

# PHYSICAL COMPUTING

**WEEK 04**

# Symbols for Components



Wires crossing – no contact



Junction (wires joined)



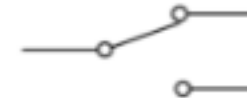
Junction



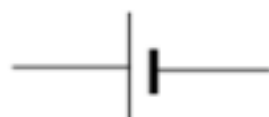
Switch (normally open)



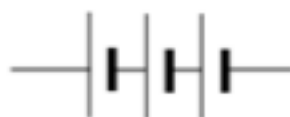
Switch (normally closed)



Two-way switch



Single cell



Battery of three cells



Power supply (DC)



Power supply (AC)



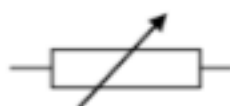
Ammeter



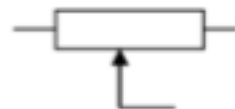
Voltmeter



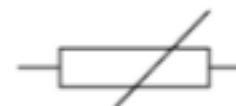
Resistor



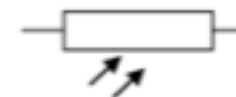
Variable resistor



Variable resistor or potentiometer



Thermistor



Light dependent resistor (LDR)



Fuse



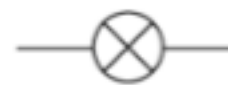
Earth



Diode



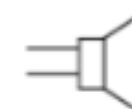
Light-emitting diode (LED)



(Signal) lamp



Filament lamp



Loudspeaker



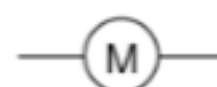
Electric bell



Buzzer



Microphone



Motor



Generator



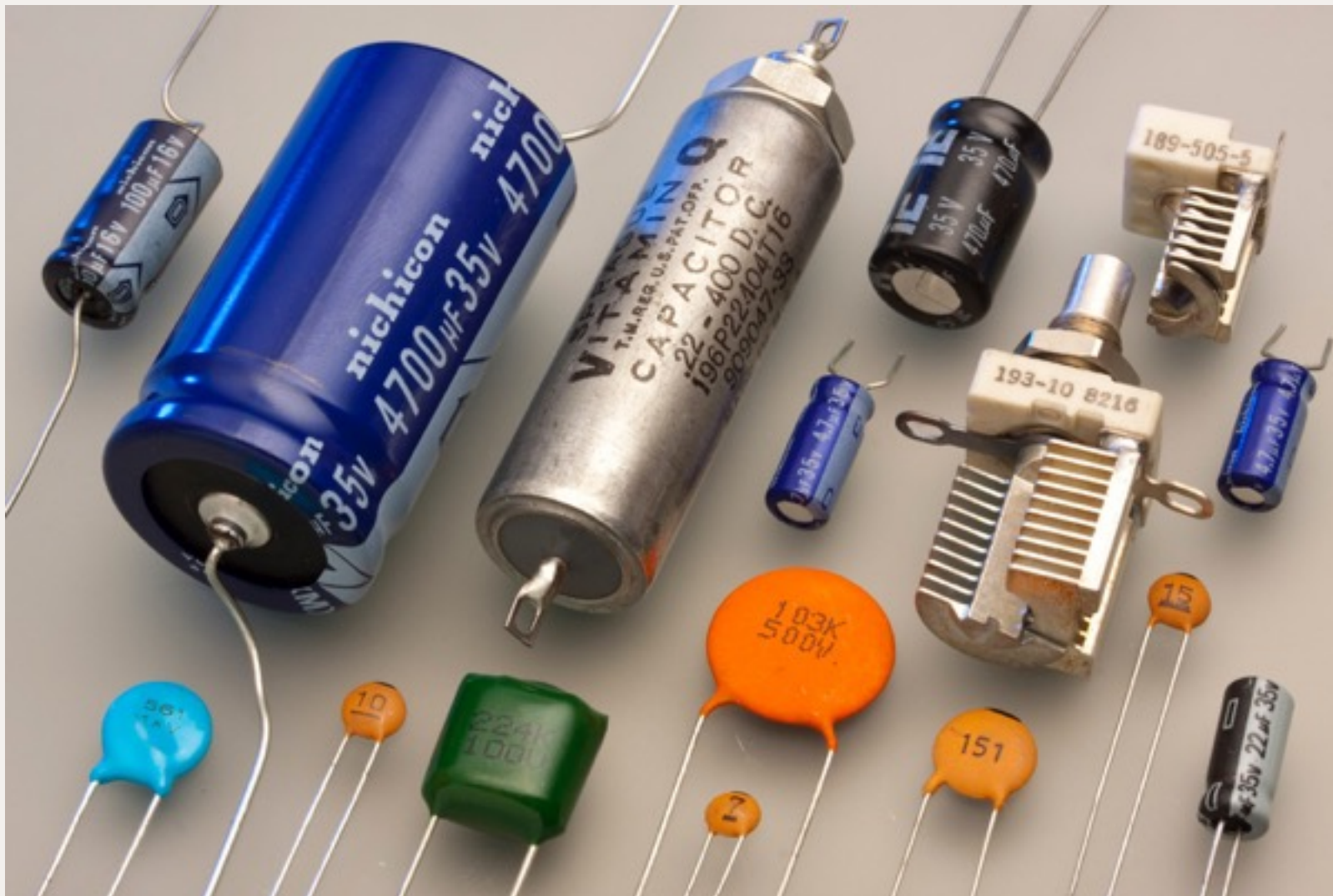
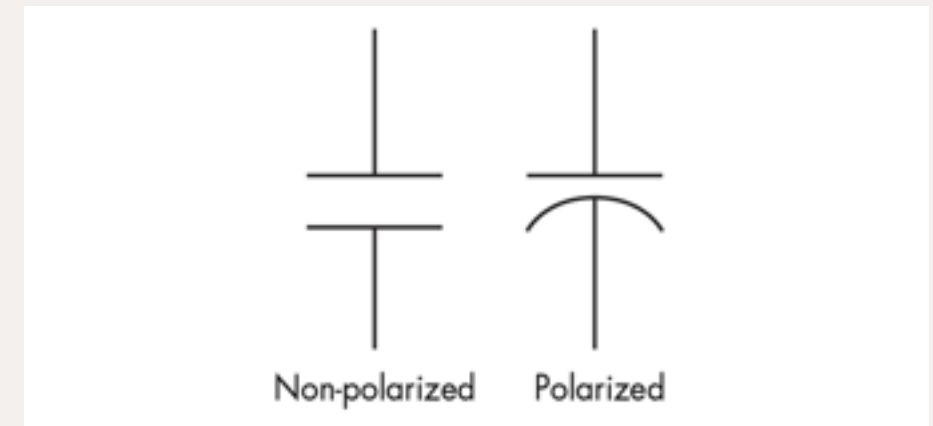
Transformer

# Capacitor

Stores electrical current for a duration

Measured in Farads.

Typical capacitance values range from about 1 pF  
(10<sup>-12</sup> F) to about 1 mF (10<sup>-3</sup> F).



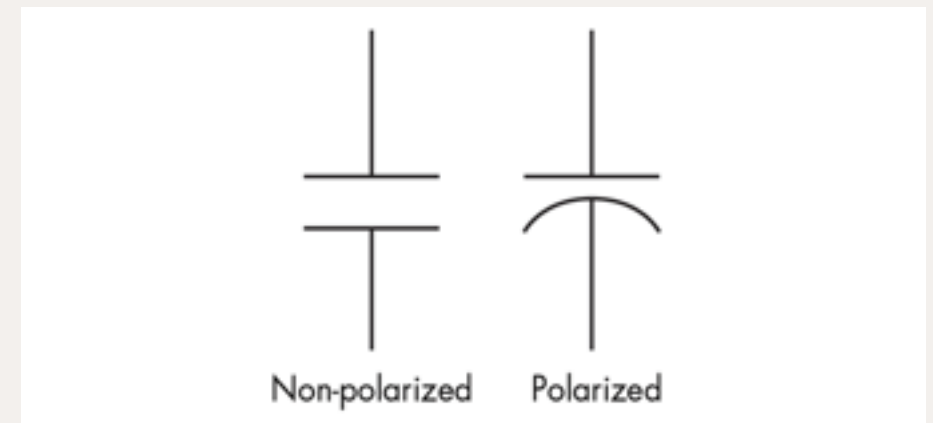
<https://www.youtube.com/watch?v=ZYH9dGl4gUE>

# Capacitor

Has two sides - two “plates” and when enough charge builds up a current flows between them.

Can serve to regulate uneven current flow

This is you, the carpet and your childhood friends.



