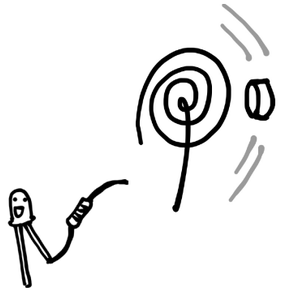
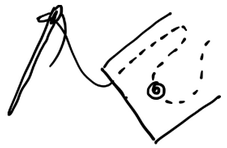
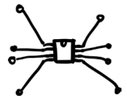


Electronics of Materials

CIID 2019

Paula Te, Hannah Perner-Wilson



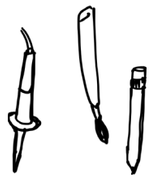


Look around you. What materials have electronic properties? Yes, devices and sensors and wires are electronics, but all materials, even paper, fabric, and biological material can have electronic behavior.

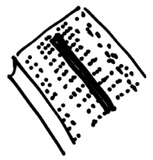
How might we imagine and build electronics differently -- instead of thinking about electronic functionality in terms of discrete components, we learn to control the flow of electricity through different materials?

In this course we learn basic principles of electronics through a lens of material and craft. The materials and craft techniques we learn will shape how we interact with electricity. This is the beginning of a longer journey in the exploration of electronics, and it's important to start by playing, taking things apart, and feeling comfortable going deeper on your own, in this course, or afterwards.

This Electronics of Materials Swatchbook was made to accompany the course and will hopefully be useful to you in the future as a reference, a collection of materials, working samples and ideas.



When we understand electronics at a basic material level, we start to think of electronics as something malleable and craftable, like any other material, and we start to imagine possibilities beyond existing devices and components.



Paula Te

I am a designer and engineer exploring ways to learn and create in the world.

I am curious about the intersection of humans, culture, and education with making, tangible interfaces, and digital fabrication.

www.itshunkydory.com

Hannah Perner-Wilson

My work combines conductive materials and craft techniques to develop new styles of building electronics that emphasize materiality and process. I create working prototypes to demonstrate the kinds of electronic artifacts we might build for ourselves in a world of electronic diversity. A significant part of my work goes into documenting and disseminating my techniques so that they can be applied by others.

www.plusea.at

contents

it is impressive how our views can change when we learn new concepts and skills.
take a moment to capture your feelings and expectations before this course,
and then come back to them and reflect on how you feel after the course is over.

feelings and expectations before the course

feelings and reflections after the course

glossary 1

conductivity

resistance

capacitance

+, positive, plus, VCC

-, negative, minus, GND

potential

power

electrons

electronics

beadboard

variable resistor

component

PCB

electromagnetism

.....

conductivity

resistance

capacitance

+, positive, plus, VCC

-, negative, minus, GND

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.....

glossary 2

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PCB

electromagnetism

.....

toy-piano tear-down

before opening up the toy piano, turn it on and take note of what it can do.
as you take it apart, use this page to document what you see inside

toy-piano components

use this page to illustrate and describe the different elements (components) you discover inside your piano

copper tape
a thin strip of copper backed with adhesive

conductive fabric tape
Nickel, Copper and Cobalt coated nylon ripstop fabric (with anti-fray). source: LessEMF (Ni/Cu/Co tape). surface resistivity: < 0.1 Ohm/sq

nickel and copper ripstop fabric
with a non-conductive hot melt adhesive (activates at 130°C). source: LessEMF (SHIELDIT SUPER)
surface resistivity: < 0.07 Ohm/sq

silver lycra fabric
Silver plated 76% Nylon, 24% elastic fiber, stretch in both directions. source: LessEM
surface resistivity: < 1 Ohm/sq (unstretched)

copper spun with nylon thread
source: Karl-Grimm

silver plated nylon thread
2ply or 4ply. source: Statex

single core “hook-up” wire
good for bread-boarding

multi-stranded wire
good for flexible connections

enameled wire
also known as magnet wire

carbon paint
nontoxic, water based, water soluble, electrically conductive paint
source: bare conductive

Velostat
packaging material made of a polymeric foil impregnated with carbon black to make it electrically conductive. source: 3M

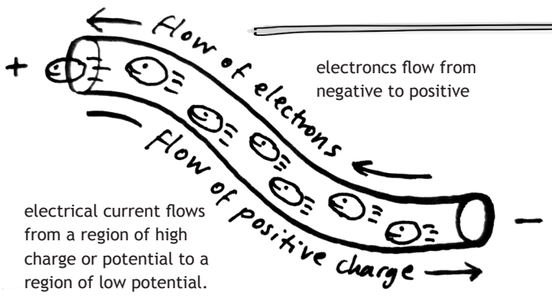
Eeontex NW170-PI-20
conductive nonwoven microfiber fabric
source: Sparkfun, Eeonyx
surface resistivity: 8 Ohm/sq - 105 Ohm/sq

pure stainless steel thread
source: Sparkfun. resistance (Ω/m) : 27

stainless steel + wool fiber
a blend of 82% wool and 18% Bekinox® stainless steel fibers
source: Bekaert (Bekinox W12/18)

Nichrome (NiCr/nickel-chrome) wire
“resistance wire”
is any of various alloys of nickel, chromium, and often iron

electricity

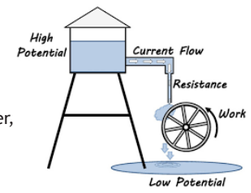


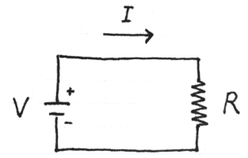
electroncs flow from negative to positive

electrical current flows from a region of high charge or potential to a region of low potential.

