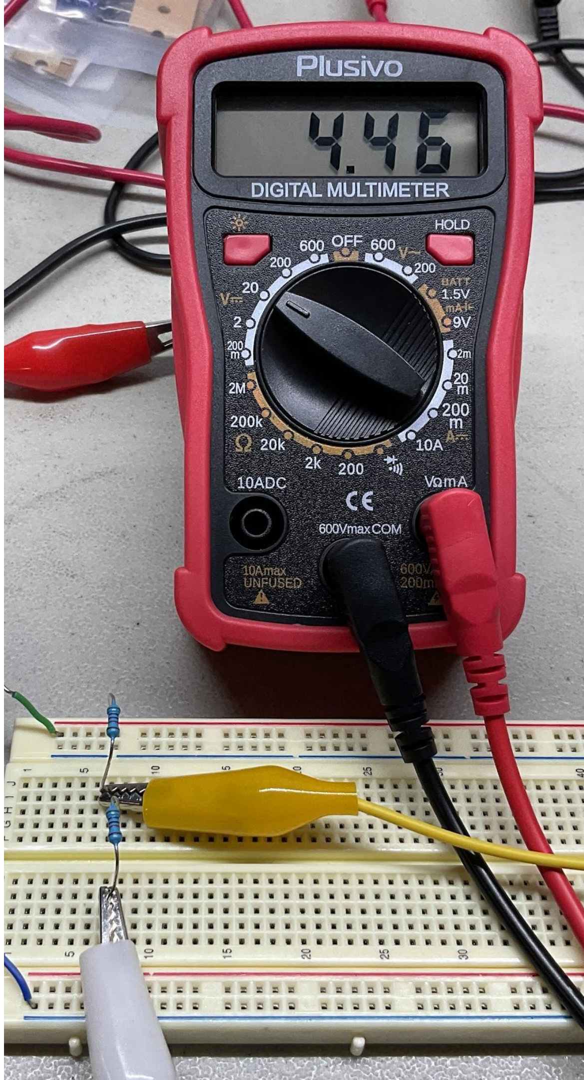
- Build a voltage divider using two 10K (brown, black, black, red) resistors.



Voltage Divider

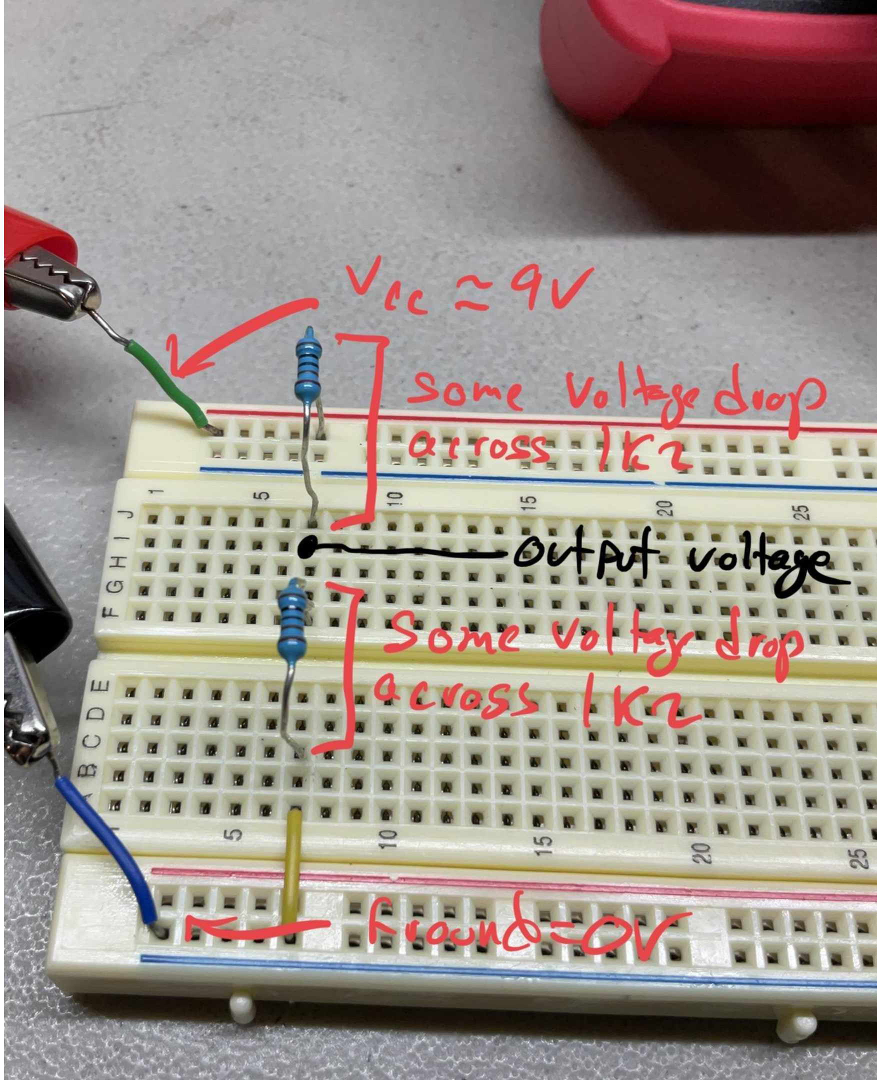
- Use a multimeter set as a voltmeter to measure the voltages at each point in the circuit.
- Using this voltage divider, our output is at roughly HALF the voltage supply!





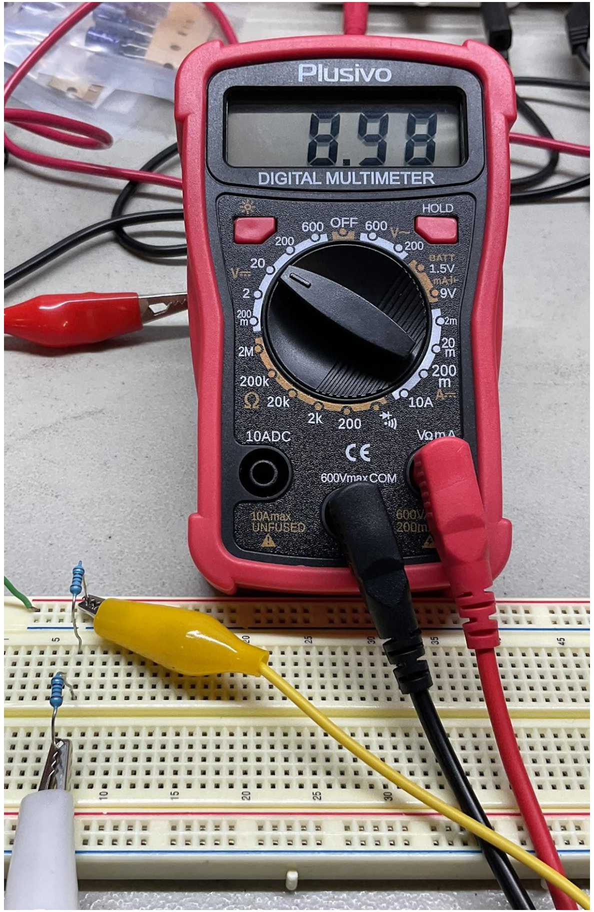
Voltage Divider

- Build a voltage divider using two 1K (brown, black, black, brown) resistors.



Voltage Divider

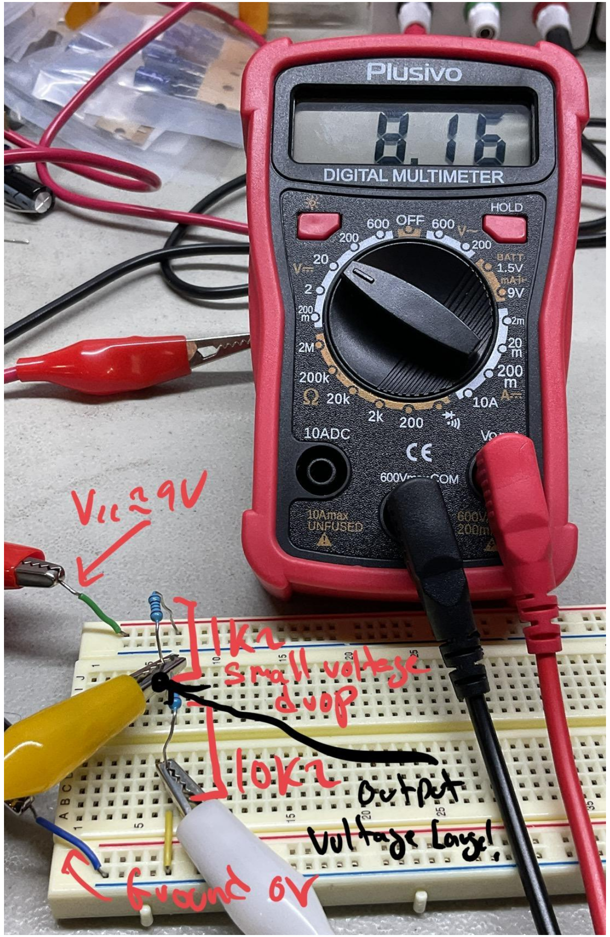
- Use a multimeter set as a voltmeter to measure the voltages at each point in the circuit.
- Using this voltage divider, our output is at roughly HALF the voltage supply!
- **In fact, anytime you use the same resistor values, your output voltage gets cut in half!**

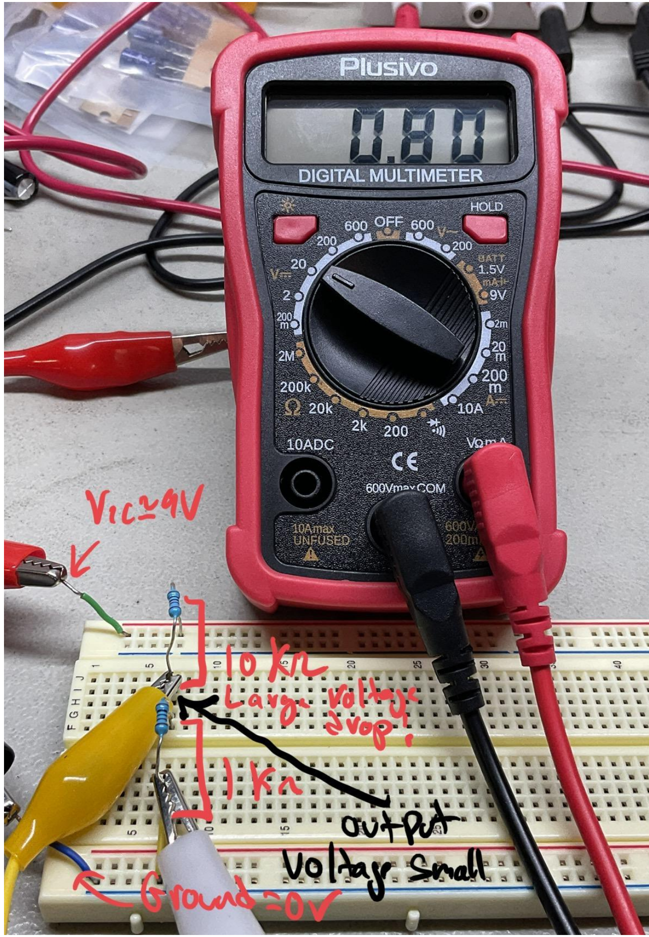


Voltage Divider

- A smaller resistor first results in a larger output voltage.
- A larger resistor first results in a smaller output voltage.

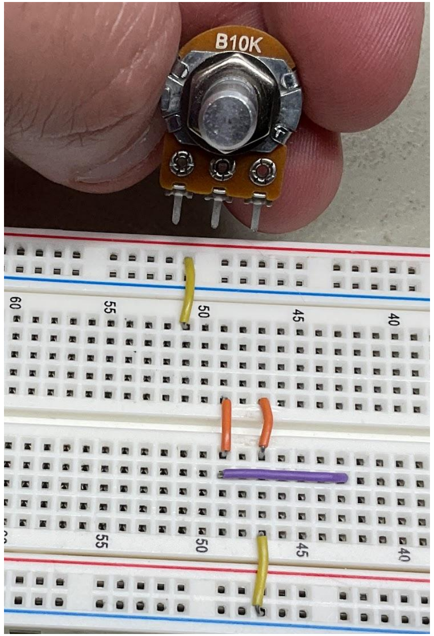
$$Vout = Vin\left(\frac{R2}{R1 + R2}\right)$$

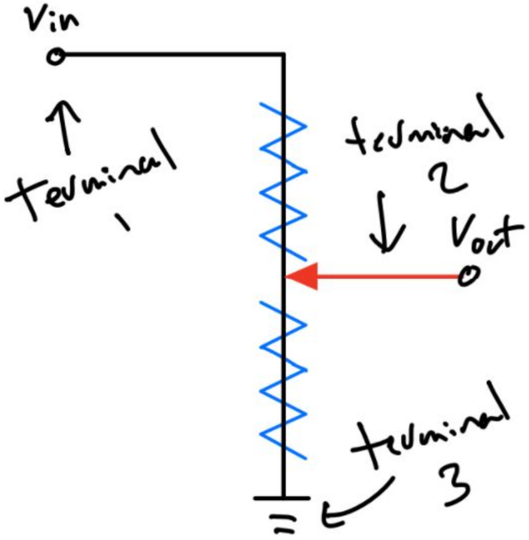




Potentiometers as Voltage Dividers

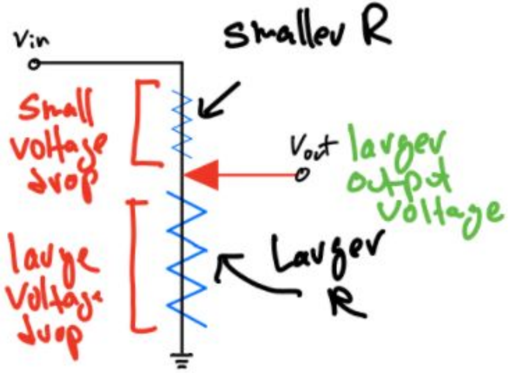
- Recall, we said that when we ground the third terminal of a potentiometer it becomes a voltage divider.
- The wiper or 2nd terminal is a shared connection between two resistors inside the potentiometer.
- We can vary where the wiper sits by turning the knob clockwise or counter clockwise.