# Capacitors II

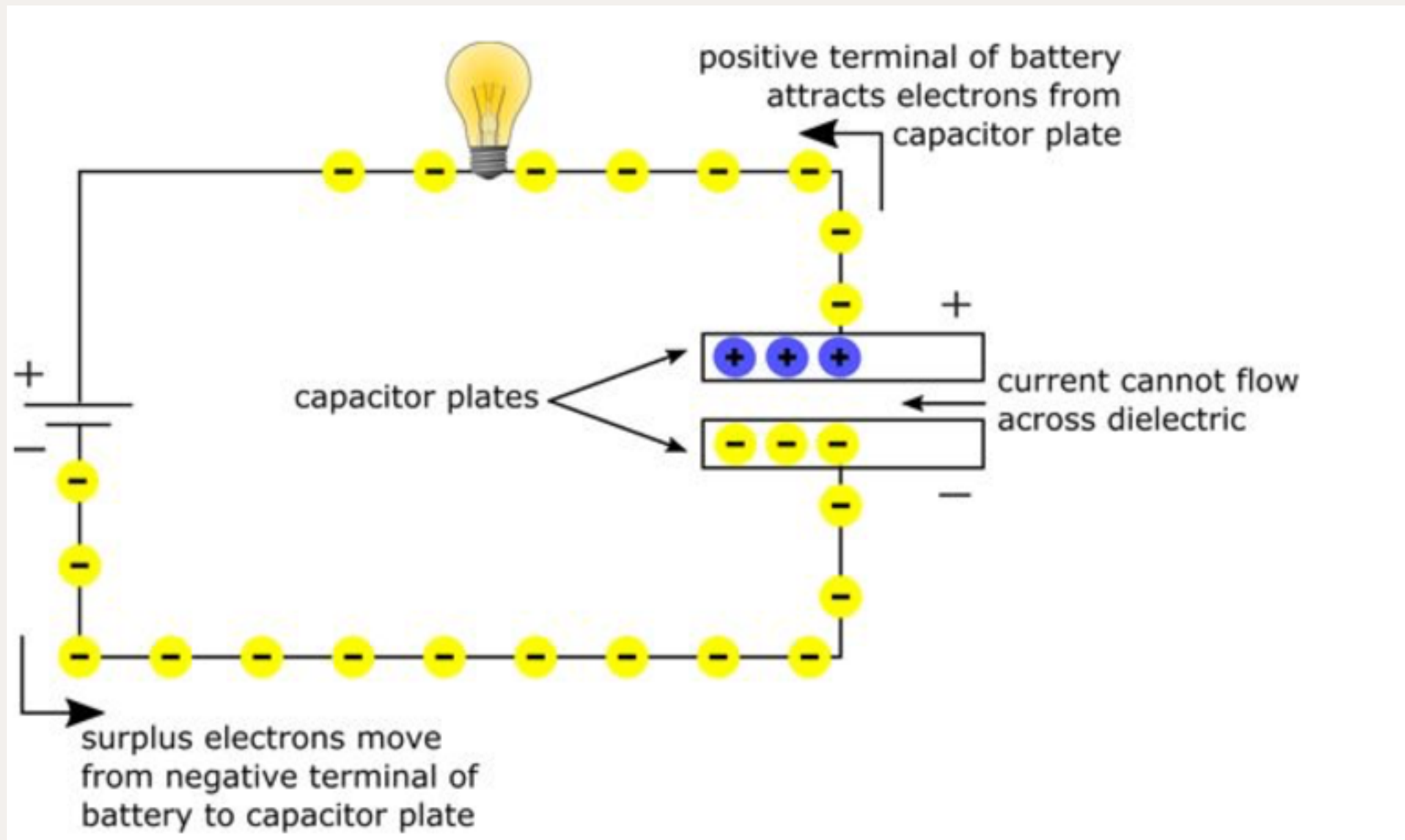
You can get energy from the source like a battery or generator  
Or from a device like a capacitor that stores it

If you remove the voltage and isolate a capacitor, it will hang onto the electrical current inside it

A capacitor is made from two metal plates separated by an insulator, which is known as a ***dielectric***.

When the voltage drop across the plates is equal to the battery voltage, the capacitor is said to be fully charged.

# Capacitors II



# Capacitors II

When the voltage drop across the plates is equal to the battery voltage, the capacitor is said to be fully charged.

The power source keeps pushing electrons onto one plate (and pulling electrons off the other plate) until the voltage drop across the capacitor plates is equal to the battery voltage.

At this equilibrium point, there is no voltage differential between the battery and the capacitor, so there's no push for electrons to flow from the battery to the capacitor. The capacitor stops charging, and electrons stop moving through the circuit.

AKA Capacitors can effectively block DC current



# Capacitors II

Think of a capacitor like a car at a red light. It takes time to slow and time to reach it's original velocity again just like a capacitor.

Common uses

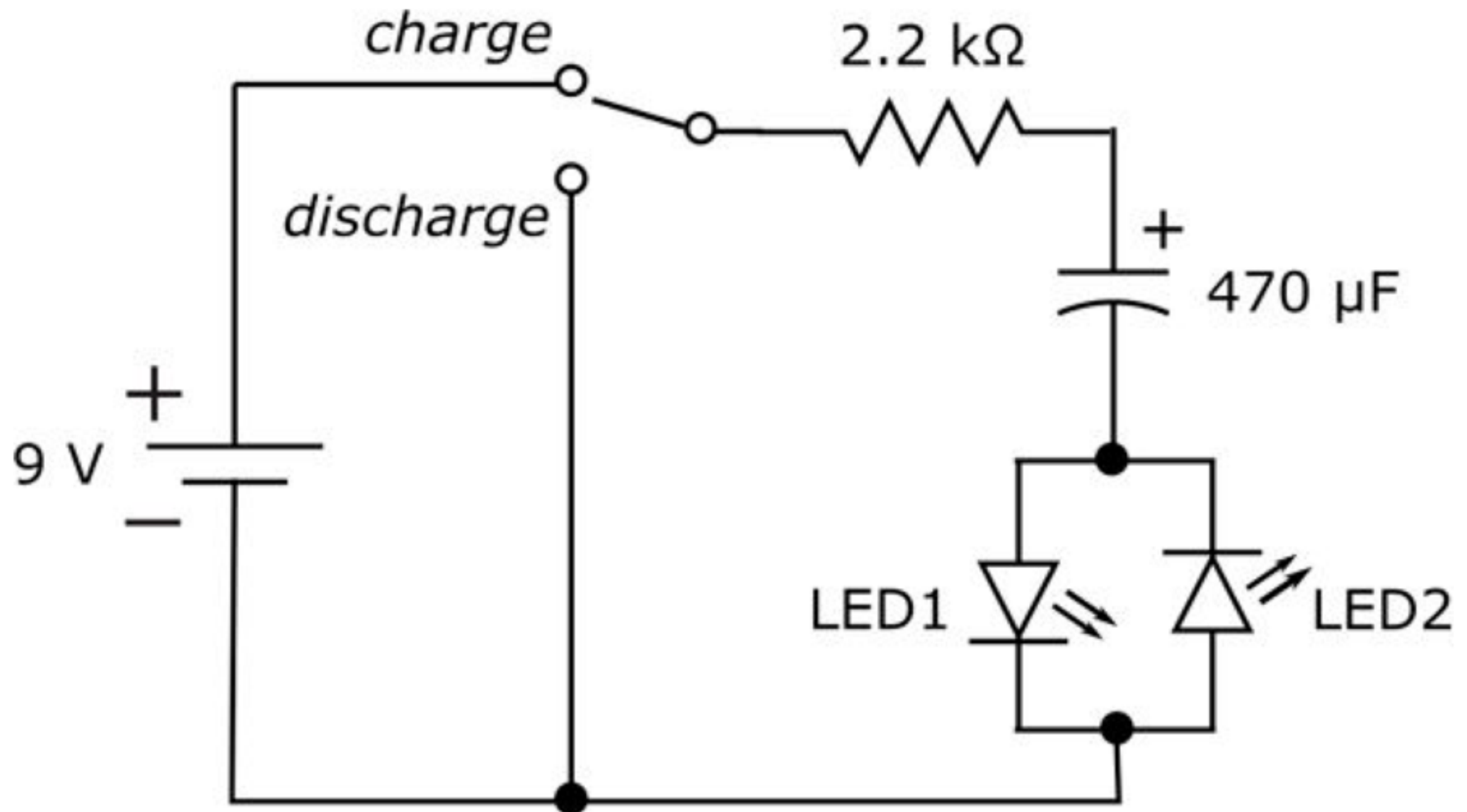
A flash in a camera

A car stereo - if it wasn't for the capacitor every time there was a large base beat the lights would dim because of the voltage change

Capacitors are often used in timing circuits to create ticks and tocks when the voltage rises above or falls below a certain level in a circuit (synths).

Because they filter voltage, they are also used to tune radios

## Simple charging and discharging circuit



# Capacitors and AC

So far in the class we've only worked with DC, such a current from a battery  
However, capacitors are often used to smooth current in AC circuits

***Whereas a capacitor can block current in a DC circuit it can make current level out and pass in an AC circuit***

As the AC source voltage rises from 0 volts to its peak voltage, the capacitor charges

When the AC supply reaches it's max voltage the capacitor might or might not be a peak charge

At some point, when the power supply goes from peak back to 0v the voltage in the capacitor will become less than the capacitor voltage. At this point, the capacitor starts to discharge.