Water Analogy

If we compare electricity to water flowing through a pipe, then:
Voltage is the water pressure,
Current is the stream of flow of water,
Resistance is the valve.





Ohm’s Law

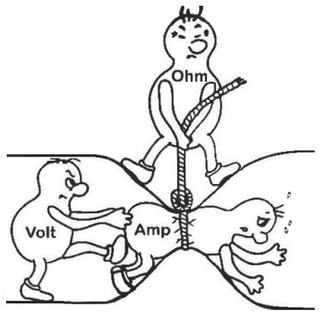
$V = I \times R$

A potential difference of 1V will force a current of 1A through a resistance of 1Ω

Voltage (V) - is electrical pressure or force. Sometimes referred to as potential. Voltage drop is the difference in voltage between the two ends of a conductor through which current is flowing.

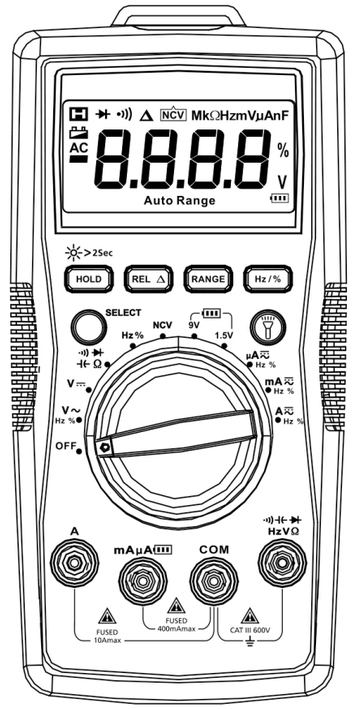
Current (I) - is the quantity of electronics passing a given point. The unit of current is Ampere.
1 Amp = 6,280,000,000,000,000,000 electronics passing a point in one second.

Resistance (R) - conductors are not perfect, they resist the flow of current to some degree. the unit of resistance is the Ohm (Ω).



multimeter

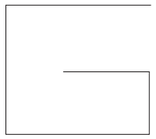
a multimeter or a multitester, also known as a VOM (volt-ohm-milliammeter), is an electronic measuring instrument that combines several measurement functions in one unit.
a typical multimeter can measure voltage, current, and resistance.



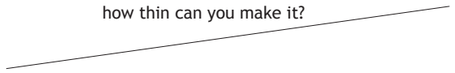
Switch Position		Measurement Function
V⎓		AC or DC voltage measurement (use SELECT button for switching to AC or DC).
Ω		Resistance measurement
⊣◂		Voltage measurement of diode PN junction
•))		Continuity measurement
⊣⊢		Capacitance measurement
Hz		Frequency measurement
%		Duty cycle
NCV		Non-contact voltage
▭	9V	For measurement of dry batteries of not exceeding 15Vdc
	1.5V	For measurement of dry batteries of not exceeding 2Vdc
μA⎓ mA⎓ A⎓		AC or DC current measurement (use SELECT button for switching to AC or DC).

SWATCH: conductive traces

samples of:
copper tape
conductive fabric tape



how square can you get?



how thin can you make it?

how small?

how curvy?

how long?

(measure and note the resistance of each of your samples)

SWATCH: conductive connections

samples of conductive materials making electrical connectinos with eachother

copper tape — solder — copper tape _____Ohm

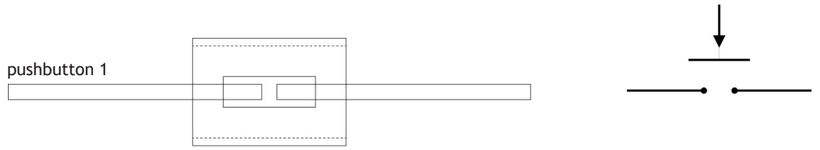
copper tape — overlap — conductive fabric tape _____Ohm

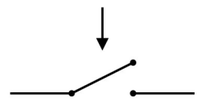
copper tape — solder — wire _____Ohm

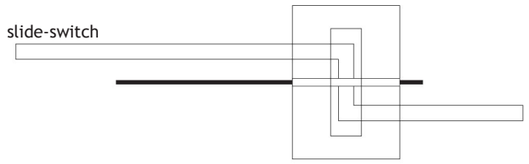
copper tape — overlap :-(— carbon paint _____Ohm

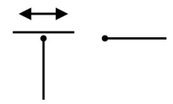
conductive fabric tape — overlap :-) — carbon paint _____Ohm

SWATCH: paper push-buttons and slide-switch







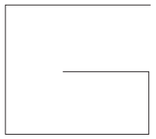


SWATCH: your own contact switch design(s)

how many mechanisms can you build that close a contact when you interact with them
from just paper and conductive tape?

SWATCH: painting with carbon paint

samples of:
carbon paint



how square can you get?

how thin can you make it?