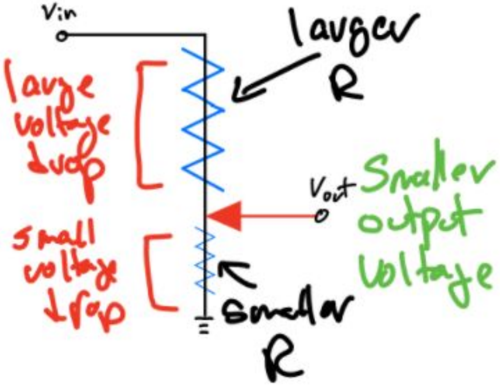




Potentiometers as Voltage Dividers

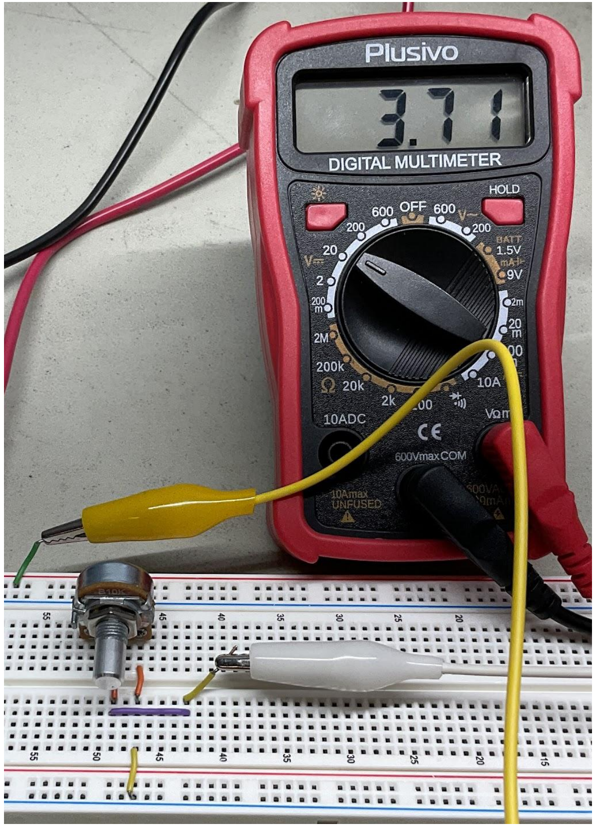
- By decreasing the resistance of the first resistor in the potentiometer, you are requiring a smaller voltage drop over that resistor, resulting in a larger output voltage.
- By increasing the resistance of the first resistor in the potentiometer, you are requiring a larger voltage drop over that resistor, resulting in a smaller output voltage.

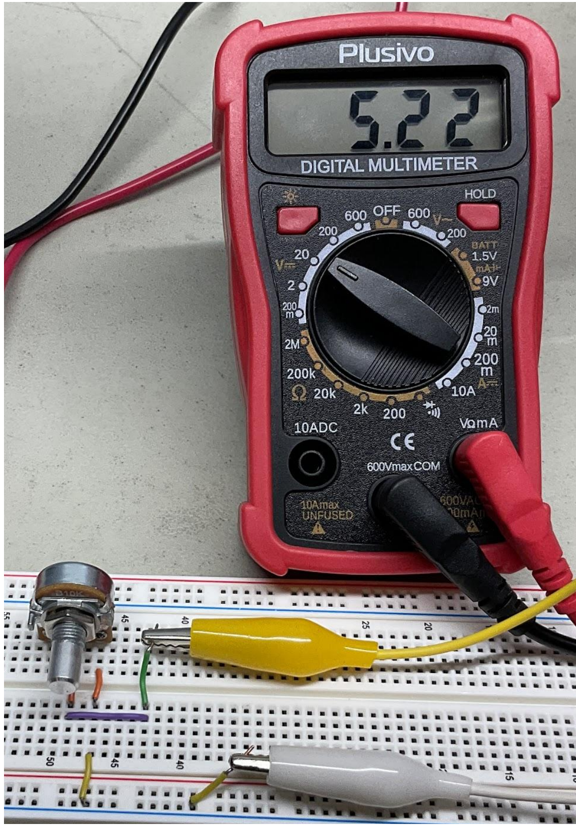




Potentiometers as Voltage Dividers

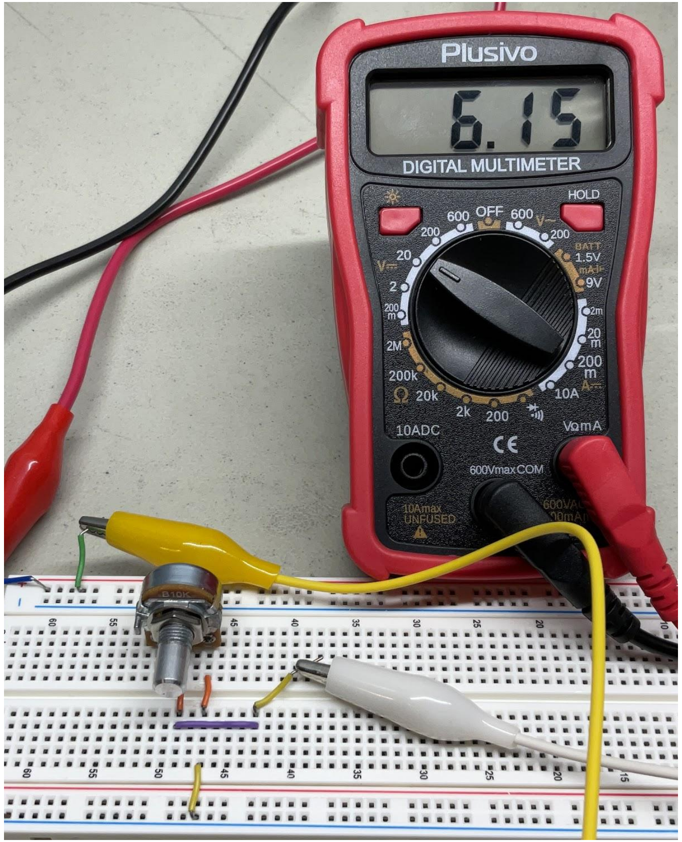
- Here we are currently dropping 3.71 volts over the first resistor and 5.22 volts over the 2nd resistor.
- R1 is SMALLER than R2.
- 3.71 + 5.22 = 8.93 which is roughly our power supply.
- The output voltage is 5.22 volts.

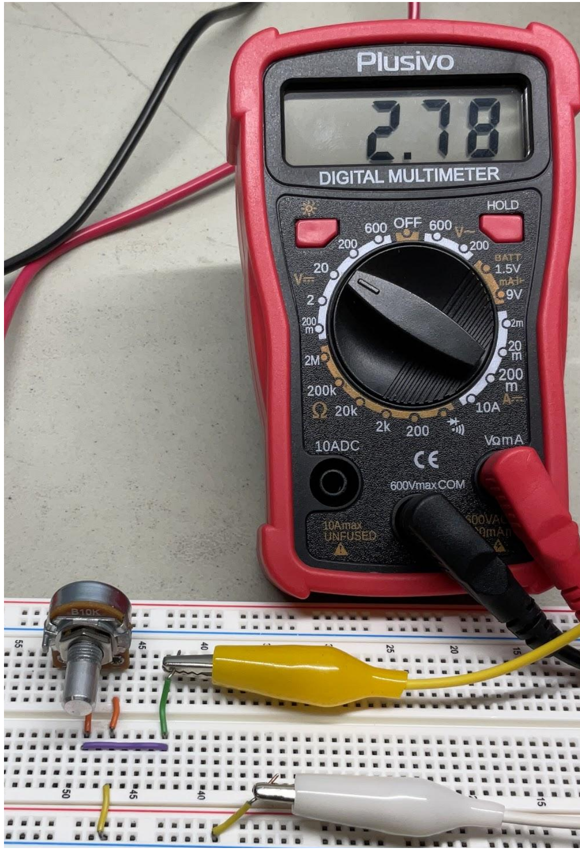




Potentiometers as Voltage Dividers

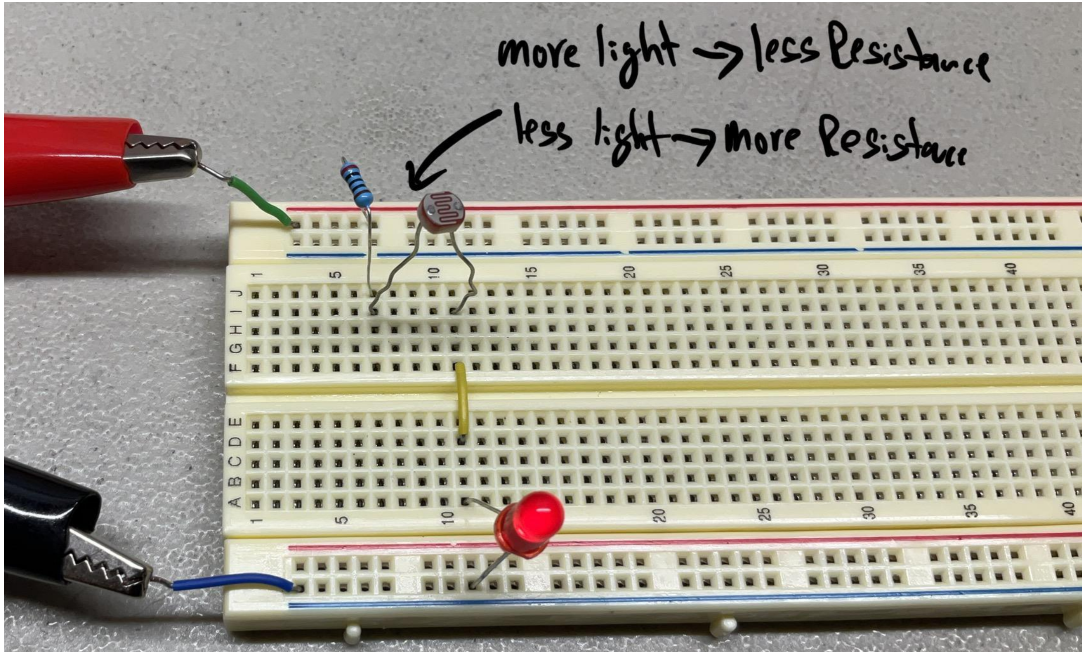
- Here we are currently dropping 6.15 volts over the first resistor and 2.78 volts over the 2nd resistor.
- R1 is BIGGER than R2.
- 6.15 + 2.78 = 8.93 which is roughly our power supply.
- The output voltage is 2.78 volts.





Revisiting the Light Dependent Resistor

- The LDR works backwards from what we would probably want in this configuration…
- When light hits the LDR, it offers less resistance causing the LED to light up.
- When it is dark, the LDR offers more resistance causing the LED to turn off.



Circuit Challenge 5

The Night Light Company

Circuit Challenge 5: The Night Light Company

You are tasked with creating a working night light! A working night light is one that turns on automatically when it is dark and turns off when there is light. Get this right and we'll start a night light company and become millionaires!

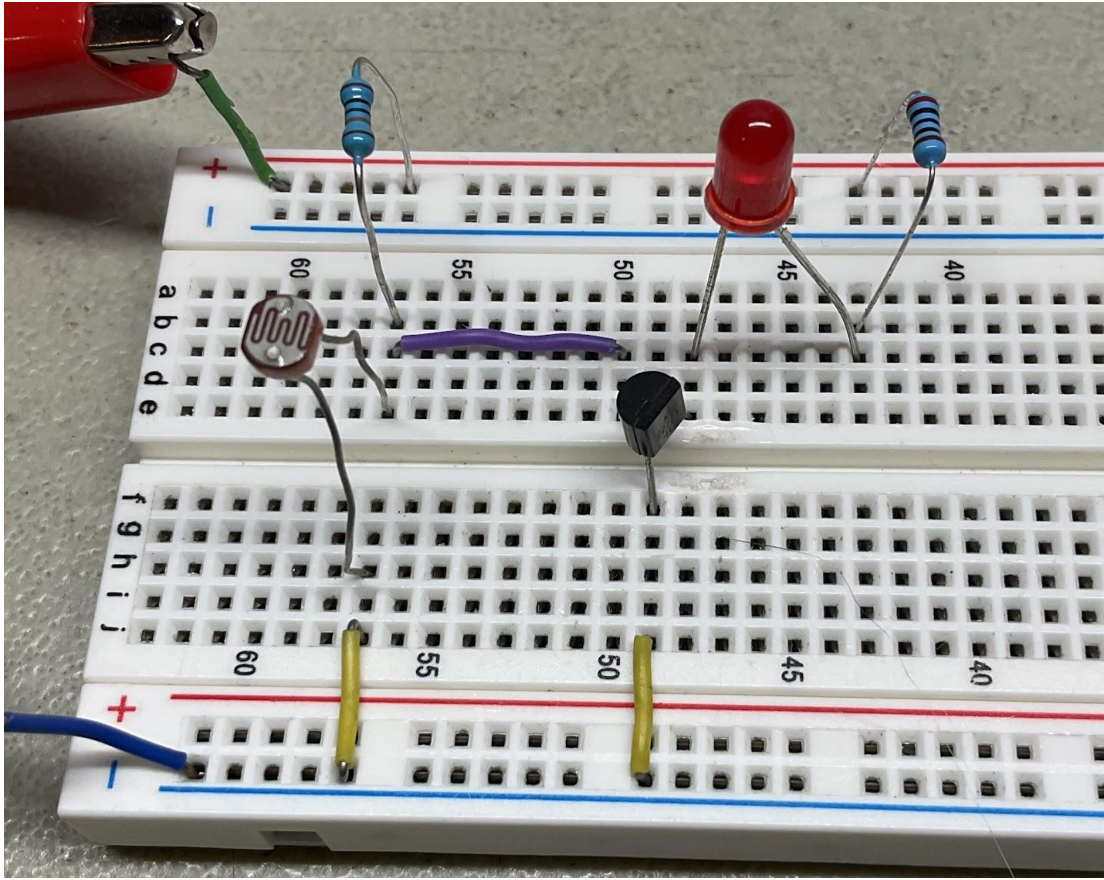
Hints:

- You will need a voltage divider that uses your LDR.
- The output of this voltage divider should go to the base of a transistor switch.
- When the transistor "turns on" it should send current through a 200 Ohm resistor and LED.