(imagine being in a circuit as an atom)

# Capacitors and AC

The charge is building up on the capacitors plates themselves and not jumping across the dielectric.

The plate that previously held more negative charges now holds positive charges, and the plate that previously held more positive charges now holds more negative charges.

As the source voltage rises from its negative peak, the capacitor again discharges through the AC source, but in the direction opposite to that of its original discharge, and the cycle repeats.

If you add a light bulb to your capacitor circuit powered by an AC voltage source, the bulb will light and will stay lit as long as the AC source is connected.

Although no current ever passes through the capacitor, the charging/ discharging action of the capacitor creates the effect of current flowing back and forth through the circuit.

# Capacitance

**Capacitance** is the capability of a body to store an electric charge. The same term — capacitance — is used to describe just how much charge a capacitor can store on either one of its plates. The higher the capacitance, the more charge the capacitor can store.

Depends on

- \* surface area of metal plates
- \* thickness of the dielectric
- \* the type of material the dielectric is made out of

# Units of measure

Capacitance is measured in units called **farads**. One farad (abbreviated **F**) is defined as the capacitance needed to get one amp of current to flow when the voltage changes at a rate of one volt per second.

Most common are microfarad ( $\mu\text{F}$ ) or picofarad ( $\text{pF}$ ) range.

A microfarad is a millionth of a farad, or 0.000001 farad,

A picofarad is a millionth of a millionth of a farad, or 0.000000000001 farad.

Here are some examples:

A 10  $\mu\text{F}$  capacitor is 10 millionths of a farad.

A 1  $\mu\text{F}$  capacitor is 1 millionth of a farad.

A 100  $\text{pF}$  capacitor is 100 millionths of a millionth of a farad, or you could say it is 100 millionths of a microfarad.

Just like resistors, capacitors have a variance

**Table 7-1 Capacitor Characteristics**

<i>Type</i>	<i>Typical Range</i>	<i>Application</i>
Ceramic	1 pF to 2.2 $\mu$ F	Filtering, bypass
Mica	1 pF to 1 $\mu$ F	Timing, oscillator, precision circuits
Metalized foil	0.01 to 100 $\mu$ F	DC blocking, power supply, filtering
Polyester (Mylar)	0.001 to 100 $\mu$ F	Coupling, bypass
Polypropylene	100 pF to 50 $\mu$ F	Switching power supply
Polystyrene	10 pF to 10 $\mu$ F	Timing, tuning circuits
Tantalum (electrolytic)	0.001 to 1,000 $\mu$ F	Bypass, coupling, DC blocking
Aluminum electrolytic	10 to 220,000 $\mu$ F	Filtering, coupling, bypass, smoothing

# Working voltage

The working voltage, sometimes abbreviated as **WV**, is the highest voltage that the manufacturer recommends placing across a capacitor safely.

***Capacitors designed for DC circuits are typically rated for a WV of no more than 16 V to 35 V.***

If you build circuits that use higher voltages, be sure to select a capacitor that has a WV of at least 10% to 15% more than the supply voltage in your



# Dielectric material application

**Electrolytic capacitors** can handle large currents but perform reliably only for signal frequencies of less than 100 kHz

Commonly used in ***audio amplifiers*** and power supply circuits.

**Mica capacitors**, however, exhibit exceptional frequency characteristics and are ***often used in radio frequency (RF) transmitter circuits***.

You need to match your capacitor to the one suggested in your diagram. The most common dielectric materials are aluminum electrolytic, **tantalum electrolytic**, **ceramic**, **mica**, **polypropylene**, **polyester** (or Mylar), and **polystyrene**.

# Capacitor polarity

Some larger-value electrolytic capacitors (1  $\mu\text{F}$  and up) are ***polarized*** — meaning that the positive terminal must be kept at a higher voltage than the negative terminal, so it matters which way you insert the capacitor into your circuit.

Polarized capacitors are designed for use in DC circuits.

Many polarized capacitors sport a minus (–) sign or a large arrow pointing toward the negative terminal. For radial capacitors, the negative lead is often shorter than the positive lead.

# WATCH!

If you reverse your polarity in a polarized circuit - kiss your components good bye.

The capacitor might even explode





# Reading values

Some capacitors have the values printed on them -

Some use a numbering system, like 103 or 104 (particularly smaller one)

The system is based on **picofarads**, not **microfarads**.

A number using this marking system, such as 103, means 10, followed by three zeros, as in 10,000, for a total of 10,000 picofarads.

For instance, a value of 22 means 22 picofarads. No third digit means no zeros to tag on to the end.

# Reading values

For values over 1,000 picofarads, your parts supplier will most likely list the capacitor in microfarads, even if the markings on it indicate picofarads.

To convert the picofarad value on the capacitor into microfarads, just move the decimal point ***six places to the left***. So a capacitor marked with a 103 has a value of 10,000 pF or 0.01  $\mu\text{F}$ .

Note there are other systems but for the sake of time we're not covering here.

# Varying capacitors

These capacitors allow you to adjust the capacitance to suit your needs

The most common type of variable capacitor is the ***air dielectric***, which is found frequently in the tuning controls of AM radios.

Smaller-variable capacitors are often used in radio receivers and transmitters, and they work in circuits that use quartz crystals to provide an accurate reference signal. The value of such variable capacitors typically falls in the 5 pF to 500 pF range.

These can also be mechanically controlled by moving the plates

There are special diodes that act as a variable capacitor; such devices are known as varactors or varicaps —

# Microphones

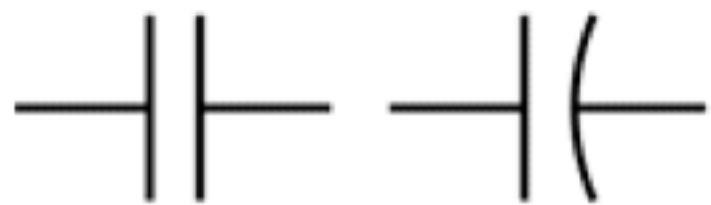
These are very common

They are in all smart phones and touch devices

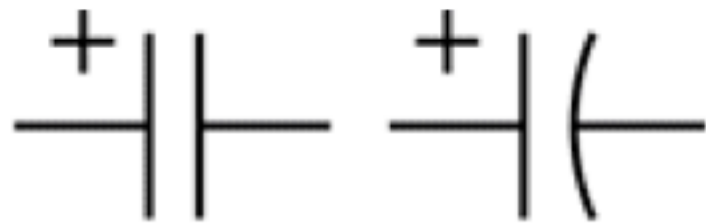
Condensers microphones uses a variable capacitor to convert sound into electrical signals, with the diaphragm of the mic acting as a movable capacitor plate.

Sound fluctuations make the diaphragm vibrate, which varies the capacitance, producing voltage fluctuations.