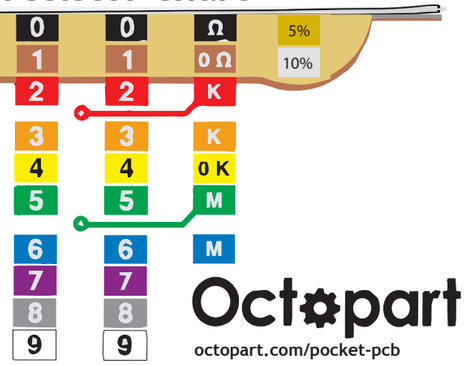
how small?

how curvy?

how long?

(measure and note the resistance of each of your samples)

resistor chart



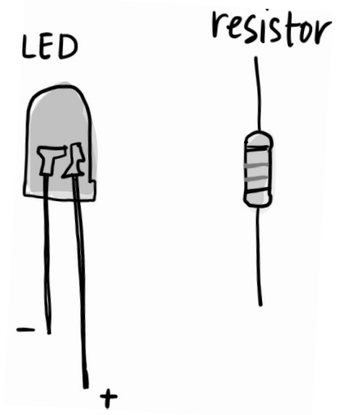
Octopart
octopart.com/pocket-pcb

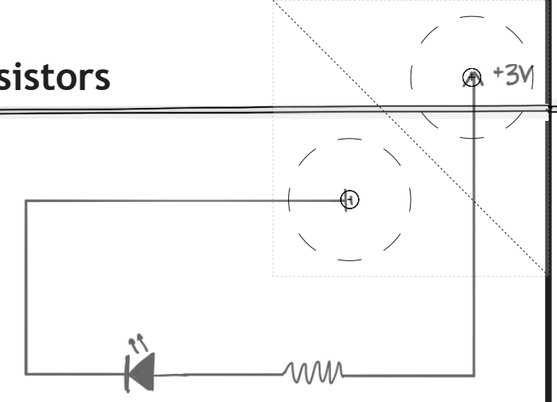
LEDs and their resistors

a light-emitting diode (LED) is a semiconductor light source that emits light when current flows through it.

an LED will draw as much current as you provide them with, and if this is too much then they will E X P L O D E ! (just kidding)

in order to limit the amount of current in the circuit you can add resistance in the form of a resistor. to calculate the relationship betweteen current, resistance and voltage we can use Ohm's Law.





LED wants 20mA @2V ↖ check specs R_{res} = ?

$V = IR$ $V_{LED} + V_{res} = V_{bat}$

$R = \frac{V}{I}$

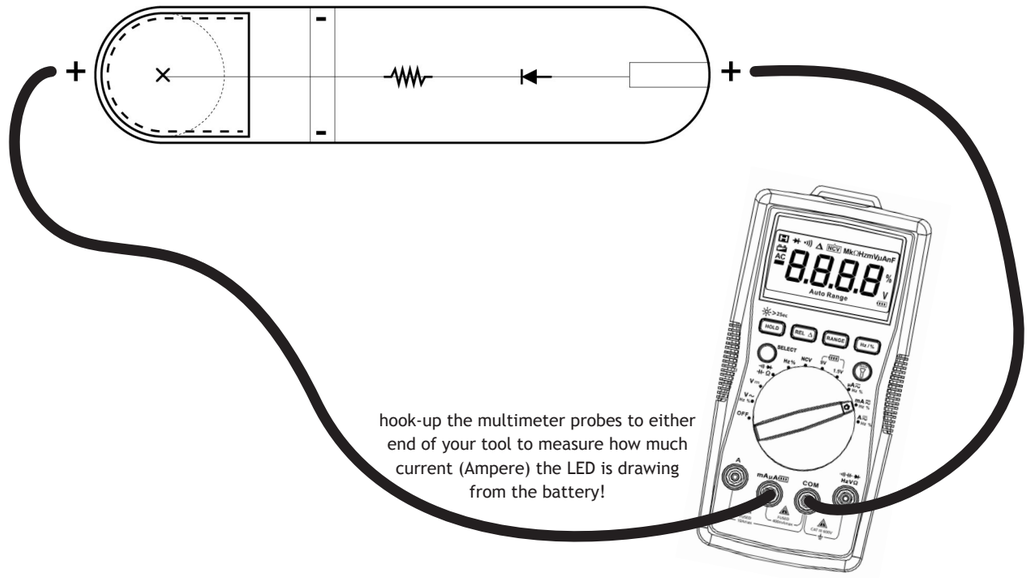
$R_{res} = \frac{V_{bat} - V_{LED}}{I}$

R_{res} = _____Ω

continuity tester tool

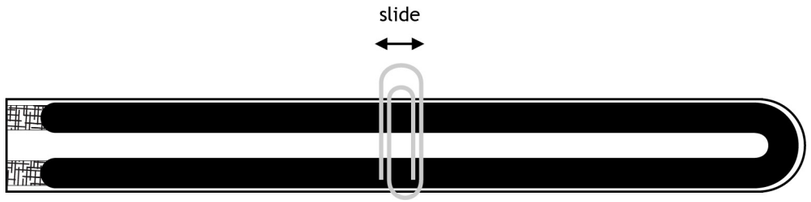
a simple LED circuit powered by a coin-cell battery and mounted on a strip of felt.
the circuit is interrupted and can be closed by touching both ends together. attach alligator clips to either end to turn the circuit into a continuity-probing tool.

if the LED lights up then you know the material between the two ends is conductive.
if the LED light is dim, then the material has some resistance.