DO NOT ADVANCE to the next slide without trying to figure this out first!

Circuit Challenge 5: Solution

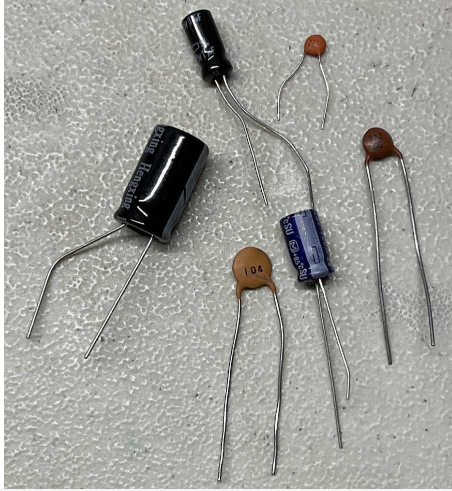
- Create a voltage divider with a 100K (brown, black, black, orange) and LDR.
- Have the LDR as the second resistor such that when light hits it, the resistance becomes small causing the output voltage to be small.
- When it is dark the resistance becomes large causing the output voltage to become large.
- The output of the voltage divider goes into the base of a transistor switch.
- When the transistor turns on, current flows from the collector to the emitter lighting our LED.

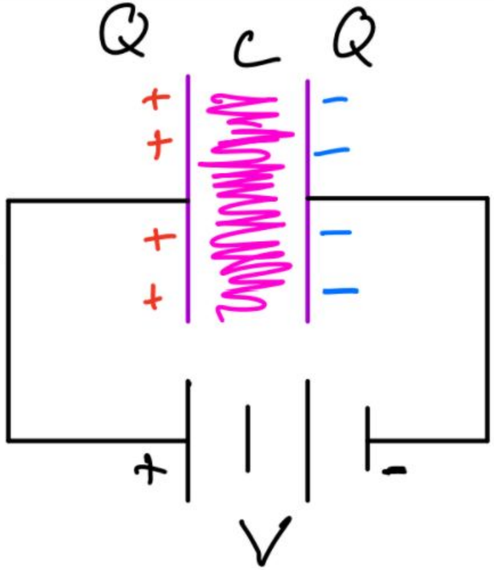


What is a Capacitor?

What is a Capacitor

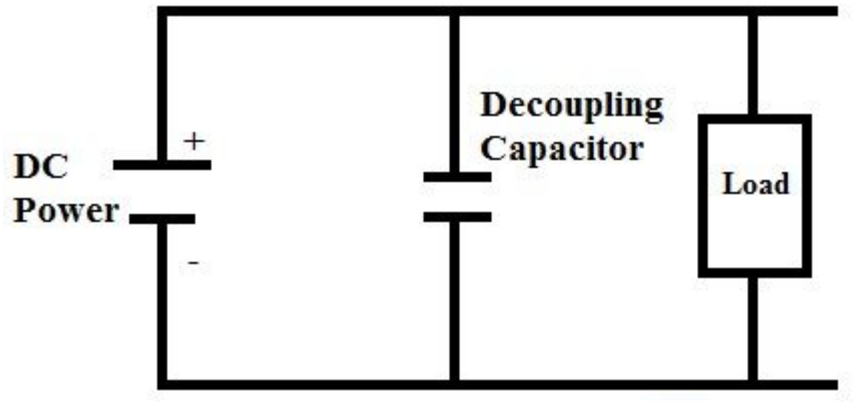
- A **capacitor** is a bit like a battery, but it has a different job to do.
- A battery uses chemicals to store electrical energy and releases it very slowly through a circuit. A capacitor also stores electrical energy but generally releases it much more rapidly—often in seconds or less.
- Take two electrical conductors and separate them with an insulator and you make a capacitor: something that can store electrical energy.
- Adding electrical energy to a capacitor is called charging; releasing the energy from a capacitor is known as discharging.
- Capacitance is measured in Farads.





What is a Capacitor

- Capacitors have many uses!
- Since capacitors can store and release electrical energy, one such use is a **decoupling capacitor**.
- A decoupling capacitor stores energy and dissipates it back into the circuit to maintain a smooth flow of current.
- Imagine if the load here was very sensitive to changes in voltage and the DC power supply had a small variation in voltage.
- The Decoupling capacitor could either store the excess voltage (charge) or release some of its own voltage (discharge)to keep the voltage of the load constant!
- **An important question is how does the capacitor charge and discharge????**



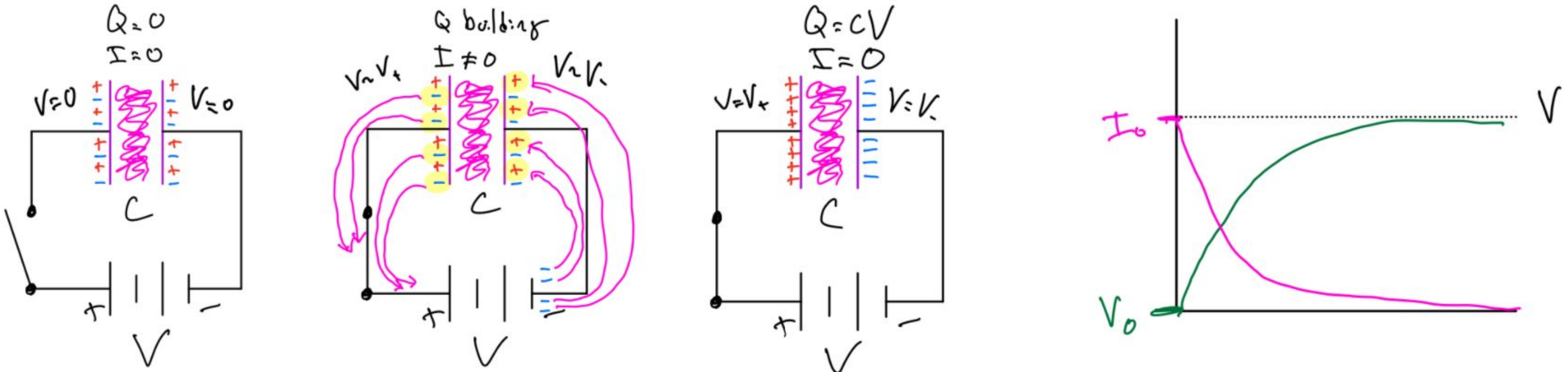
What is a Capacitor

- Applying a voltage across a capacitor causes charge to build up on each plate of the capacitor.
- This charge (Q) that builds is proportional to the voltage (V) across the plates.

$$\mathbf{Q = CV}$$

$$\mathbf{I = C * dV/dt}$$

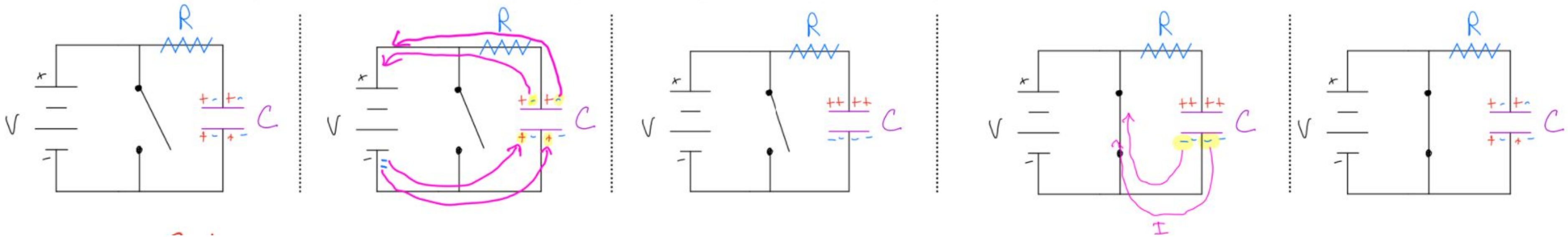
- For a constant voltage, (V=0, V=Vcc) no current flows.
- For a changing voltage, current flows. Hence, when the switch below is closed, the voltage changes from 0 to Vcc and current flows. Once the voltage across the capacitor approaches the voltage of the battery, there is no longer a change in voltage and current stops flowing.



What is a Capacitor

- Once the capacitor is charged, it will hold onto that charge until it has a path to discharge.
- Case 1: There is no charge on the capacitor as we hook it up to the battery.
- Case 2: Current begins to flow as there is a change in voltage from 0 volts to the voltage of the battery.
- Case 3: Charge has built up on the capacitor, the voltage across the capacitor is equal to the voltage of the battery; no more current flows.
- Case 4: The switch is closed and now there is a path for the capacitor to discharge. The capacitor acts like a battery providing voltage to the resistor. Current flows.
- Case 5: The capacitor is discharged, the voltage across the capacitor is back to 0, no current flows.

The charging and discharging of the capacitor takes time!

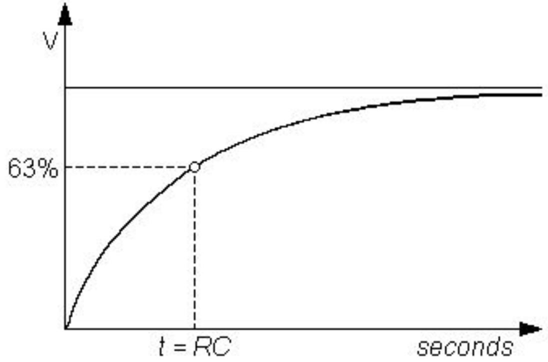


RC Time Constant

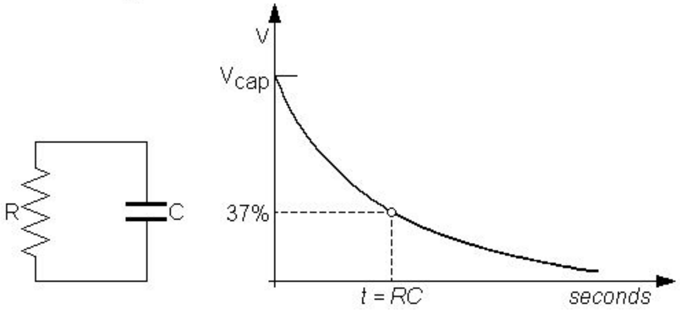
- The time the capacitor takes to charge/discharge is given by the RC time constant. The capacitor needs charge to build on it's plates and the resistor limits how quickly that charge can flow. The product of the resistance and capacitance used is known as the RC time constant for a given circuit.