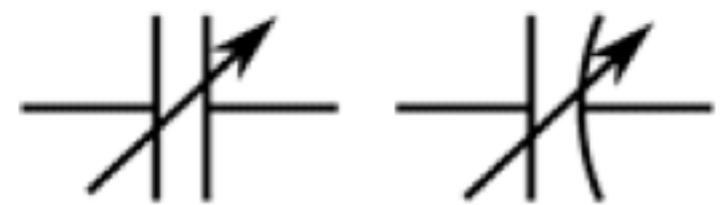
# Capacitor diagrams



nonpolarized  
capacitors



polarized  
capacitors

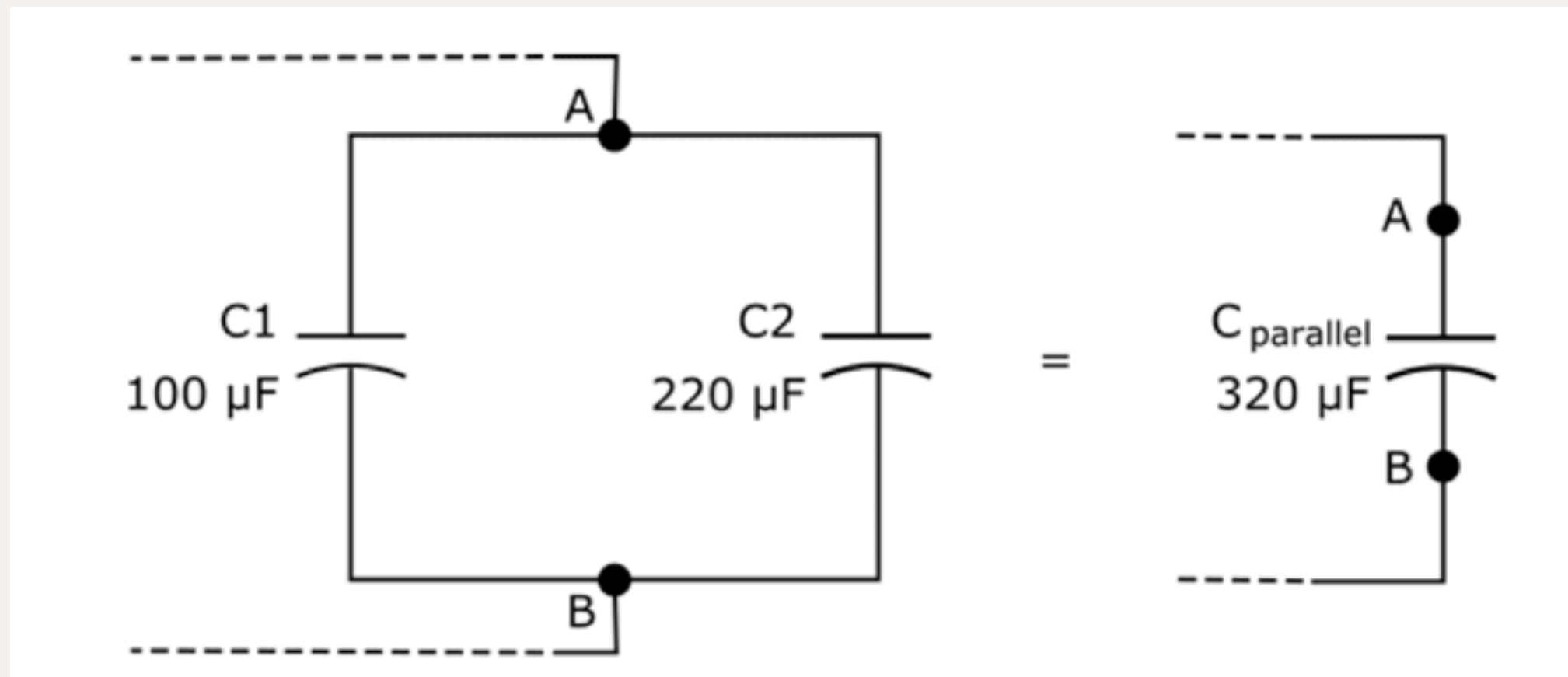


variable  
capacitors



# Capacitor in parallel

$$C_{\text{parallel}} = C_1 + C_2 + C_3 \dots$$



# Capacitor in series

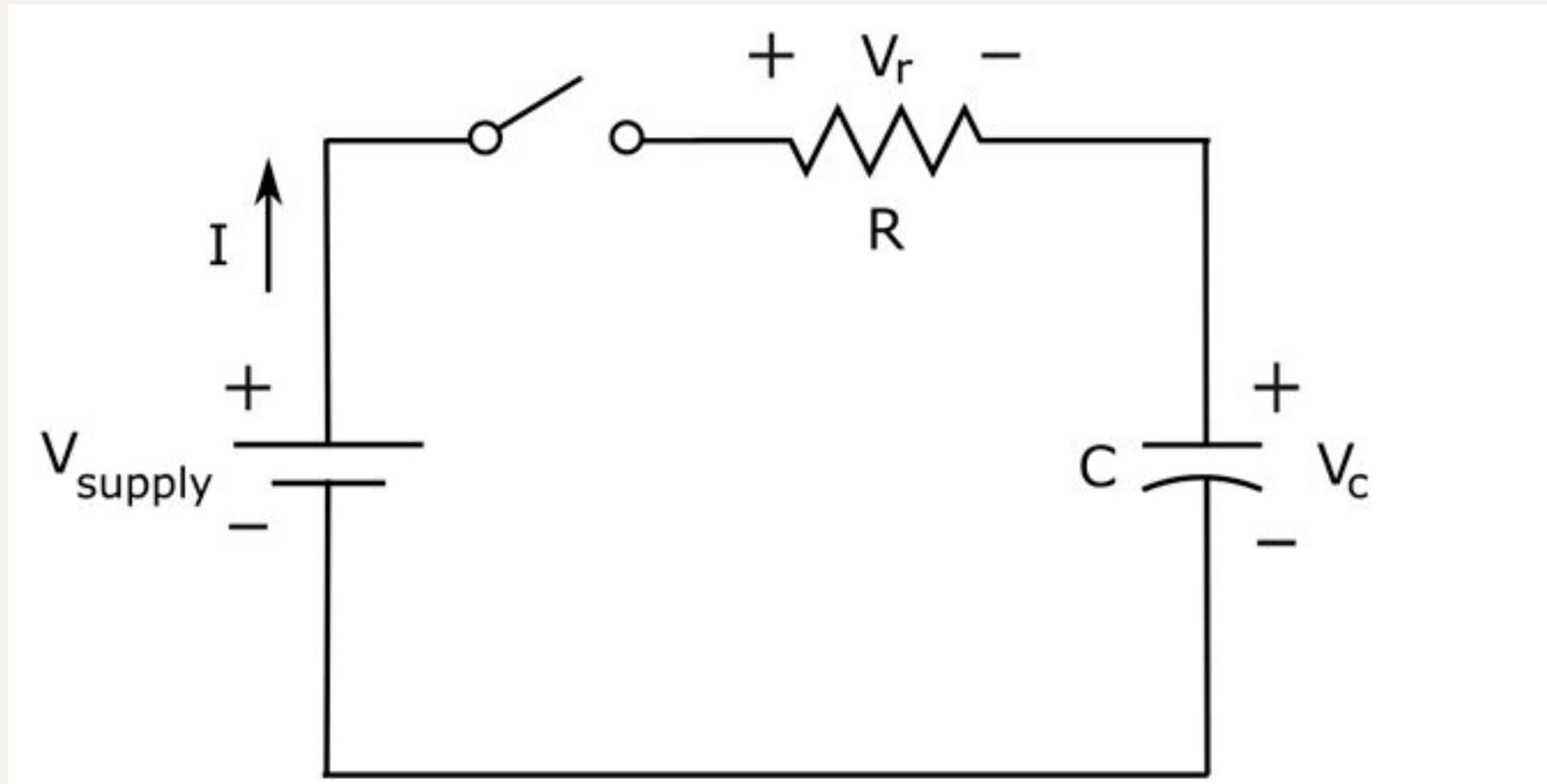
$$C_{\text{series}} = \frac{C_1 \times C_2}{C_1 + C_2}$$

# Teaming up with resistors

This is where the magic happens

Capacitors are often found working hand in hand with resistors in electronic circuits, combining their talent for storing electrical energy with a resistor's control of electron flow.

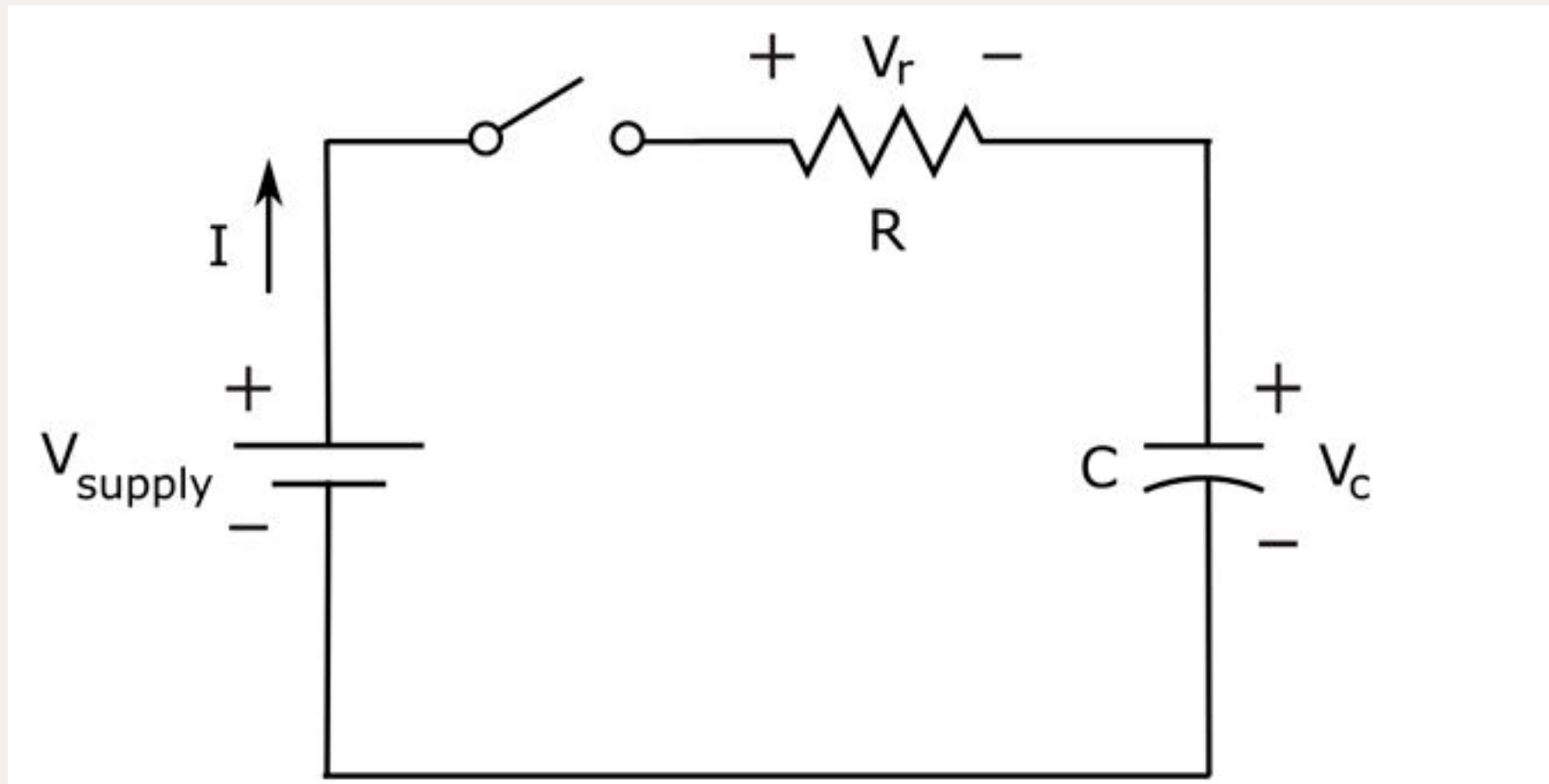
Put these two capabilities together and you can control how fast electrons fill (or charge) a capacitor — and how fast those electrons empty out (or discharge) from a capacitor. This dynamic duo is so popular that circuits containing both resistors and capacitors are known by a handy nickname: ***RC circuits***.