SWATCH: paper slider potentiometer

made by painting a "resistive track" with carbon paint between two tabs of conductive fabric tape and then using a metal paperclip as a "conductive slider" to shorten the distance of the resistive track.

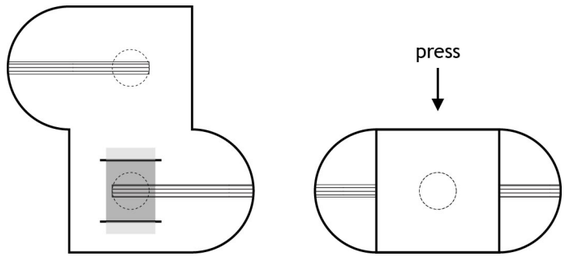


min: _____Ohm

max: _____Ohm

SWATCH: paper pressure sensor

made by sandwiching a piece of Velostat between two conductors.
when the layers are pressured together the resistance through the Velostat decreases and becomes more conductive, this is known as the piezoresistive effect.



min: _____Ohm

max: _____Ohm

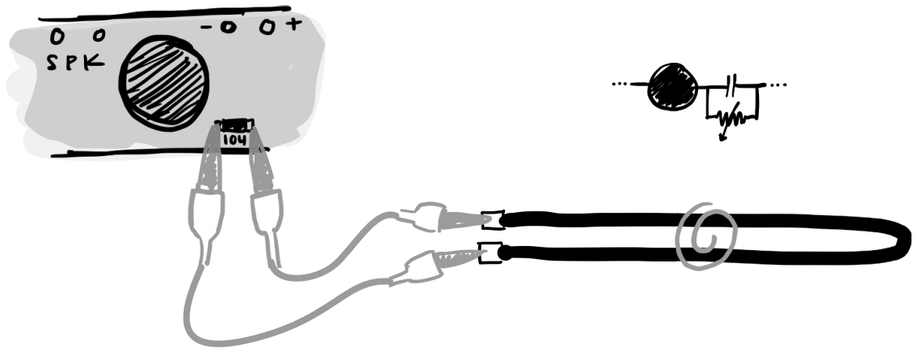
circuit bending

the integrated circuit (IC) underneath the black epoxy blob runs off a clock that determines its speed.
the faster the clock runs, the quicker & higher the sounds; the slower the clock, the slower & lower the sounds.

There are 2 components that control the speed of the clock:
a resistor and a capacitor

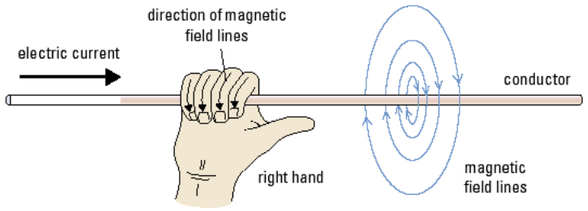
mount a resistor in parallel with the clock capacitor:
use alligator clips to connect to either side of the capacitor
and then connect to one of your resistive sensors.

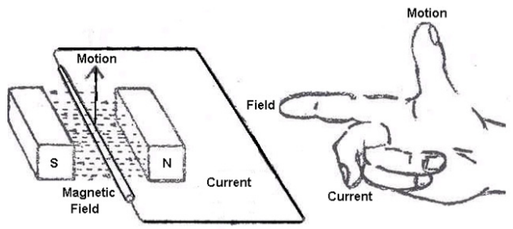
play a melody, and then bend your circuit by varying the resistance of your sensor!



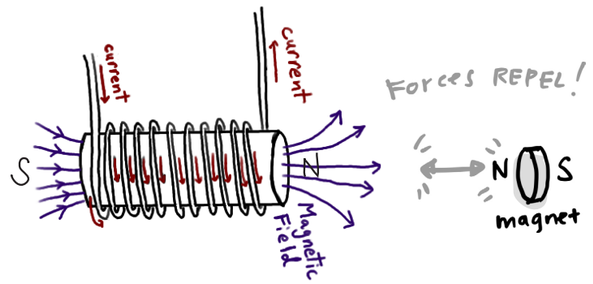
electromagnetism

A current flowing through a wire creates a magnetic field around the wire. This is called electromagnetism.
The magnetic field disappears when the current is turned off.
You cannot see the field, but you can observe its effect.





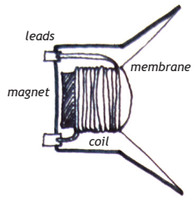
Electromagnets usually consist of insulated wire wound into a coil because this allows you to increase the strength of the magnetic field. The more turns in your coil, the stronger the electromagnetic field. The electromagnetic field is concentrated in the hole in the center of the coil.