T = RC

- 1 time constant is how long the capacitor takes to charge to 63% or discharge to 37%.
- **After approximately 5 time constants the capacitor is considered fully charged or discharged and no more current will flow.**

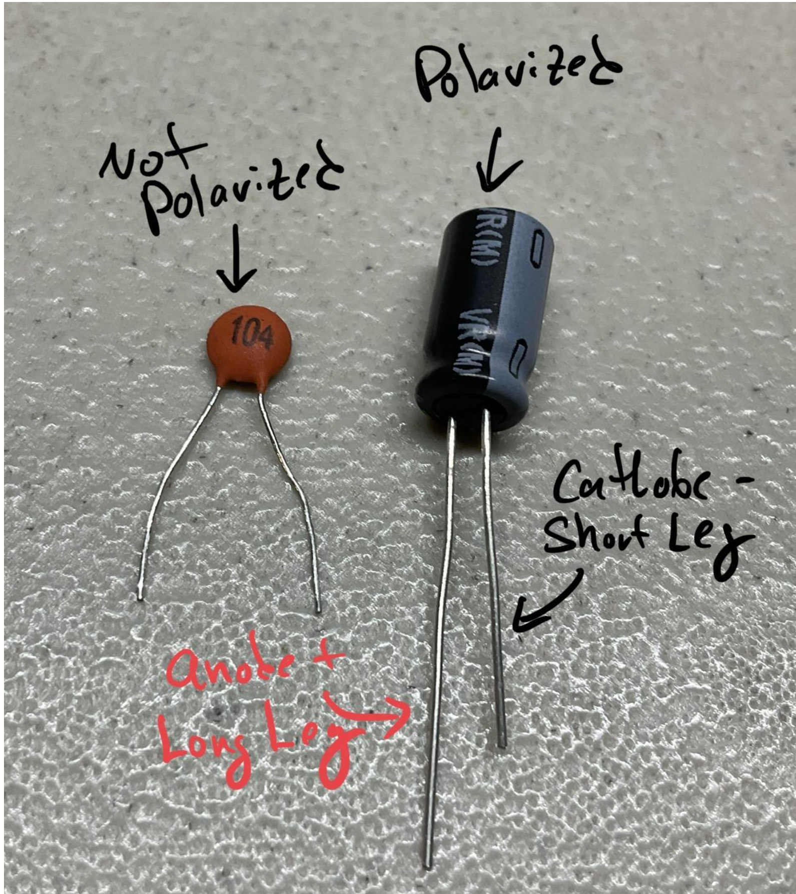


RC Discharge



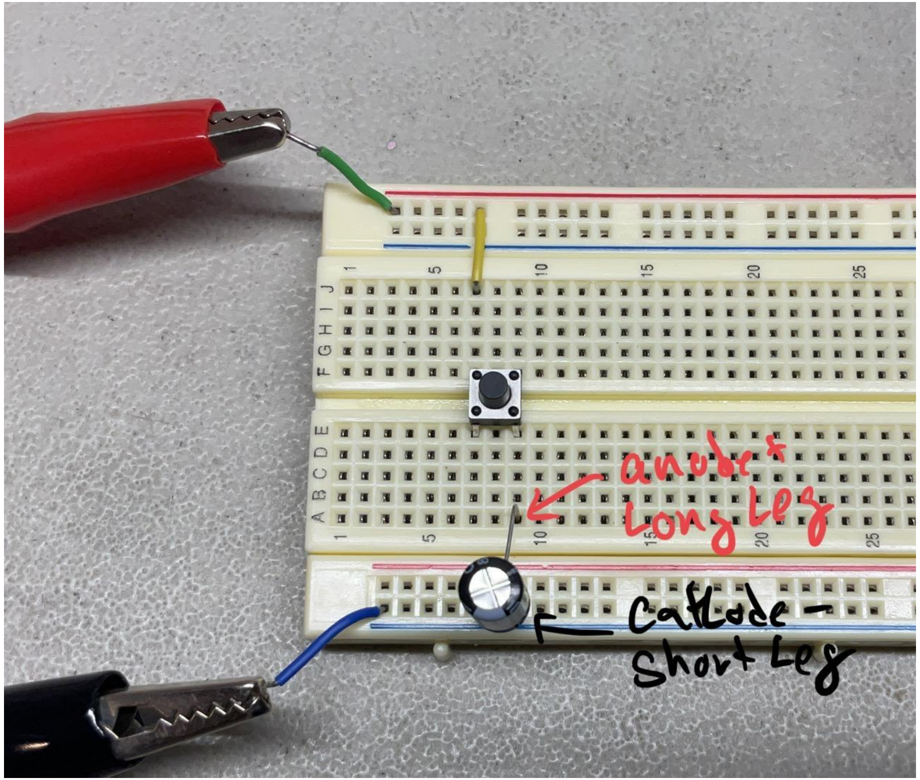
Charging the Capacitor

- So far in working with LEDs, we have provided a voltage and the LEDs have “instantly” turned on/off.
- Now, with capacitors we can introducing timing into our circuits such that they gradually fade in/out over a period of time.
- We have lots of capacitors we can use just like resistors.
- One key difference is that some capacitors are polarized; they have an anode (positive long leg) and cathode (negative short leg).
- When using a polarized capacitor, the way you put it in the circuit matters!



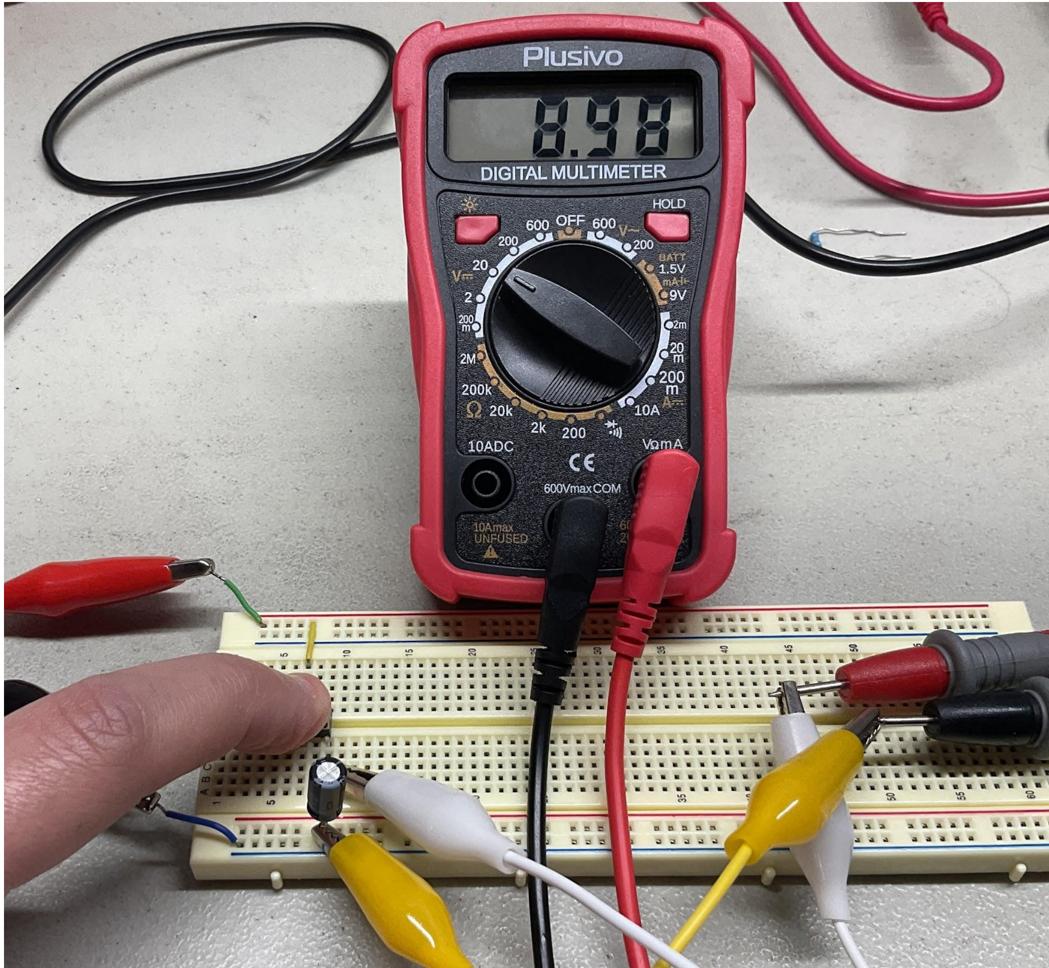
Charging the Capacitor

- Hook up your 9 volt battery to the Vcc and ground rails.
- Place a push button across the gap with one end connected to Vcc.
- Place a 100 microFarad capacitor on the opposite end of the push button going to ground.
- Make sure you have the cathode (short leg) of the capacitor to ground.



Charging the Capacitor

- Set a multimeter as a voltmeter to read a maximum voltage of 20 V (or something similar to your meter).
- Connect the voltmeter across the capacitor.
- Press the button and read the voltage across the cap.
- You should see the voltage change from 0 to the voltage of your battery!
- We have effectively charged the capacitor! Now we need to have a way to discharge it!



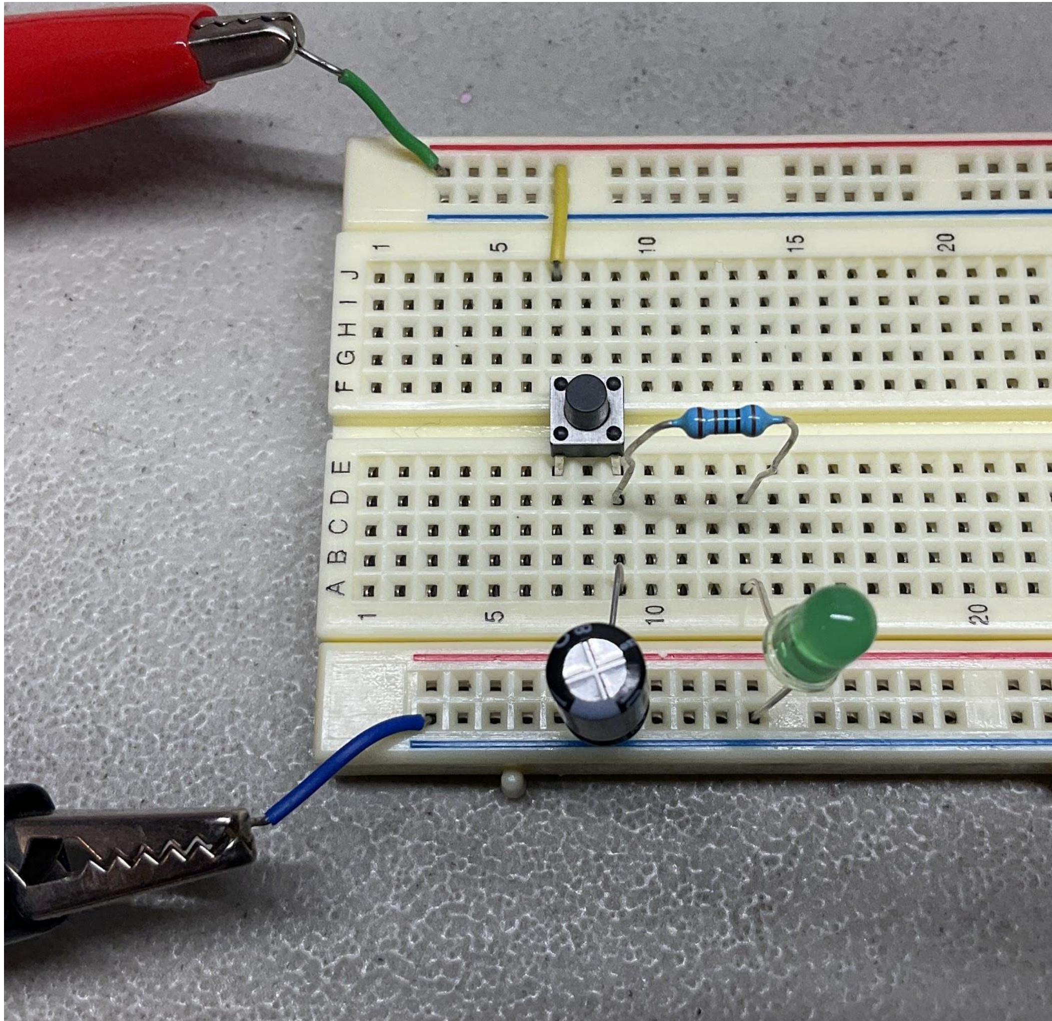
RC Timing Circuits

Discharging the Capacitor

- Place a 1K (brown, black, black brown) resistor to an LED to ground in parallel with the capacitor.
- Now when you press the button, the capacitor will charge up and the LED will be on.
- When we release the button, there is no more voltage present from the battery, however the capacitor will discharge through the resistor -> LED -> ground.
- The LED should fade out.
- The time constant is R*C:

  RC = 1,000 ohms*.0001 F = .1s

- The LED will completely fade out in approximately 5*RC = **0.5 seconds**



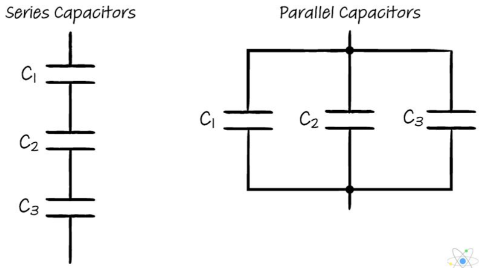
Increasing the RC Time Constant

- If we want the LED to fade longer we can either either increase the overall capacitance or resistance of our RC circuit since the time constant T = RC.
- Increasing resistance will cause the LED to fade longer but it will not be as bright! Increasing the capacitance will cause the LED to fade longer and keep its brightness.
- To increase capacitance we can add capacitors in parallel!

$$\mathbf{Ct = C1 + C2 + C3 + ...}$$

- To decrease capacitance we can add capacitors in series!

$$\mathbf{1/Ct = 1/C1 + 1/C2 + 1/C3 + ...}$$



- Note, this is backwards from how we combine resistors.