When you close the switch, current starts to flow and charges start to build up on the capacitor plates.

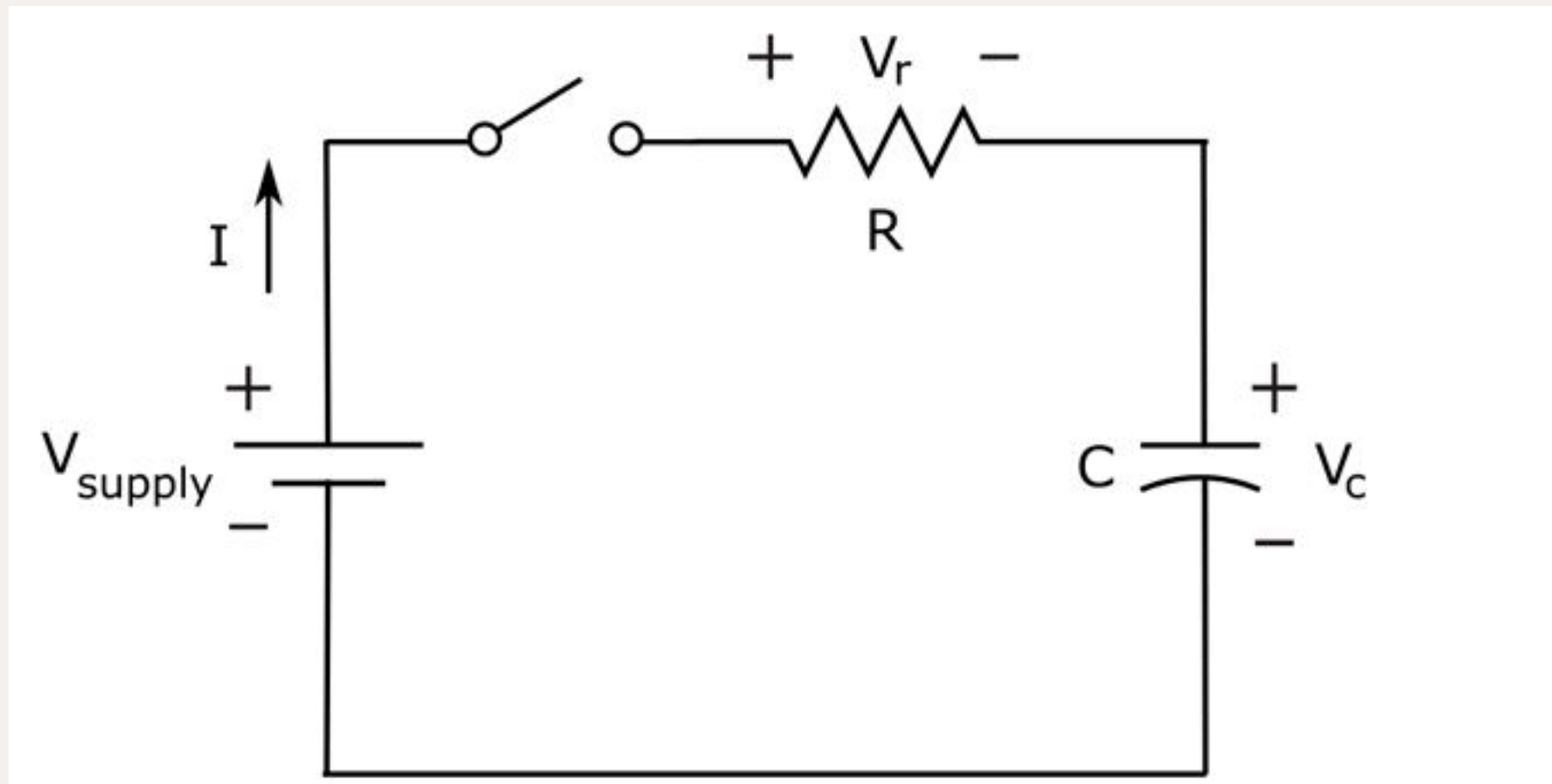
Ohm's Law tells you that the charging current,  $I$ , is determined by the voltage across the resistor,  $V_r$ , and the value of the resistor,  $R$ .

$$I = V_r / R$$



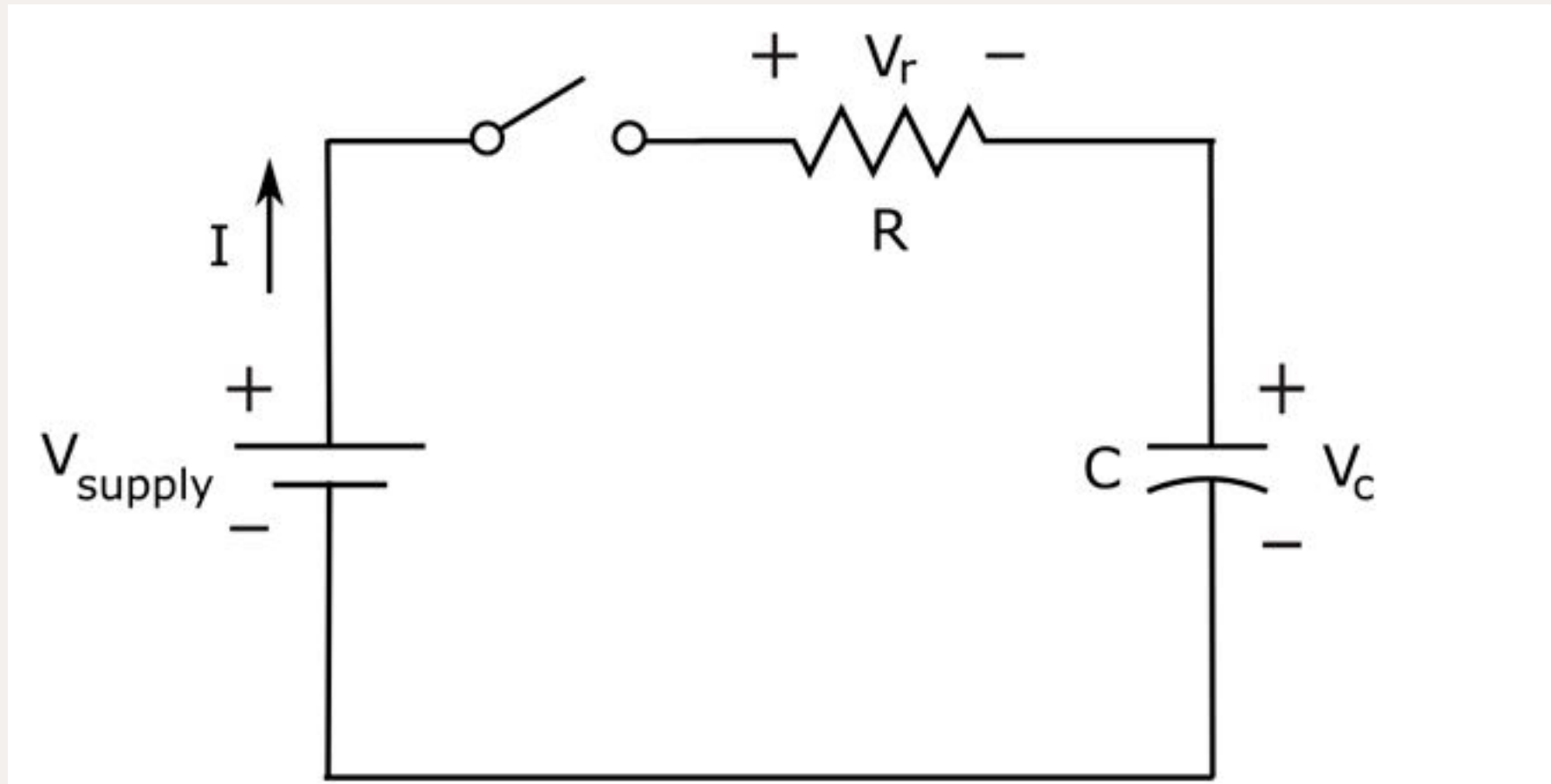
And because the voltage drops equal the voltage rises around the circuit, you know that the resistor voltage is the difference between the supply voltage,  $V_{\text{supply}}$ , and the capacitor voltage,  $V_c$