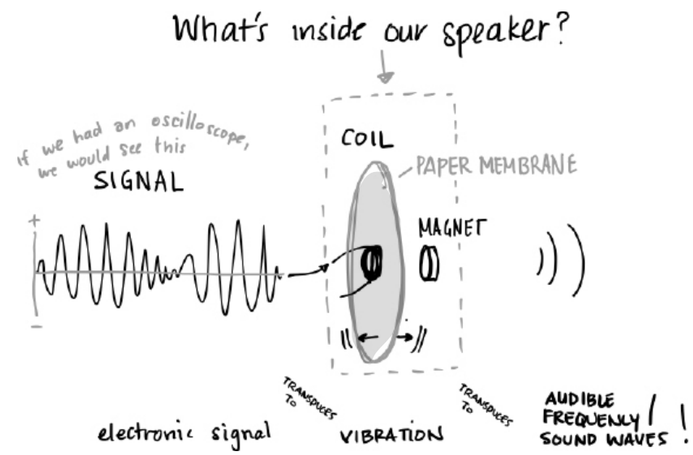


speakers & transduction

The process of converting one form of energy to another is known as transduction.
A transducer is a device that converts a signal in one form of energy to a signal in another.
Transducers are often employed where electrical signals are converted to and from other physical quantities (energy, force, torque, light, motion, position, etc.).

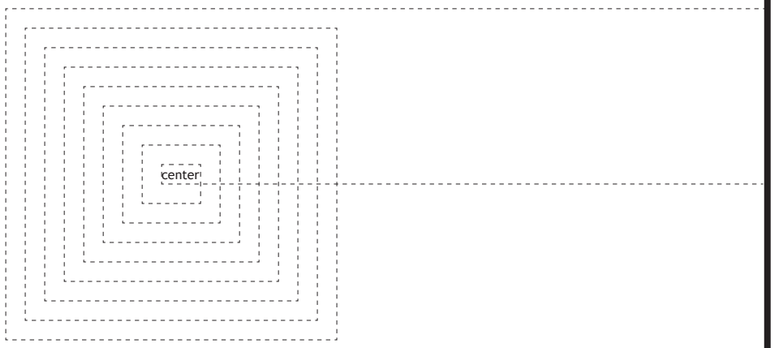
A speaker is a transducer. Take apart the speaker in the toy piano. What do you see?





SWATCH: copper tape coil

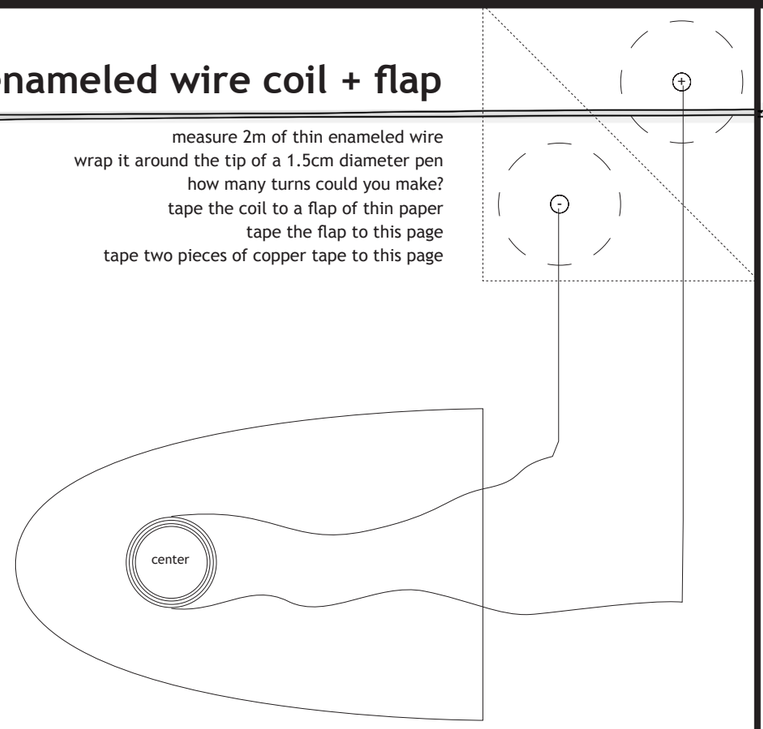
cut a strip of copper tape in half
start at the edge of the page
tape to the middle of the page
then insulate your trace with some masking tape
now continue to coil the tape around in a square
until you have at least 5-6 turns
measure how much resistance your coil has



_____Ohm

SWATCH: enameled wire coil + flap

measure 2m of thin enameled wire
wrap it around the tip of a 1.5cm diameter pen
how many turns could you make?
tape the coil to a flap of thin paper
tape the flap to this page
tape two pieces of copper tape to this page



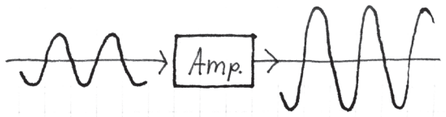
_____Ohm

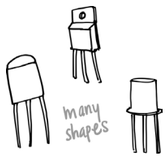
magnet!

fix magnet here

amplification & transistors

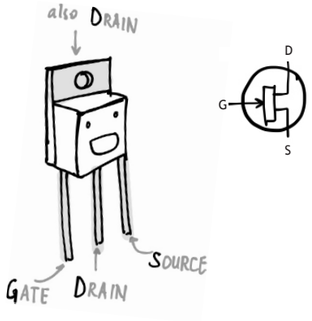
An electronic amplifier (amp) is a device that can increase the power of a signal (a time-varying voltage or current). It takes power from a different power supply and controls the output signal to match the input signal shape but with a larger amplitude.