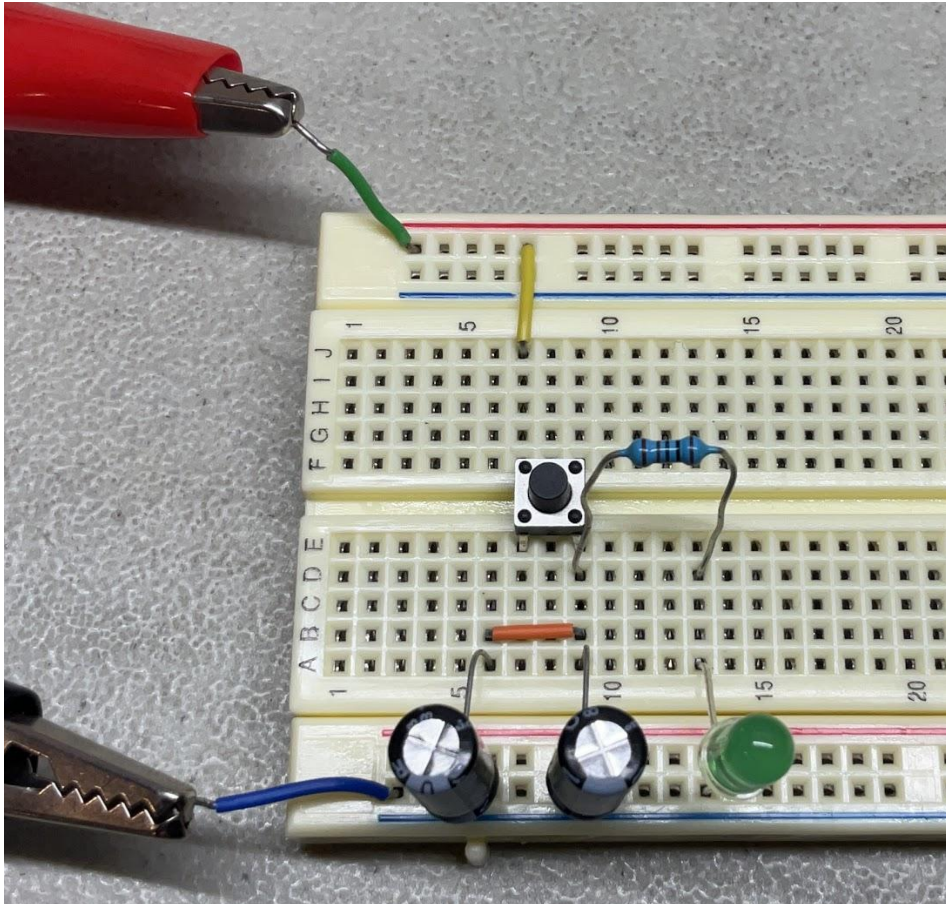
A Longer Discharge

- Place a second 100 microFarad capacitor in parallel with the first capacitor.
- Now when you press the button, both capacitors will charge. Releasing the button causes both capacitors to discharge into the LED.

Ct = C1 + C2 = .0001F + .0001F = .0002F

RC = 1000 ohms * .0002 F = .2s

- The LED will completely fade out in approximately 5*RC = **1.0 seconds**



An Even Longer Discharge

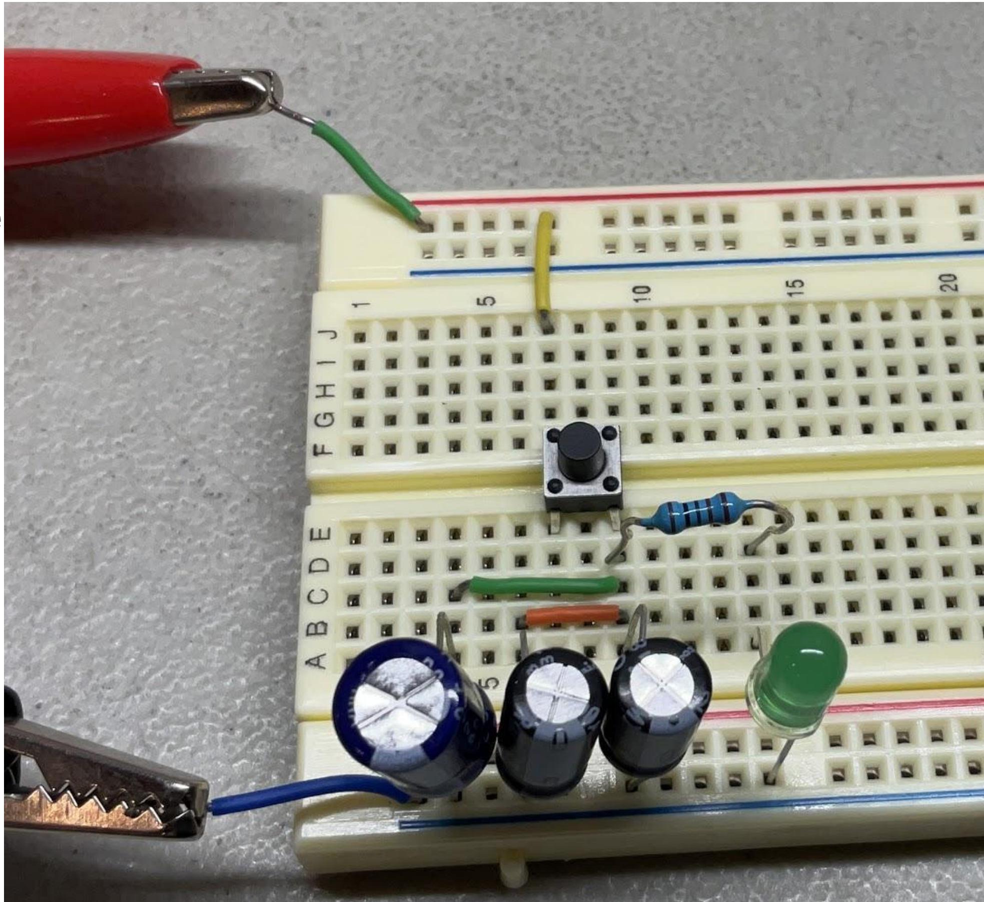
- Place a 220 microFarad capacitor in parallel with the two previous capacitors.
- Now when you press the button, all three capacitors will charge. Releasing the button causes all three capacitors to discharge into the LED.

Ct = C1 + C2 + C3 =

.0001F + .0001F +.00022F = .00042F

RC = 1000 ohms * .00042 F = .42s

- The LED will completely fade out in approximately 5*RC = **2.1 seconds**

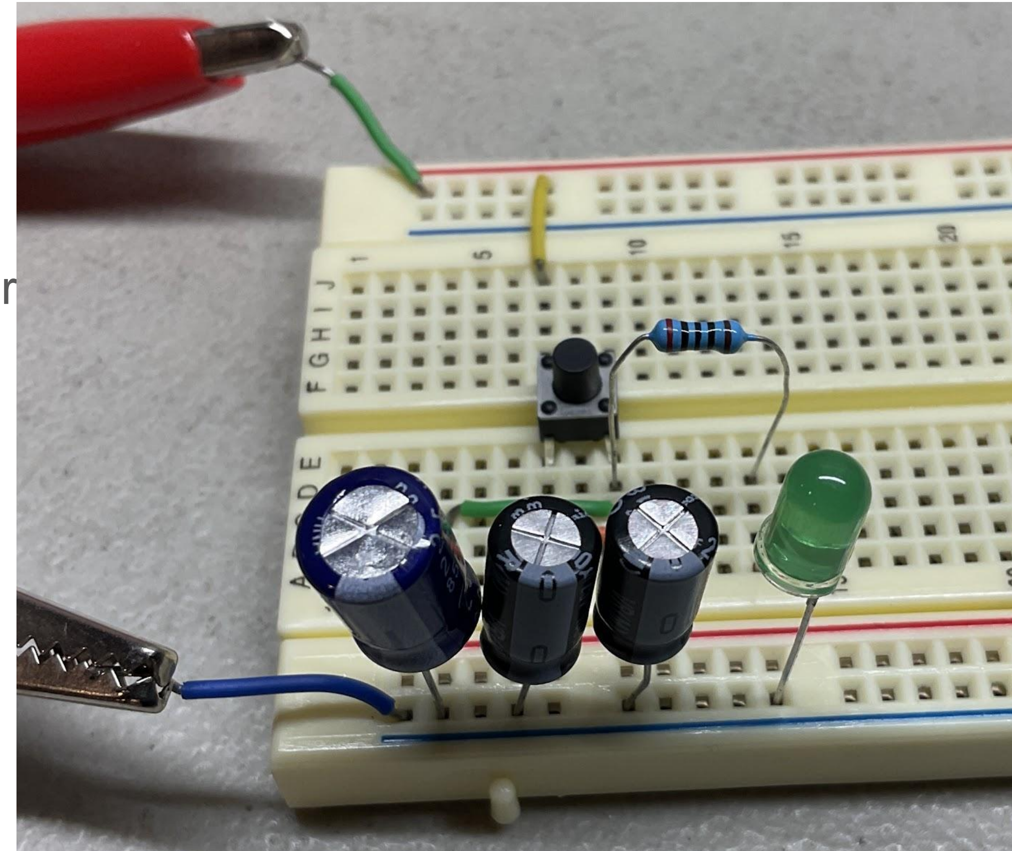


Changing Resistors

- Change the resistor in the RC circuit from 1K to 200 ohms (red, black, black, black).
- Now, the LED will be brighter (less resistance) but the fade will be shorter due to the reduced time constant.

RC = 200 ohms * .00042F = .084s

- The LED will completely fade out in approximately 5*RC = **0.42 seconds**



What About Fading In?

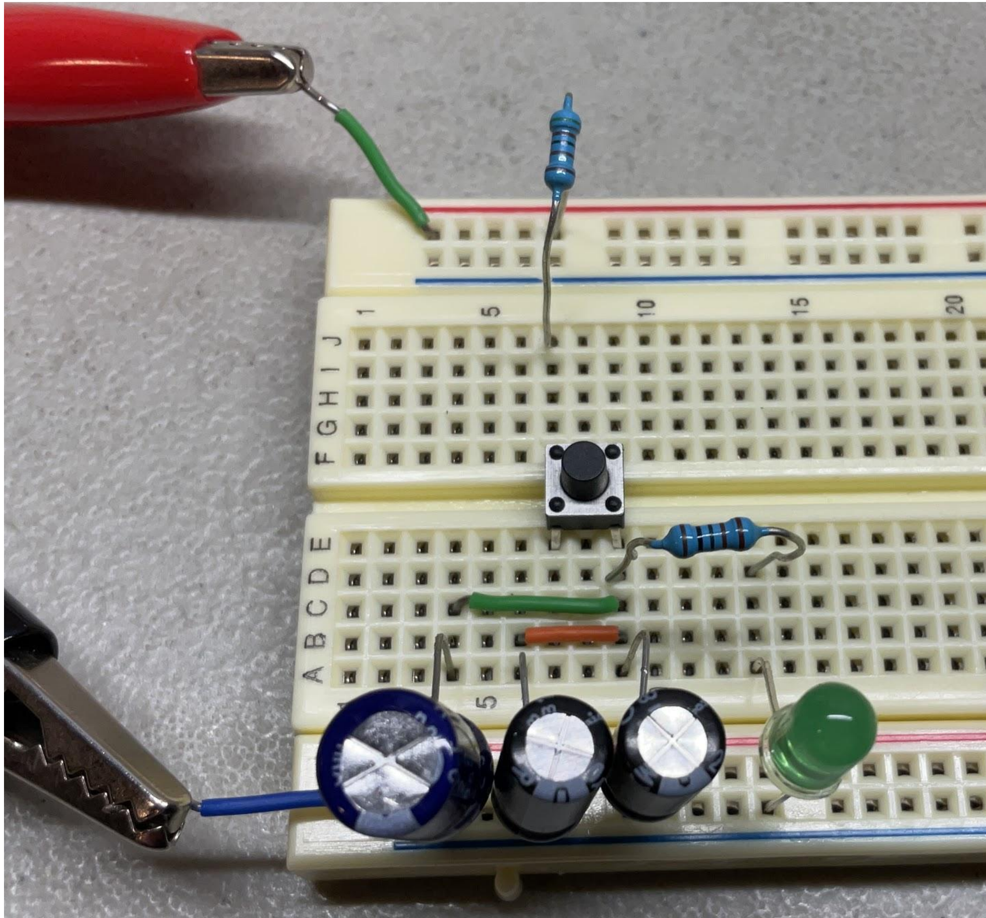
- To fade in, we can replace our jumper wire from Vcc to our button with a resistor.
- We still have our discharging RC circuit:

Parallel Capacitors -> Resistor -> LED

- And we now have a charging RC circuit:

Vcc -> Resistor -> Button -> Parallel Capacitors

- Use a 5.1K (green, brown, black, brown) resistor from Vcc to the button.
- Switch back to a 1K (brown, black, black, brown) resistor on your LED.



Why Does the Fade In Seem Quicker than the Fade Out?

- The charging/discharging of a capacitor is exponential.
- An LED needs anywhere from 1.7 to 4.0 Volts to “turn on”.
- Let’s assume that our LED needs 2.0 volts to turn on.
- For fading in, one time constant gives us about 63% of our Vcc across the capacitor.

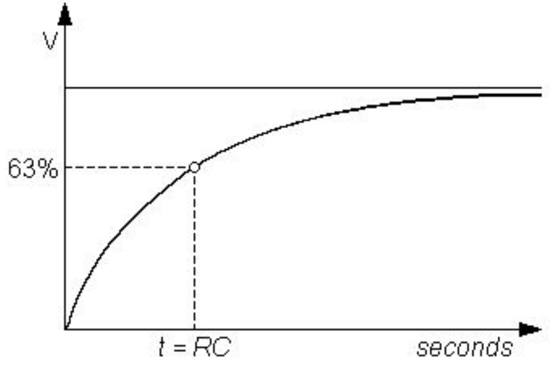
$$9v*0.63 = 5.67v$$

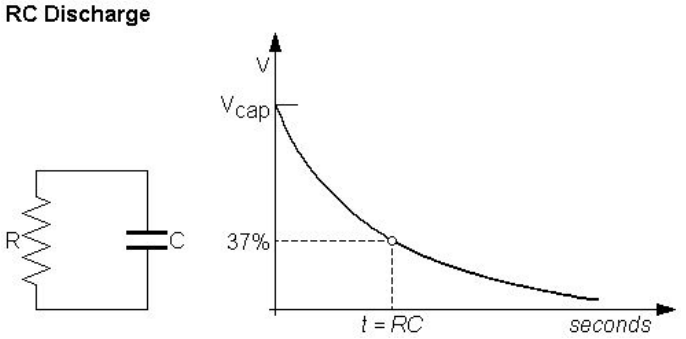
Therefore the LED will be on after 1 time constant!