$$V_r = V_{\text{supply}} - V_c$$



And because the voltage drops equal the voltage rises around the circuit, you know that the resistor voltage is the difference between the supply voltage,  $V_{\text{supply}}$ , and the capacitor voltage,  $V_c$

$$V_r = V_{\text{supply}} - V_c$$



**Initially:** Because the capacitor voltage is initially zero, the resistor voltage is initially equal to the supply voltage.

**Charging:** As the capacitor begins to charge, it develops a voltage, so the resistor voltage begins to fall, which in turn reduces the charging current. The capacitor continues to charge, but at a slower rate because the charging current has decreased. As  $V_c$  continues to increase,  $V_r$  continues to decrease, so the current continues to decrease.

**Fully charged:** When the capacitor is fully charged, current stops flowing, the voltage drop across the resistor is zero, and the voltage drop across the capacitor is equal to the supply voltage.

**How fast the capacitor charges (and discharges) depends on the resistance and capacitance of the RC circuit.**

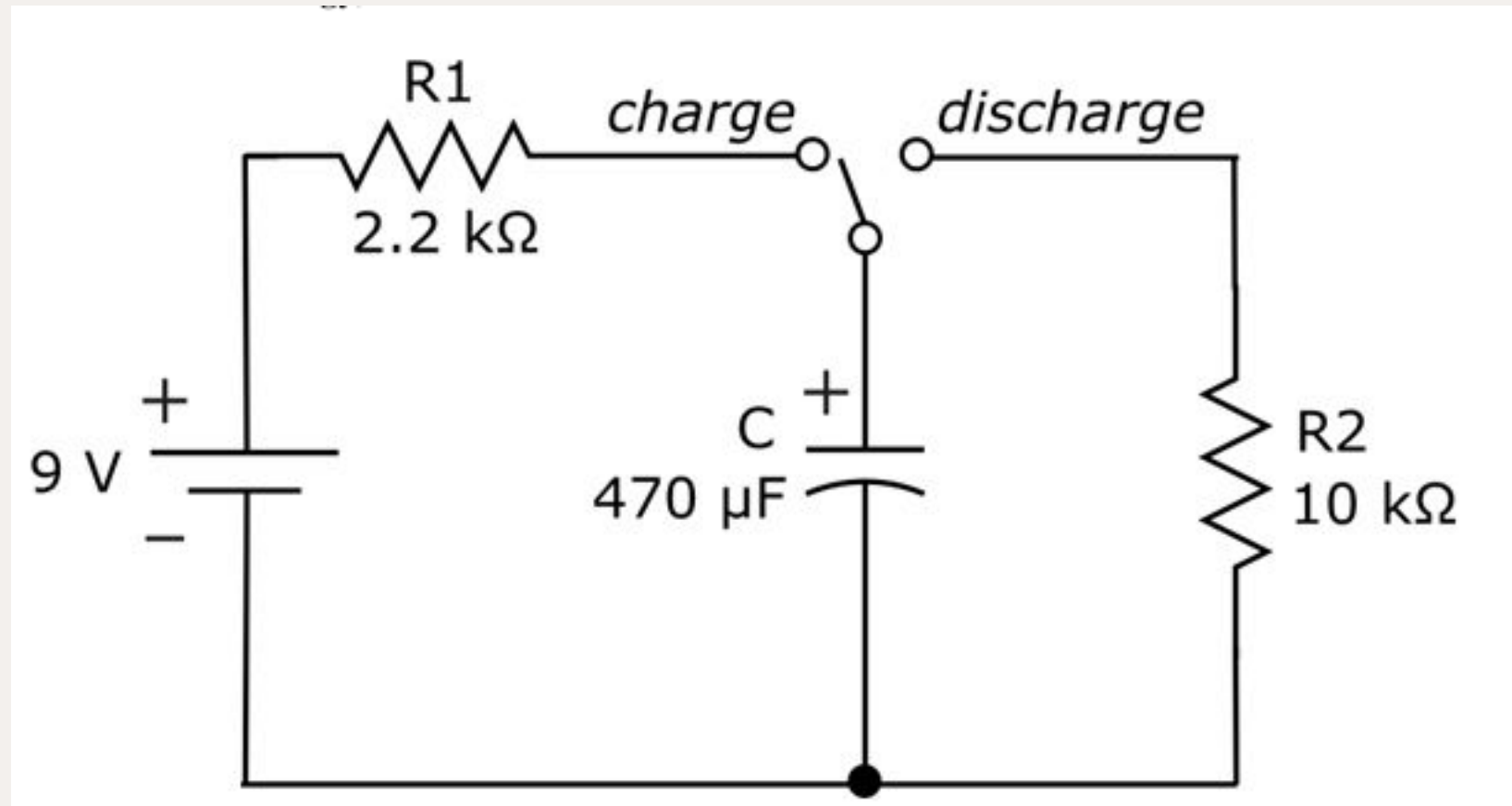
Larger the resistance, the slower it takes the capacitor to charge

A smaller resistance the faster the capacitor charges.



**To calculate the time it takes for the capacitor to charge:**

$$T = R \times C$$

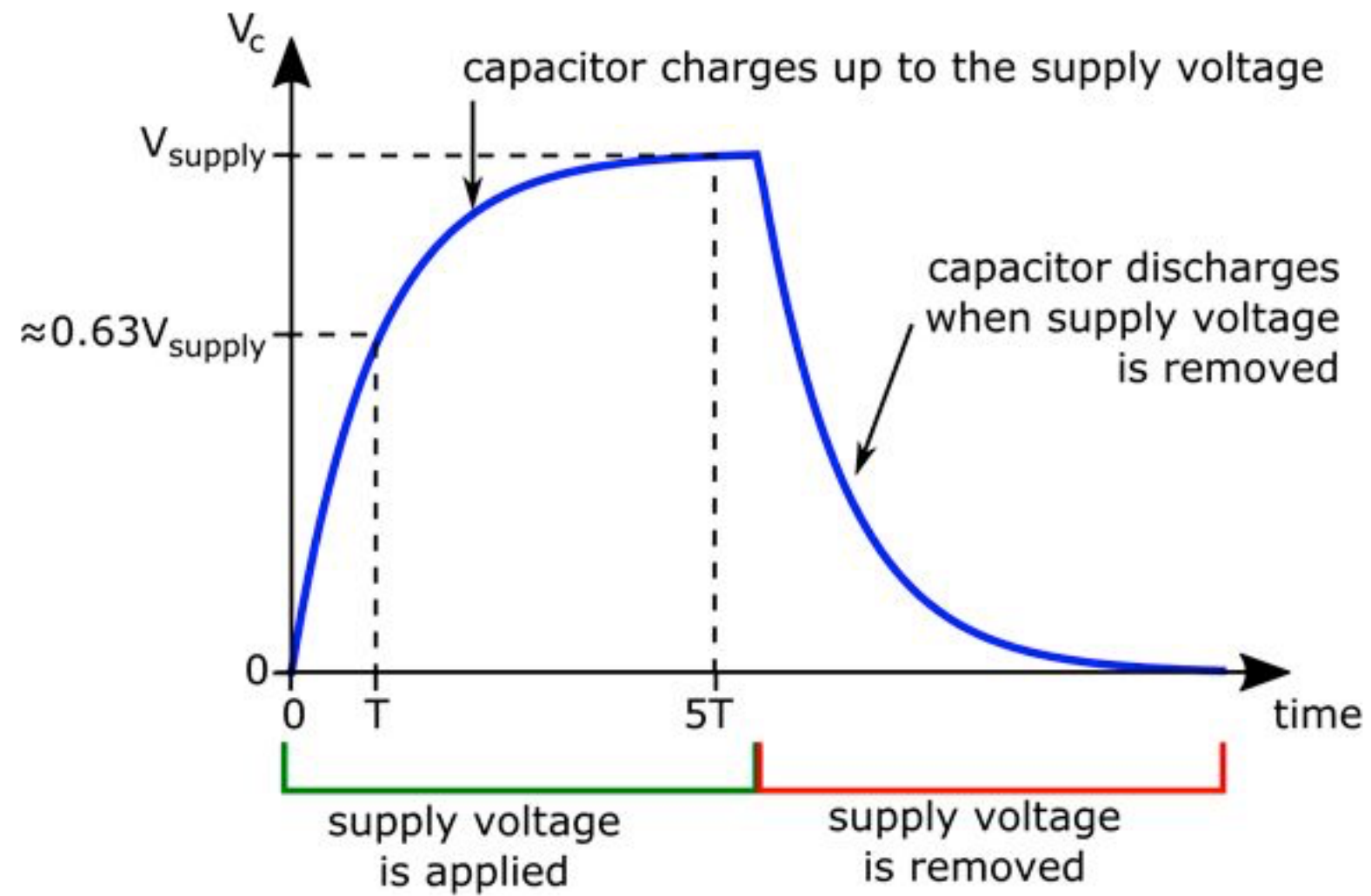


if you replace the power supply with a wire by pressing a button, as in this circuit, it will discharge it's charge!