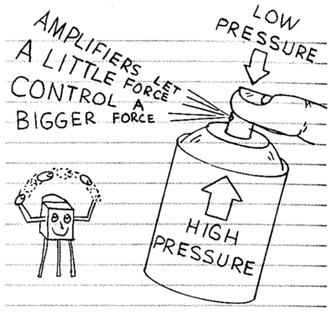




A TRANSISTOR is a device that can be used as an amplifier (among many other things). Transistors are semiconductor devices with three leads. A very small current or voltage at one lead can control a much larger current flowing through the other two leads. This means transistors can be used as amplifiers and switches (which we'll learn about later).

There are many kinds of transistors, but we are using a MOSFET.

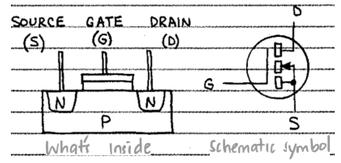




Think of the GATE as the GATEWAY for the signal.
The SOURCE is attached to ground / ⊖ because that is the source for electrons.
The DRAIN is where all the electrons DRAIN to, so it should end up at ⊕ eventually.
(Remember, electrons flow from − to +)

MOSFETs

THE METAL-OXIDE-SEMICONDUCTOR FET (OR MOSFET) HAS BECOME THE MOST IMPORTANT TRANSISTOR. MOST MICROCOMPUTER AND MEMORY INTEGRATED CIRCUITS ARE ARRAYS OF THOUSANDS OF MOSFETS ON A SMALL SLIVER OF SILICON. WHY? MOSFETS ARE EASY TO MAKE, THEY CAN BE VERY SMALL, AND SOME MOSFET CIRCUITS CONSUME NEGLIGIBLE POWER. NEW KINDS OF POWER MOSFETS ARE ALSO VERY USEFUL.



Even though this is the symbol, we will use the simplified circuit symbol for the FET to represent this MOSFET.

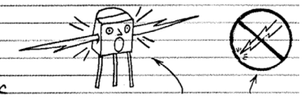
☐ MORE ABOUT MOSFETS — THE INPUT RESISTANCE OF THE MOSFET IS THE HIGHEST OF ANY TRANSISTOR. THIS AND OTHER FACTORS GIVE MOSFETS IMPORTANT ADVANTAGES:

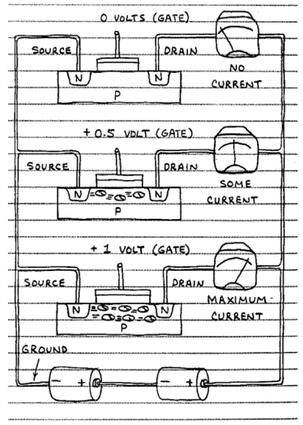
1. THE GATE-CHANNEL RESISTANCE IS ALMOST INFINITE (TYPICALLY 1,000,000,000,000,000 - OHMS). THIS MEANS THE GATE PULLS NO CURRENT FROM EXTERNAL CIRCUITS. (WELL, IT MAY BORROW A FEW TRILLIONTHS OF AN AMPERE.)

2. MOSFETS CAN FUNCTION AS VOLTAGE-CONTROLLED VARIABLE RESISTORS. THE GATE VOLTAGE CONTROLS CHANNEL RESISTANCE.

3. NEW KINDS OF MOSFETS CAN SWITCH VERY HIGH CURRENTS IN A FEW BILLIONTHS OF A SECOND.

☐ CAUTION — BECAUSE THE GLASS-LIKE SILICON OXIDE LAYER BELOW THE GATE IS SO THIN, IT CAN BE PIERCED BY TOO MUCH VOLTAGE OR EVEN STATIC ELECTRICITY. EVEN THE STATIC CHARGE GENERATED BY CLOTHING OR A CELLOPHANE WRAPPER CAN ZAP THE GATE OF A MOSFET!