- For fading out, one time constant gives us about 37% of our Vcc across the capacitor.

$$9v *0.37 = 3.33V$$

Therefore the LED will still be on after 1 time constant; slowly fading out!



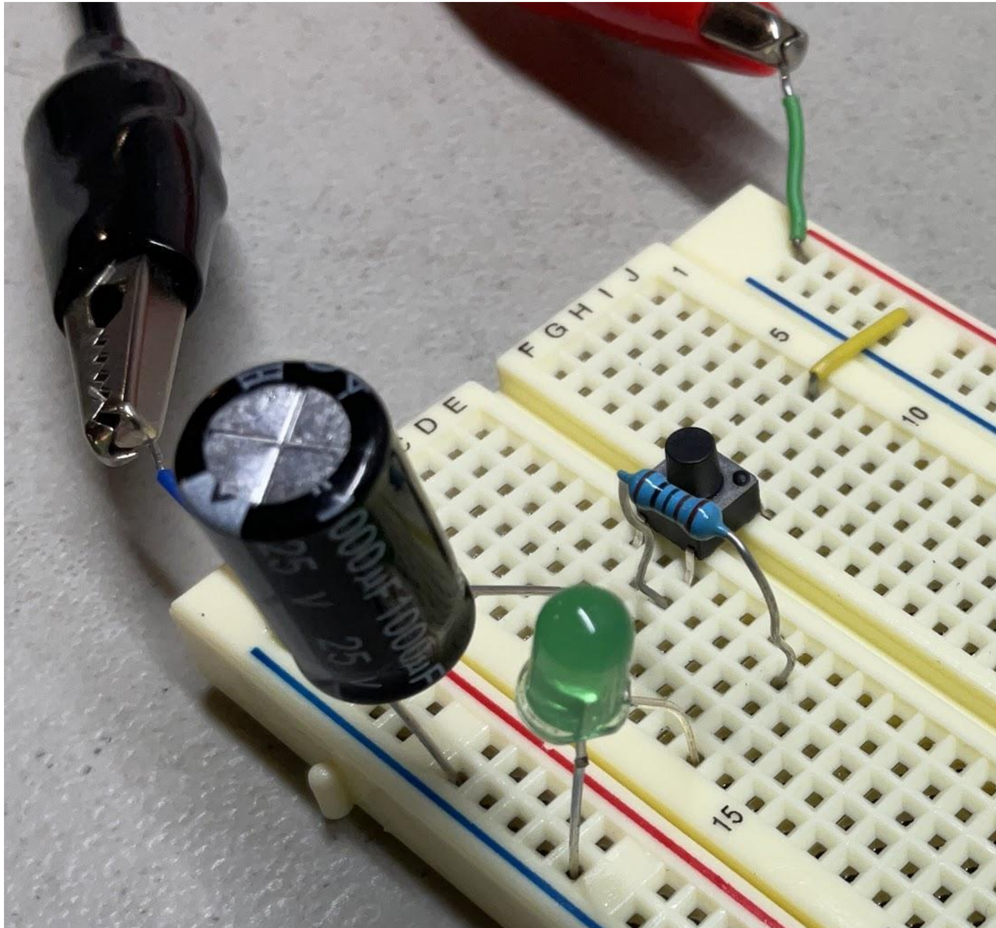


The Big Fade

- Let's replace our three capacitors with a single 1,000 microFarad capacitor.
- Now our RC time constant is:

RC = 1000 ohms*.001F = 1s

- The LED will completely fade out in approximately 5*RC = **5 seconds!**



Circuit Challenge 6

The Cascade Fade

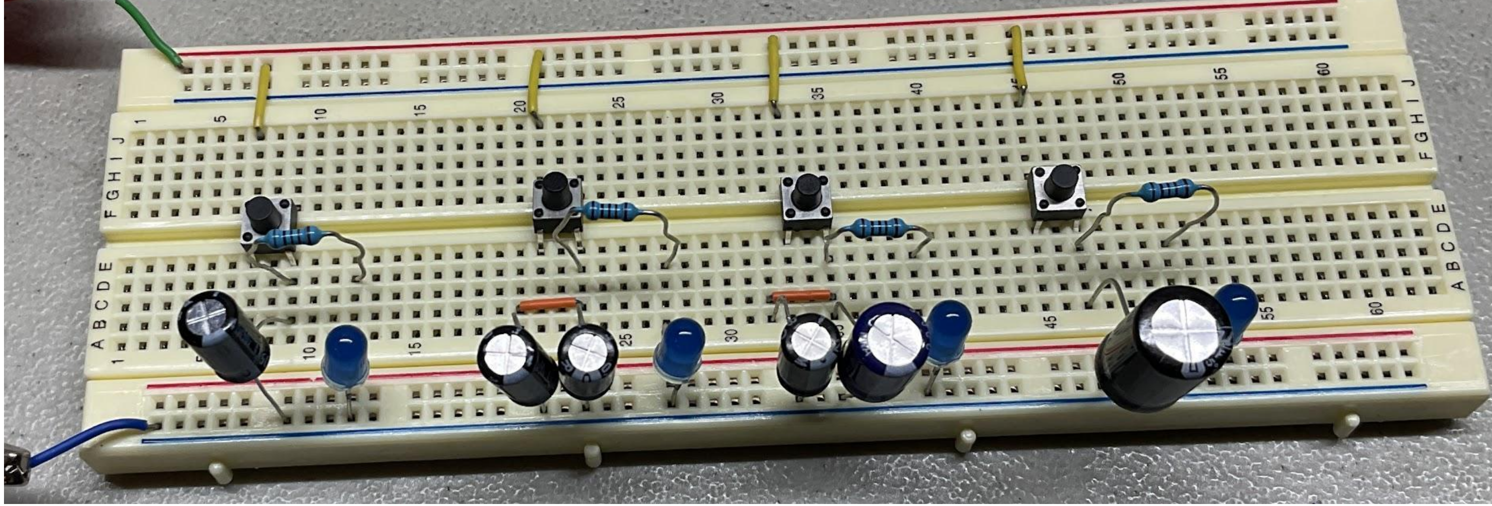
Circuit Challenge 6: The Cascade Fade

- Can you wire up 4 separate RC timing circuits using 1000 ohm resistors, various capacitors, 4 push buttons, and 4 LEDs of the same color such that:
    - The first LED fades out after 0.235 seconds
    - The second LED fades out after 0.735 seconds
    - The third LED fades out after 1.6 seconds
    - The fourth LED fades out after 2.35 seconds

- When you press and hold all 4 buttons simultaneously, all LEDs should turn on and capacitors should charge.
- When you release all 4 buttons simultaneously, each LED should fade out for its respective duration giving a cascade effect.
- **HINT**: Recall that it takes 5 time constants (R*C) to fully charge or discharge an RC circuit!

DO NOT ADVANCE to the next slide without trying to figure this out first!

Circuit Challenge 6: Solution



1st RC circuit

Time to fade: 0.235 s

RC = 0.235/5 = .047

.047 = 1000 * C

C = 47 microFarads

A single 47 microFarad cap!

2nd RC circuit

Time to fade: 0.735 s

RC = 0.735/5 = .147

.147 = 1000 * C

C = 147 microfarads

A 47 and 100 microFarad cap in parallel!

3rd RC circuit

Time to fade: 1.6 s

RC = 1.6/5 = .32

.32 = 1000 * C

C = 320 microfarads

A 100 and 220 microFarad cap in parallel!

4th RC circuit

Time to fade: 2.35 s

RC = 2.35/5 = .47

.47 = 1000 * C

C = 470 microfarads

A single 470 microFarad cap!

RC Timed Transistor Switches

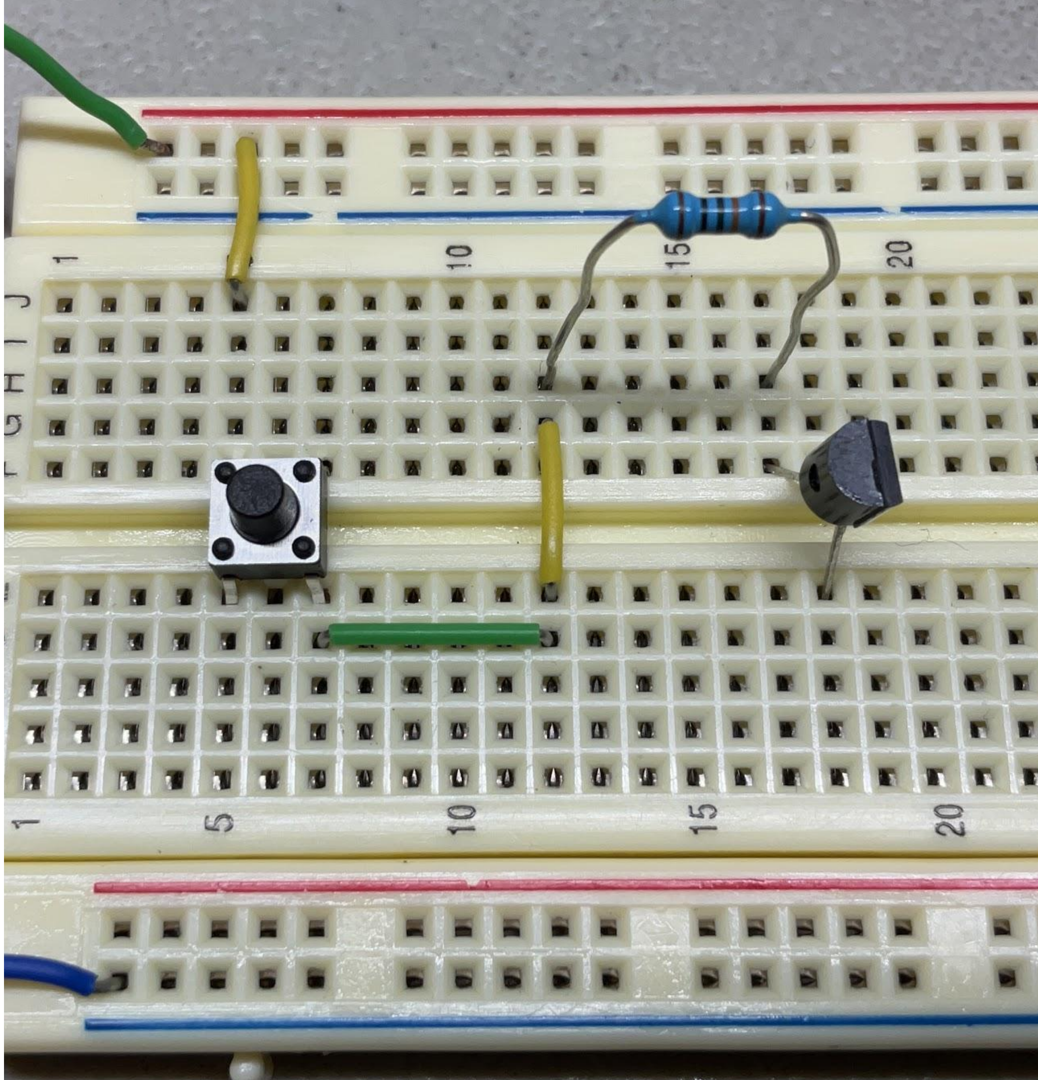
RC Delayed Switch

- We’ve now seen how to use transistors as switches such that a small current can turn on/off a larger current.
- We’ve also seen how to use RC circuits to add timing to our circuits.
- Now we will work on using an RC circuit to control how long a transistor switch is on/off for.

RC Delayed Switch

- Begin by hooking one end of a push button to Vcc.
- On the opposite end of the button, attach a 100K (brown, black, black, orange) resistor .
- Feed this resistor into the base of a transistor.