**Initially:** Because the capacitor is fully charged, its voltage is initially  $V_{\text{supply}}$ . Because , the resistor voltage is initially  $V_{\text{supply}}$ , so the current jumps up immediately to  $V_{\text{supply}} / R$ . This means the capacitor is shuffling charges from one plate to the other pretty quickly.

**Discharging:** As charges begin to flow from one capacitor plate to the other, the capacitor voltage (and so  $V_r$  ) starts to drop, resulting in a lower current. The capacitor continues to discharge, but at a slower rate. As  $V_c$  (and so  $V_r$  ) continues to decrease, so does the current.

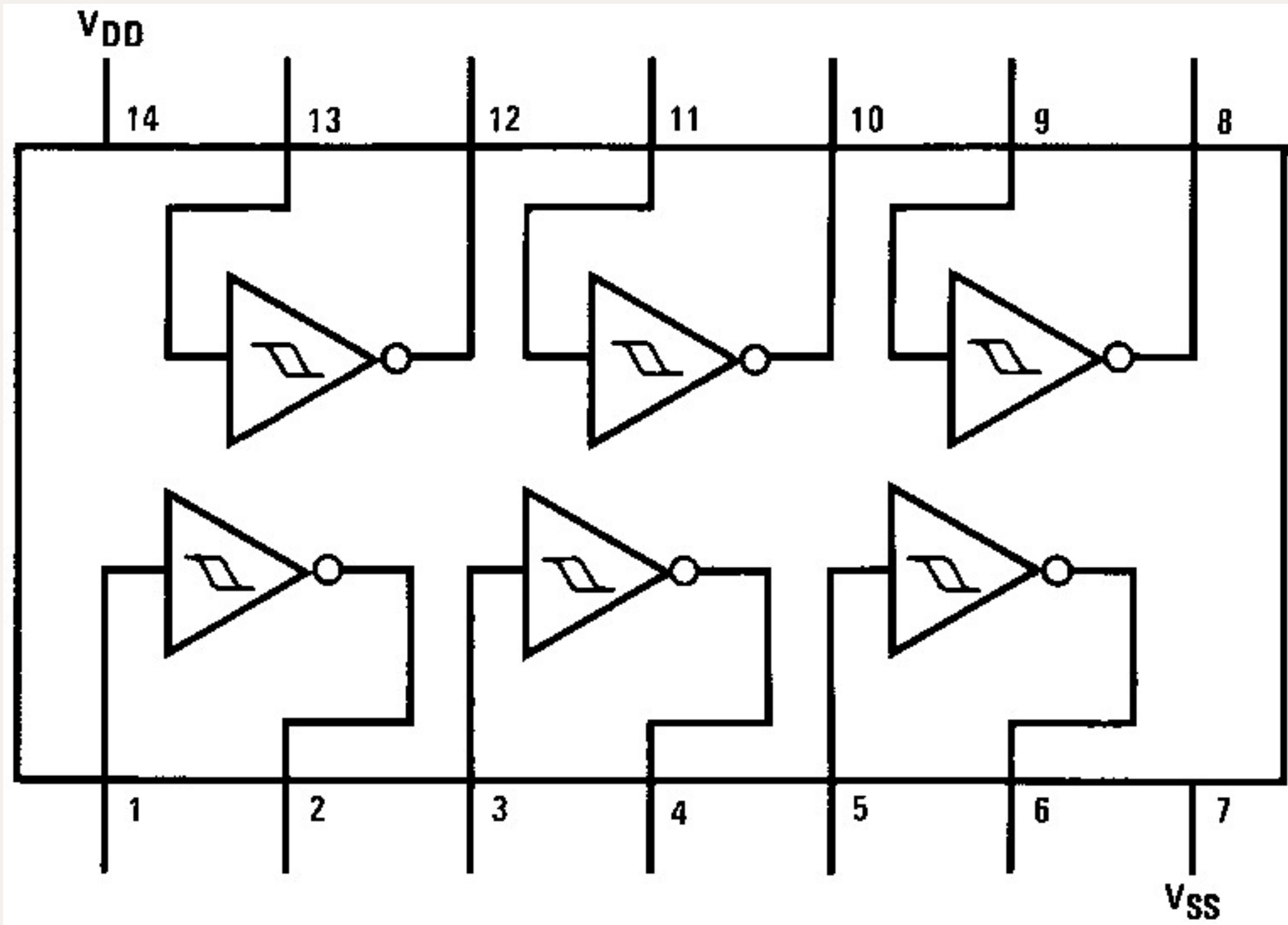
**Fully discharged:** When the capacitor is fully discharged, current stops flowing, and no voltage is dropped across either the resistor or the capacitor.



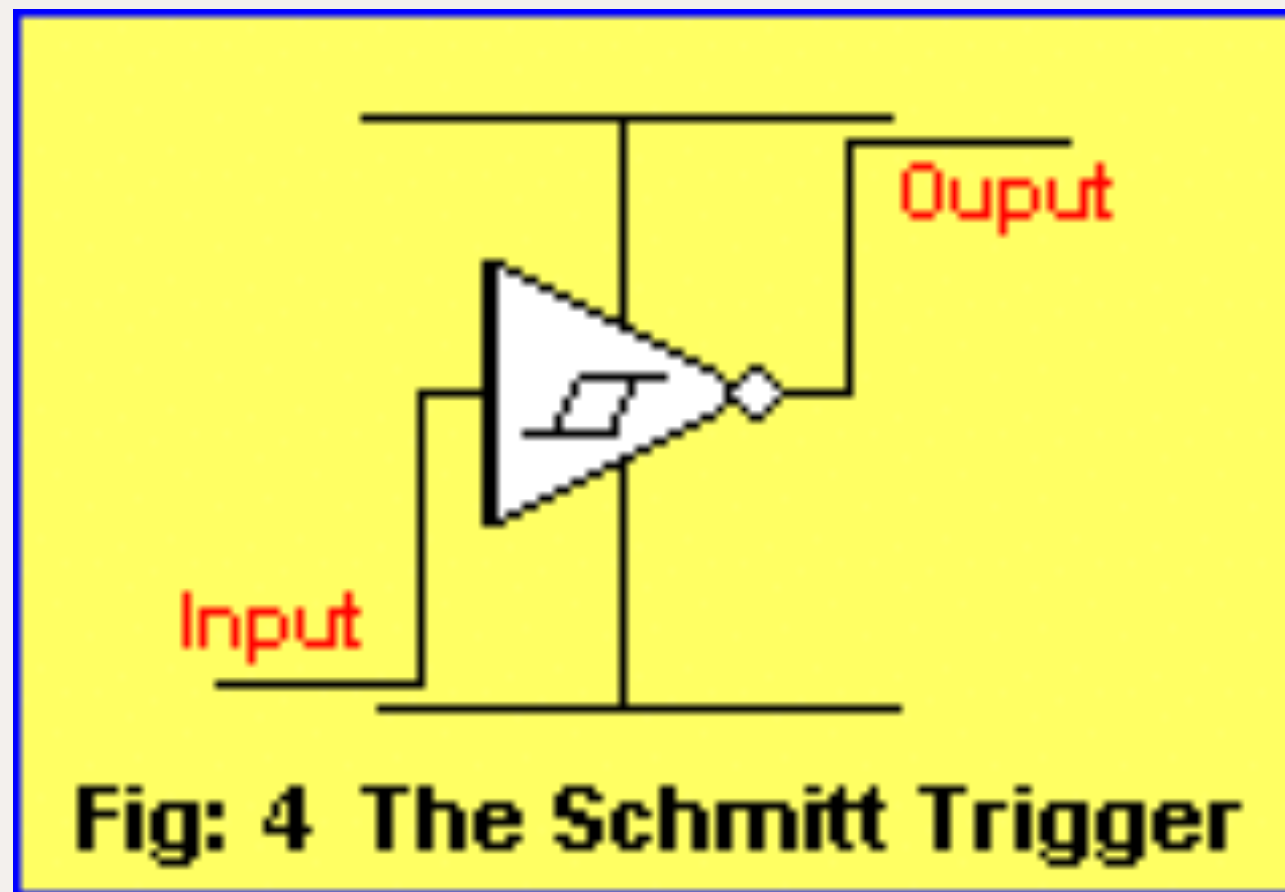
Note: much of the description of this process is covered from Shamieh, Cathleen (2015-07-16). Electronics For Dummies.Wiley. Kindle Edition.