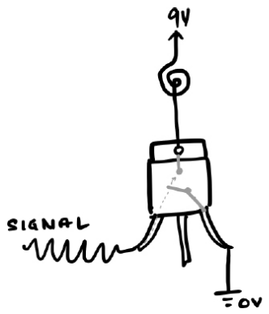




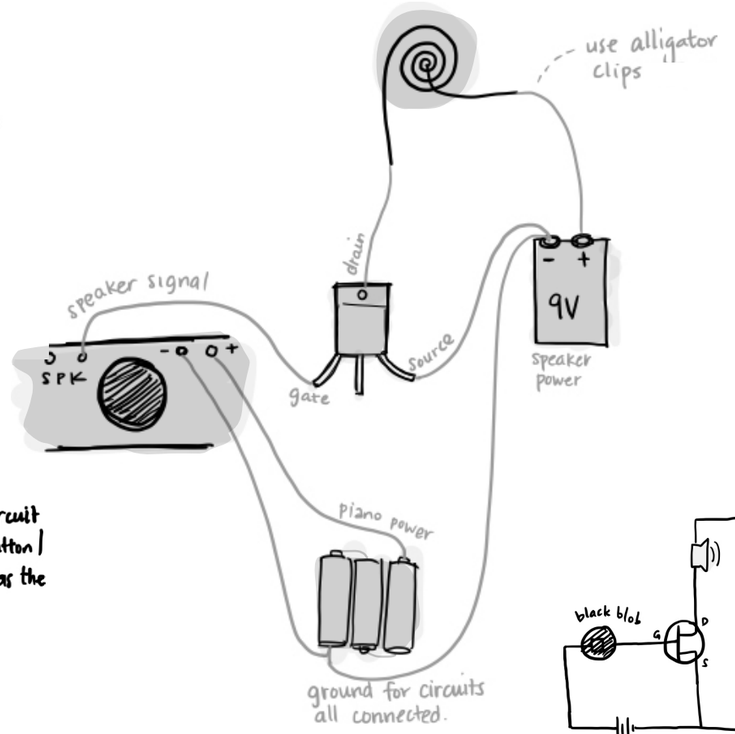
The mosfet we are using is FQP30N06L.
For more info, see "Getting Started in Electronics" pp 54-56

transistor amplifier + diy speaker

WHY DOES IT AMPLIFY?

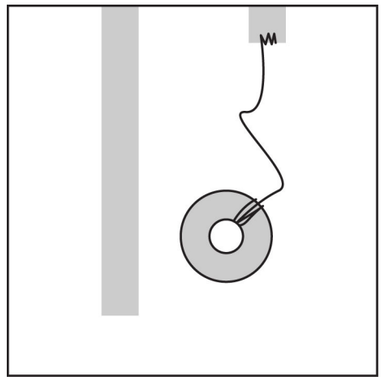


transistor effectively allows circuit to the speaker to close (e.g. button/switch) at the same frequency as the audio signal.



SWATCH: e-textile tilt switch

Contact Switch detects if two contact points are touching or not. By extending one of the contact points with conductive thread and metal bead with weight, you can create a sensor that detects tilting direction. The metal bead swings with gravity and touches with open contact as it gets tilted.



Materials: cotton fabric, conductive thread, conductive fabric, fusible interfacing, metal bead or danish kroner, galss/plastic beads

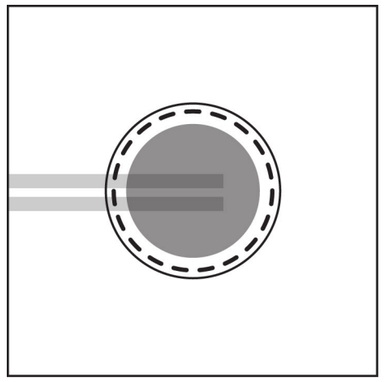
Tools: scissors, iron, sewing needle

Techniques: fusing, sewing

Beaded Tilt Sensor >> http://www.kobakant.at/DIY/?p=201

SWATCH: e-textile pressure sensor

This pressure sensor is very similar to the paper one you already made but instead of Velostat we use an Eeonyx piezoresistive fabric. The two conductors are fused to your base fabric and the Eeontex fabric is stitched ontop underneeth a piece of felt to make it inviting to press.



Materials: neoprene, conductive thread, piezoresistive material (velostat, eeonyx non-woven or eeonyx stretch), conductive fabric (silver stretch), fusible interfacing

Tools: scissors, sewing needle, iron

Techniques: cutting, fusing, layering, sewing

Neoprene Pressure Sensor >> http://www.kobakant.at/DIY/?p=65

SWATCH: e-textile pressure/bend sensor

This pressure sensor is made by layering a piece of Eeonyx piezoresistive fabric ontop of two conductive fabric strips. The conductive fabric strips are fused to your base felt fabric with an iron-on glue and the Eeontex fabric is held in place by fusing a final layer of regular fabric ontop of it.

You can press this sensor to pressure the layers together and make them more conductive, or you can bend the sensor which will also pressure the layers together and have the same effect.

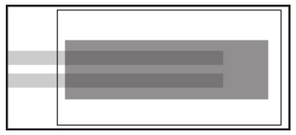
Materials: felt, piezoresistive material, conductive fabric, fusible interfacing, non-conductive fabric

Tools: scissors, iron

Techniques: cutting, fusing, layering

Neoprene Pressure Sensor >> http://www.kobakant.at/DIY/?p=65

Neoprene Bend Sensor >> http://www.kobakant.at/DIY/?p=20



SWATCH: thermochromic pigment...

Thermochromism is the property of substances to change color due to a change in temperature. Thermochromic Capsule Powder is a very fine, colored powder that changes to a clear powder when you heat it to about 92˚F (33˚C). You can mix this pigment with paint to create thermo-chromatic paint and many other materials to give them thermochromic properties.