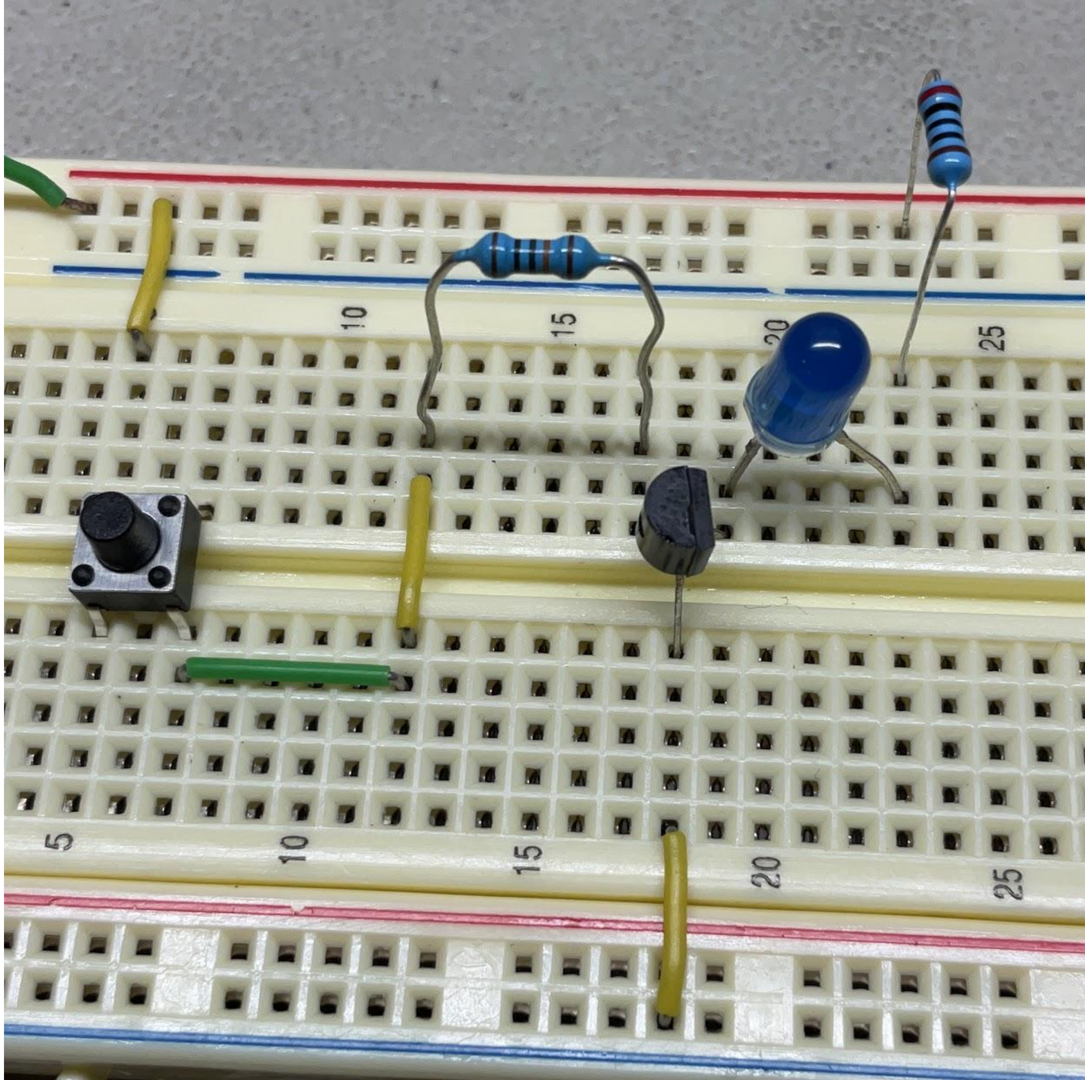
Now, every time the button is pressed, a small voltage/current will be present at the base of the transistor, effectively turning it on.



RC Delayed Switch

- Ground the emitter of the transistor.
- Place a 200 ohm (red, black, black, black) resistor from Vcc into an LED into the collector of the transistor.

Your transistor should be wired up as a switch now. Anytime you press the small voltage/current will turn the transistor on allowing a much larger current to flow through the collector to emitter (passing through the LED)

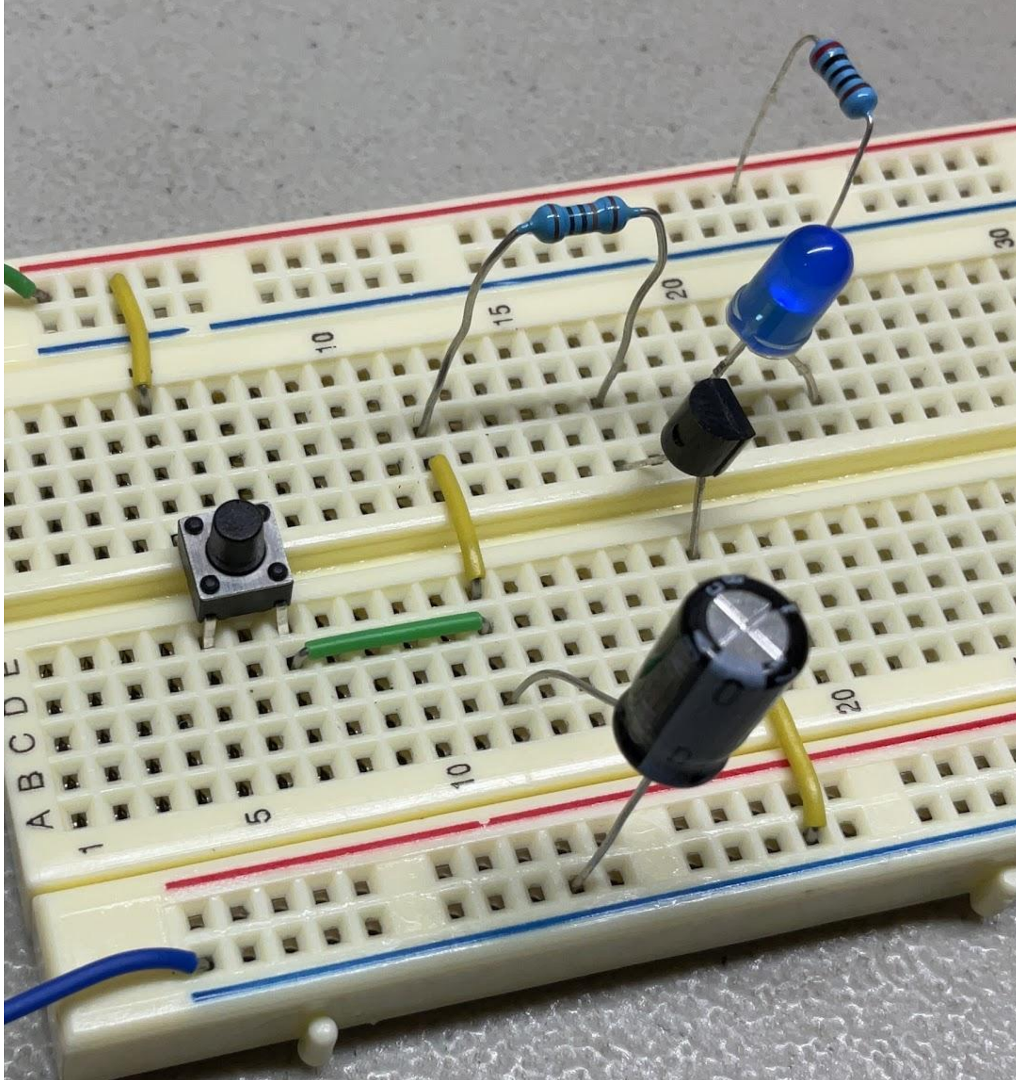


RC Delayed Switch

- Add a 47 microFarad capacitor in parallel with the transistor by placing it off the end of the push button.
- Now when you press the button, not only will the transistor turn on but the capacitor will also charge.
- When you release the button, the capacitor will discharge through the 100K resistor.
- The RC time constant is:

100K Ohms * 47 microFarads = 4.7 s

- This means it will take 5*4.7 = 23.5 s for the capacitor to fully discharge!
- Because the resistor is so big, the current generated would not be enough to light up the LED on its own, but it's enough to turn the transistor on and keep it on for 23.5 seconds!



Circuit Challenge 7

Don’t Make Me Wait

Circuit Challenge 7: Don’t Make Me Wait

- In the last circuit you build an RC delayed switch that kept an LED on for roughly 25 seconds. The LED was connected to the collector of a transistor switch.

- In this challenge, you are tasked with wiring up an RC delayed switch that keeps an LED on for roughly **75 seconds**.

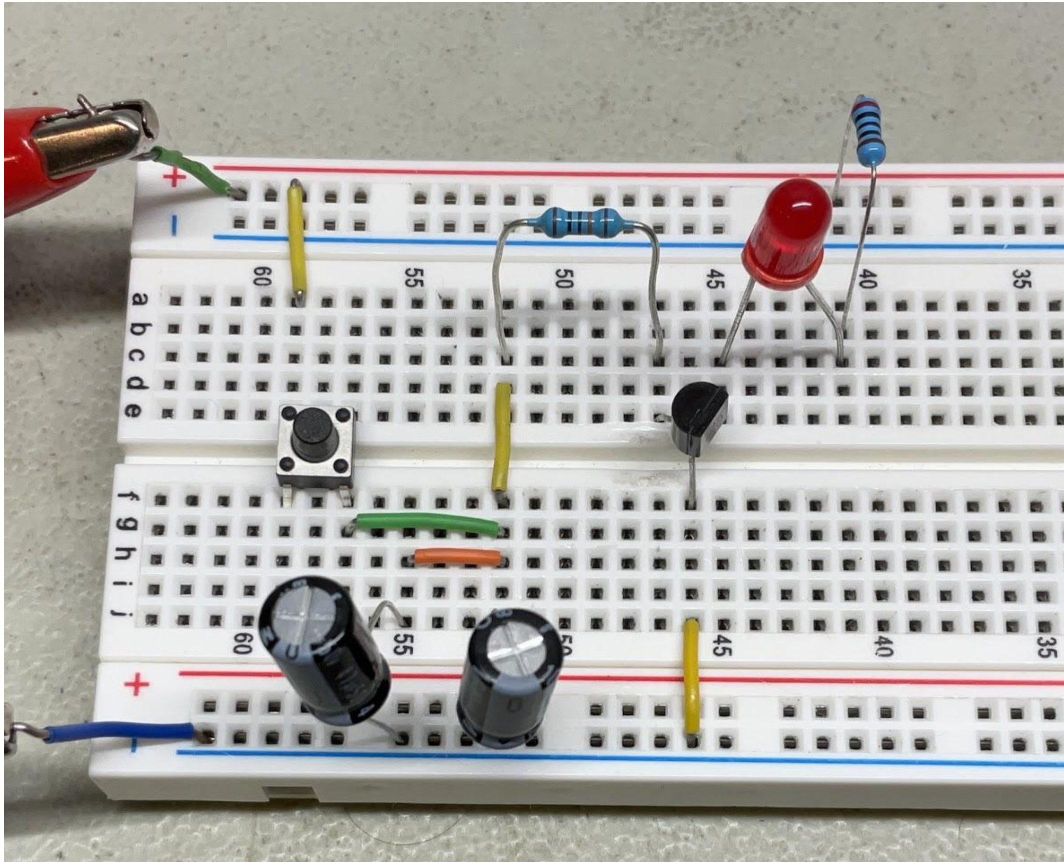
DO NOT ADVANCE to the next slide without trying to figure this out first!

Circuit Challenge 7: Solution

- Two capacitors in parallel should be used; 47 microFarad and 100 microFarad.
- Total capacitance is 147 microFarads.
- The RC time constant is:

  RC = 100K Ohm * 147 MicroFarad = 14.7 s

- This means it will take 5*14.7 = 73.5 s for the capacitors to fully discharge.



Build Together 1

Ping Pong Flashers

Build Together 1: Ping Pong Flashers

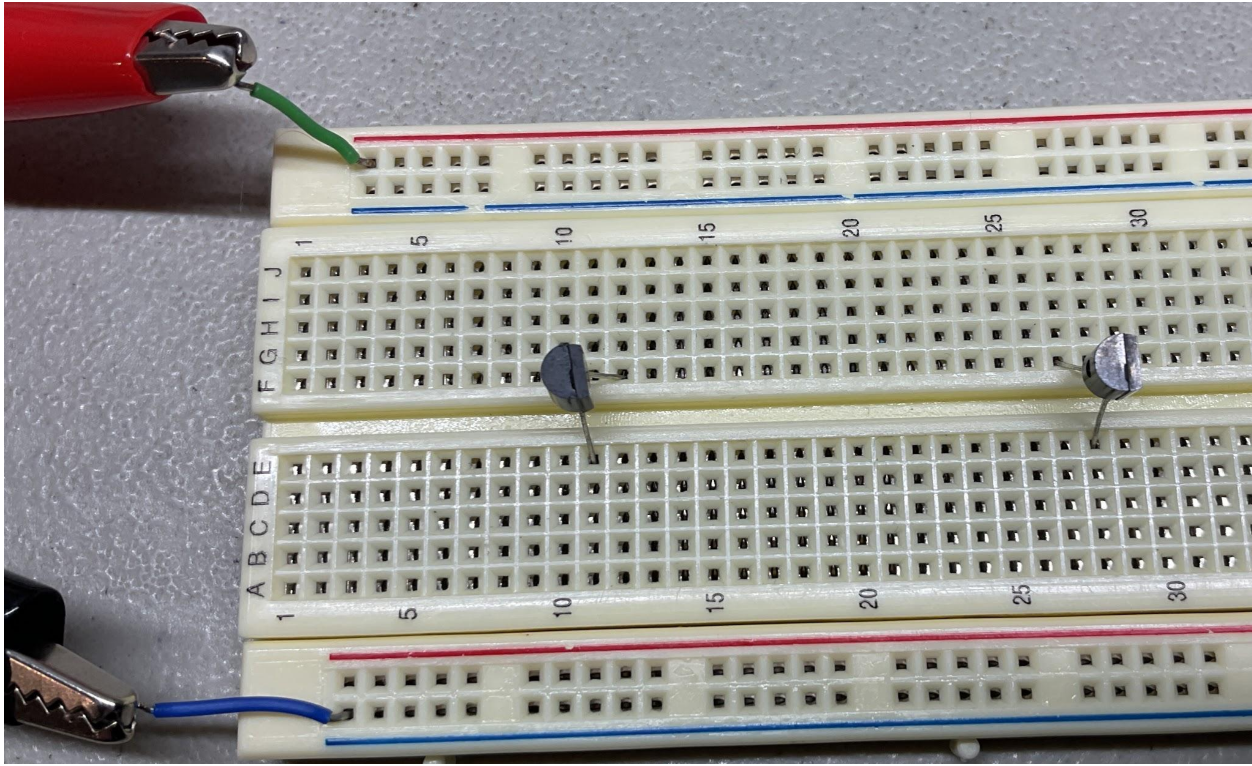
- We are going to create a 2 LED flasher using two transistors. I would like you to follow along and build step by step what I show you.
- This is known as an astable multivibrator.
- We will look more at astable circuits when we discuss 555 timers.