I love this book. I encourage folks to buy it. In fact, you can consider this half of the slide deck slides for her chapter on Capacitors.

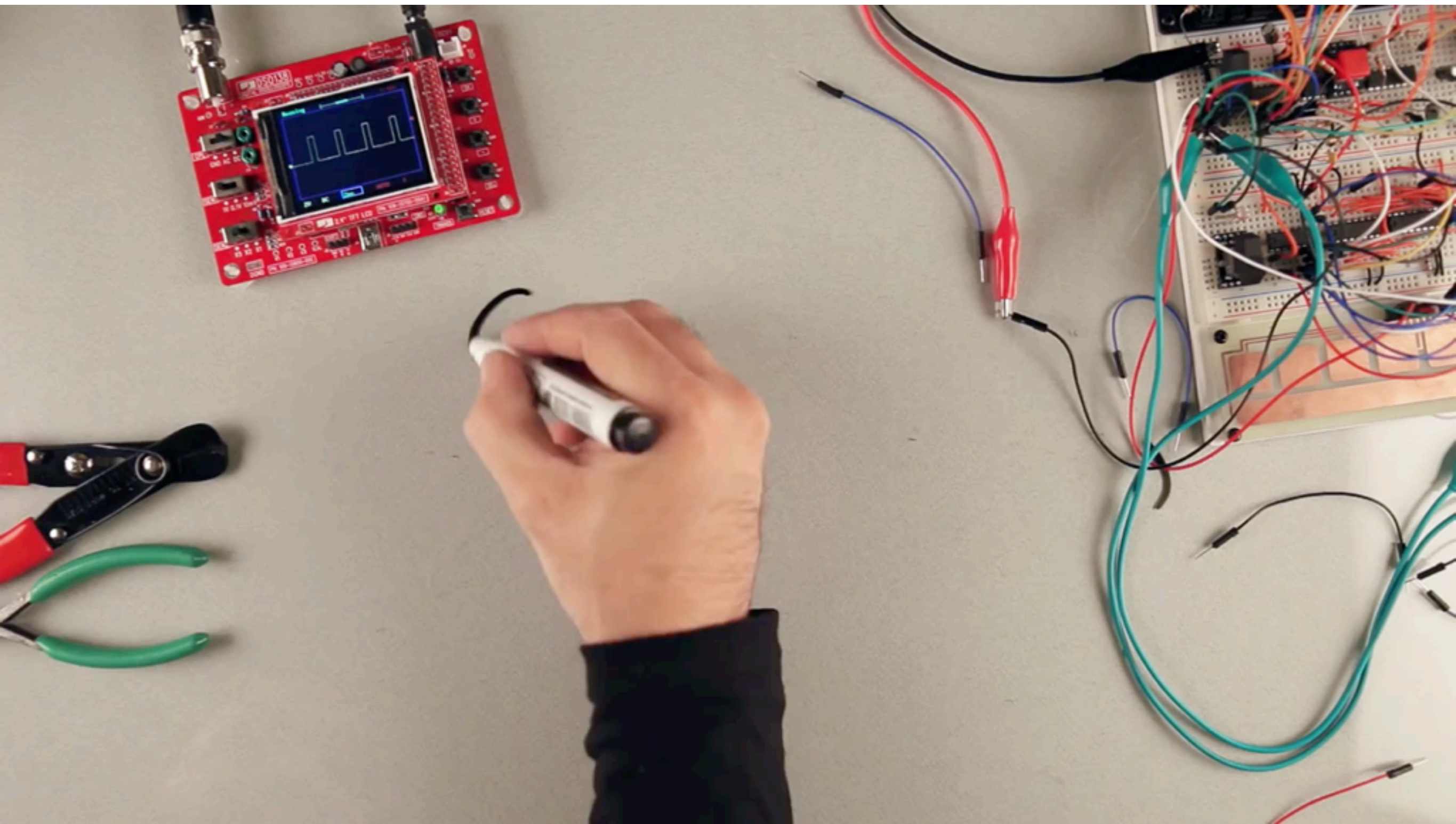
# Hex Schmitt Trigger



# Hex Schmitt Trigger





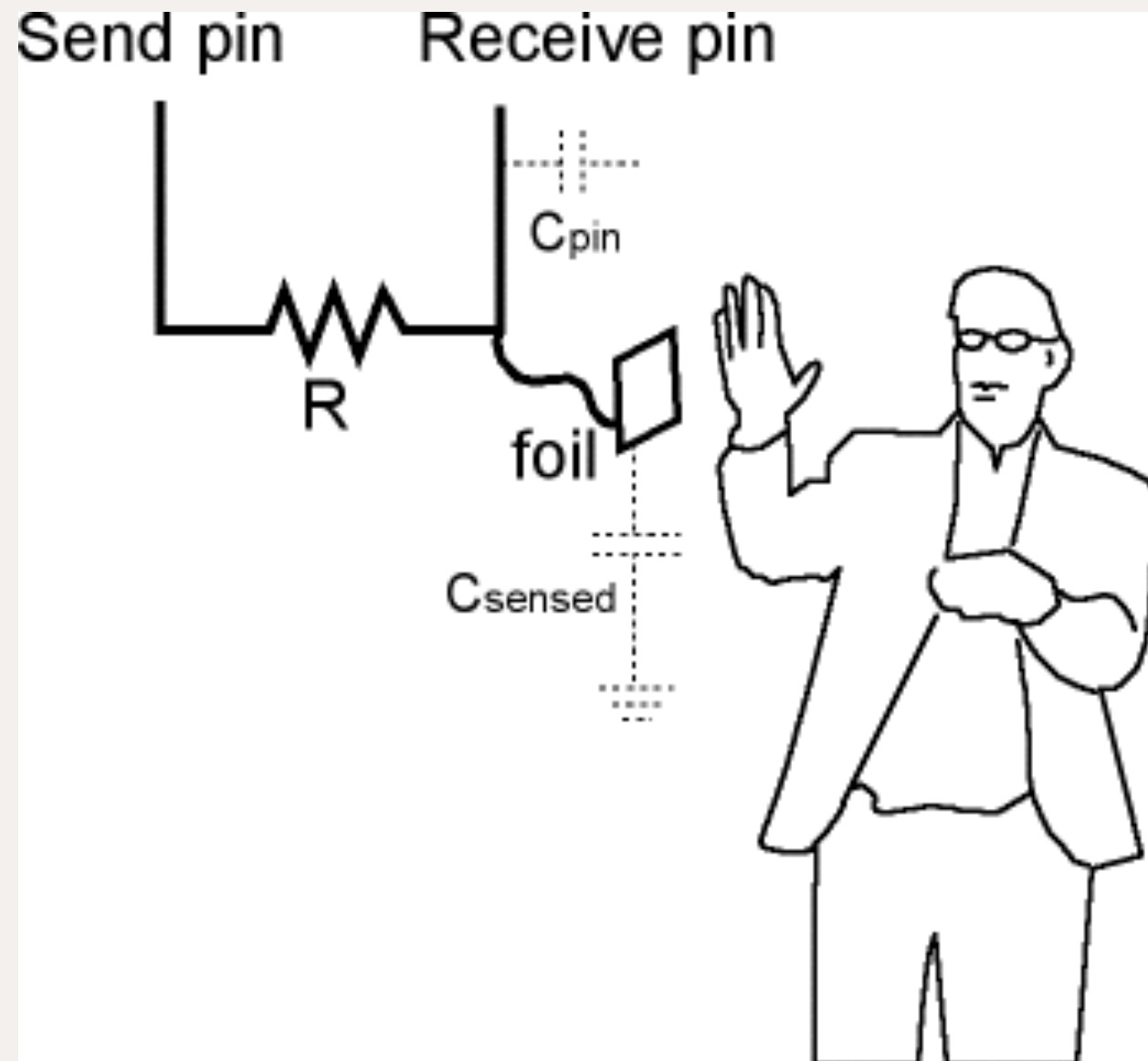


<https://www.youtube.com/watch?v=FaoJaLmZaL4>



# Capsense Library for Capacitive Touch

<http://playground.arduino.cc/Main/CapacitiveSensor?from=Main.CapSense>





[https://www.youtube.com/watch?v=BHQPqQ\\_5ulc](https://www.youtube.com/watch?v=BHQPqQ_5ulc)