- As you are building, try to think about what you are doing and why the circuit is designed the way that it is.

ADVANCE to the next slide, let's build this together!

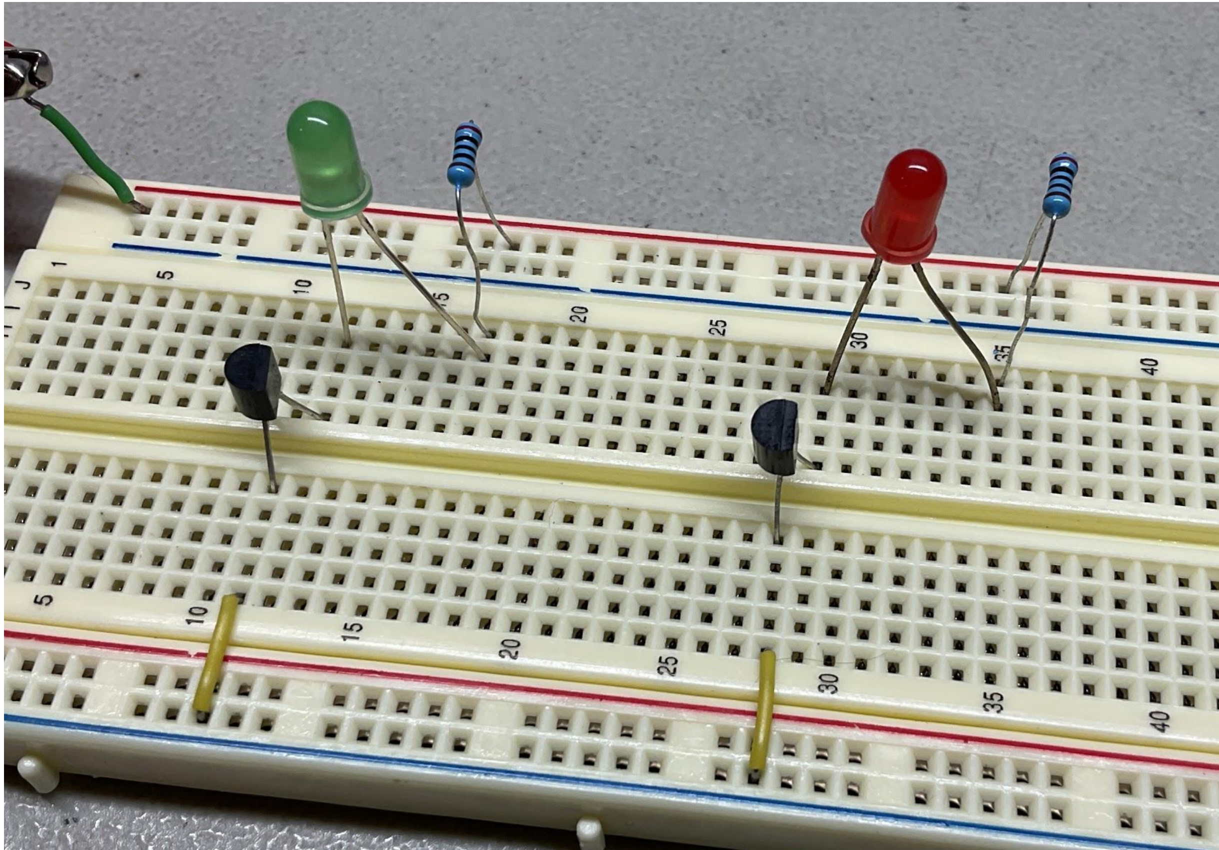
Ping Pong Flashers

- Begin by putting two transistors into the bread board.
- You will need some space between them; no need to only use a small portion of the board.



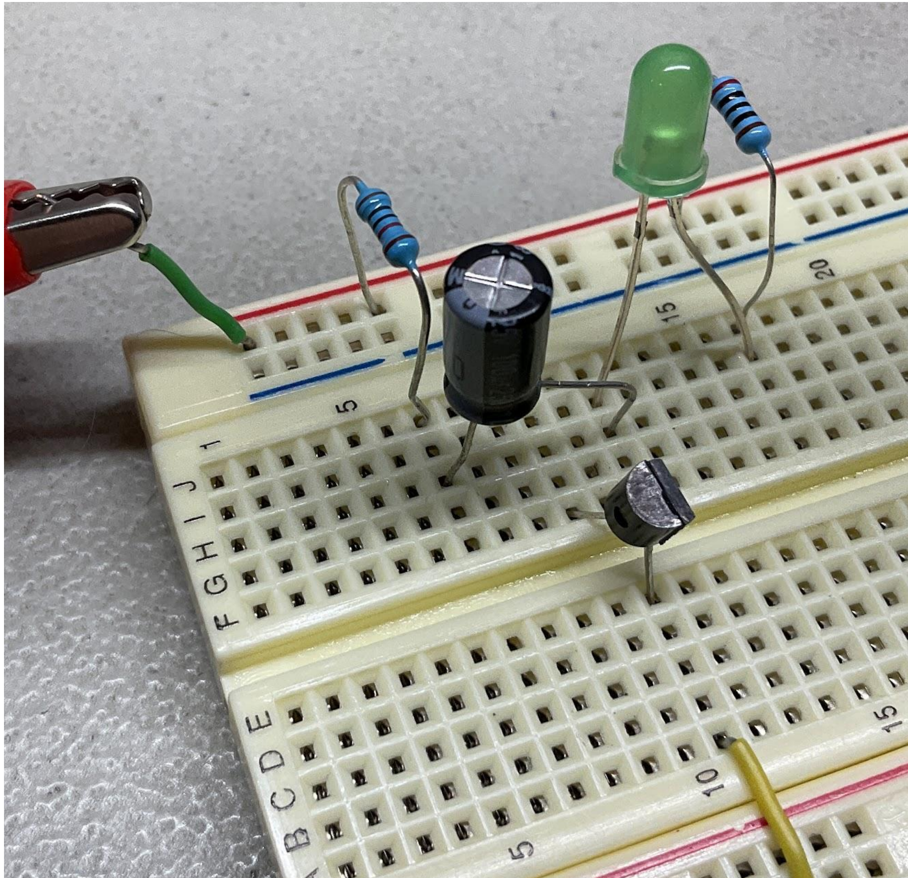
Ping Pong Flashers

- Ground the emitter of each transistor.
- From Vcc go into a 200 ohm (red, black, black, black) resistor, into an LED, into the collector of each transistor.
- Make sure the short leg (cathode) of your LED is going into the collector.
- Pick whatever colors you want! I chose green and red...CHRISTMAS!



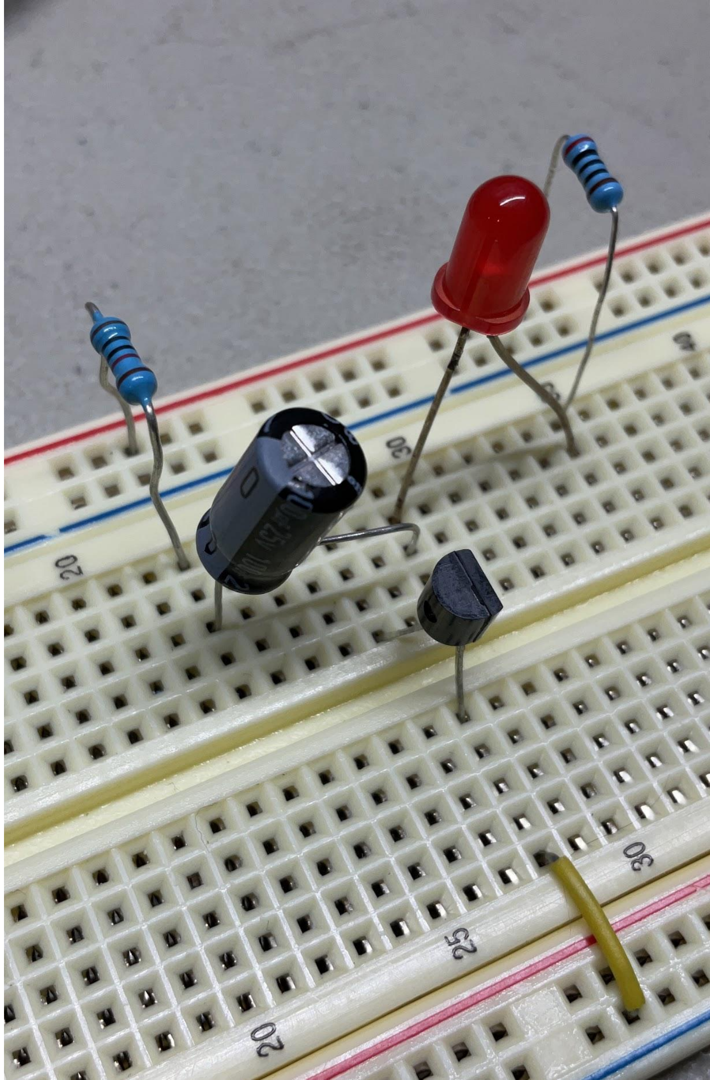
Ping Pong Flashers

- Add an RC timing circuit to your first transistor.
- From Vcc go into a 10K (brown, black, black, red) resistor .
- Then go into the short leg (cathode) of a 100 microFarad capacitor.
- Then the long leg (anode) should go to the collector of the transistor and meet the short leg (cathode) of the LED.



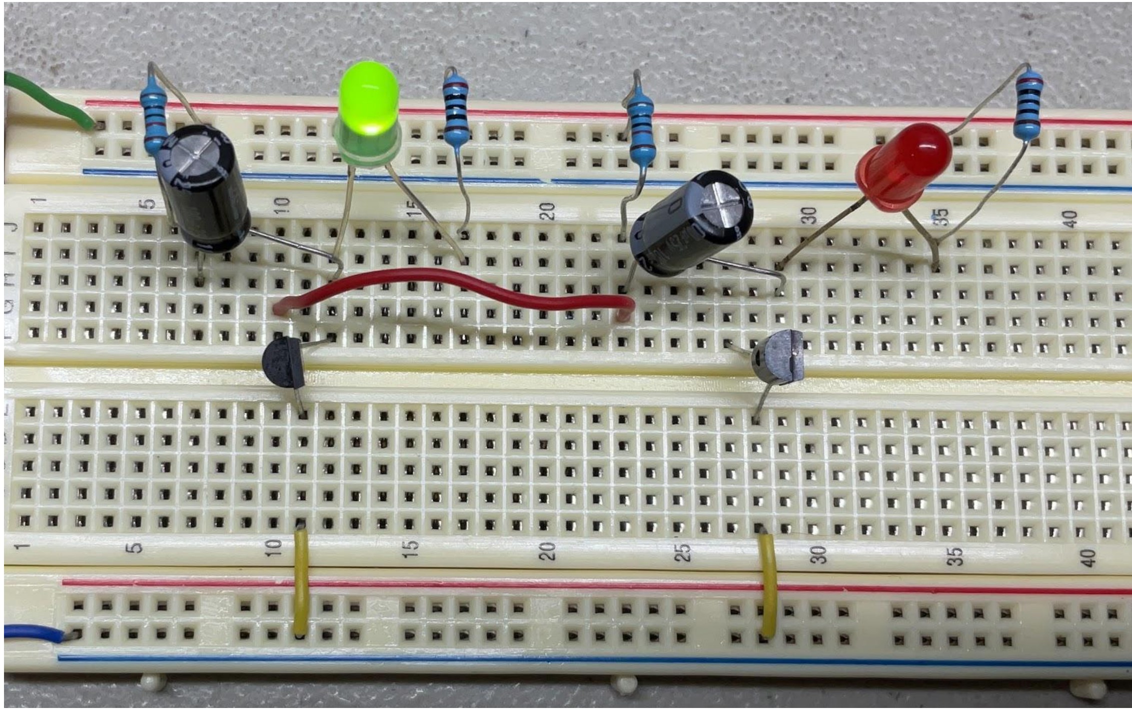
Ping Pong Flashers

- Add an RC timing circuit to the second transistor.
- From Vcc go into a 10K resistor (brown, black, black, red).
- Then go into the short leg (cathode) of a 100 microFarad capacitor.
- Then the long leg (anode) should go to the collector of the transistor and meet the short leg (cathode) of the LED.



Ping Pong Flashers

- The capacitors will charge anytime a transistor turns on as current flows from collector to emitter.
- We need a way to discharge the capacitors now..and we need something to turn the transistors on at the base.
- We can do both by taking the short leg (cathode) of our second capacitor and sending it to the base of our first transistor.
- Now when the second capacitor discharges, it will turn on the first transistor!



Build Together 1: Final Circuit

- When the first transistor turns on, the first capacitor will charge.
- We can discharge the first capacitor and turn on our second transistor by sending the short leg (cathode) of our first capacitor to the base of our second transistor.
- Now when the first capacitor discharges, it will turn on the second transistor!
- **Explore the effect of your RC circuit by swapping out the 100 microFarad and 10K ohm components for other values.**