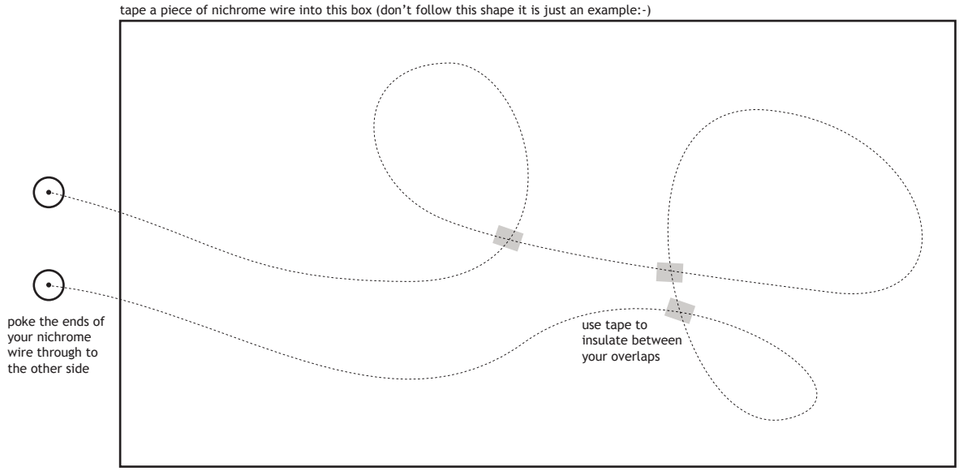
apply a layer of thermichromic paint inside this window and let it dry

hold a 9V battery to the ends of your nichrome wire and watch what happens!

... and nichrome wire

Nichrome (NiCr, nickel-chrome, chrome-nickel, etc.) is any of various alloys of nickel, chromium, and often iron. The most common usage is as resistance wire. Almost any conductive wire can be used for heating, but most metals conduct electricity with great efficiency, requiring them to be formed into very thin and delicate wires in order to create enough resistance to generate heat. When heated in air, most metals then oxidize quickly, become brittle, and break. Nichrome wire, however, when heated to red-hot temperatures, develops an outer layer of chromium oxide, which is thermodynamically stable in air, is mostly impervious to oxygen, and protects the heating element from further oxidation.

tape a piece of nichrome wire into this box (don't follow this shape it is just an example:-)



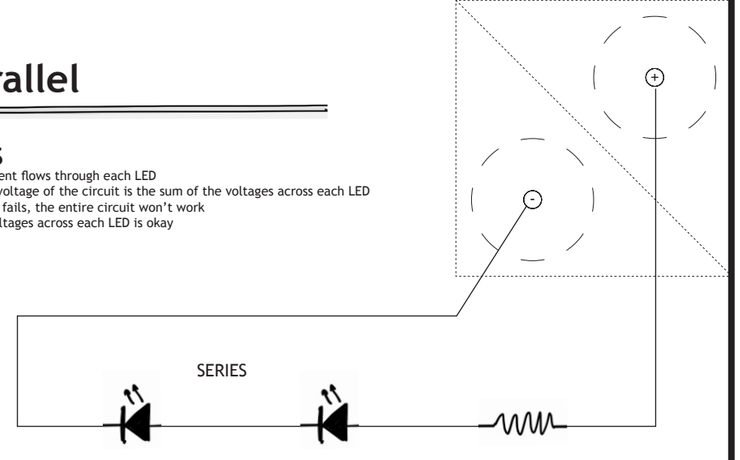
SWATCH: series and parallel

SMD LED - 1206 package

white) Forward Voltage: 3.2-3.8 V @ 20mA
green) Forward Voltage: 3.2-3.8 V @ 20mA
blue) Forward Voltage: 3.2-3.8 V @ 20mA
red) Forward Voltage: 2-2.4 V @ 20mA
yellow) Forward Voltage: 2-2.4 V @ 20mA
orange) Forward Voltage: 2-2.4 V @ 20mA
pink) Forward Voltage: 1.9-2.5 V @ 20mA

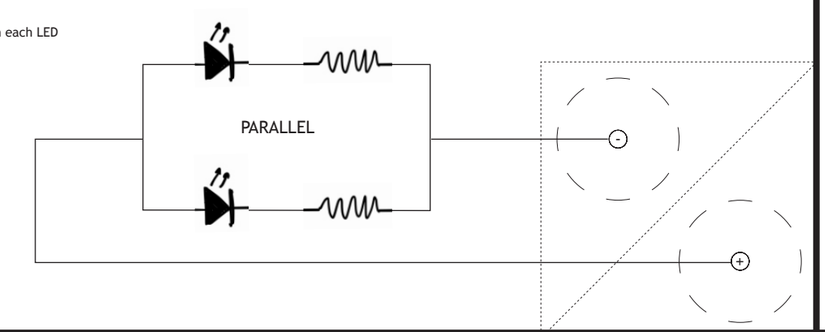
SERIES

- Same current flows through each LED
- The total voltage of the circuit is the sum of the voltages across each LED
- If one LED fails, the entire circuit won't work
- Varying voltages across each LED is okay



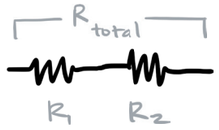
PARALLEL

· The voltage across each LED is the same
· The total current is the sum of currents through each LED
· If one LED fails, the others will still work

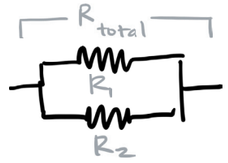


resistors in series & parallel

Make each circuit below on the breadboard. For each, use the multimeter to test how many Ohms are going across all of the components.



R_1 = _____ Ohms
R_2 = _____ Ohms
R_{total} = _____ Ohms



R_1 = _____ Ohms
R_2 = _____ Ohms
R_{total} = _____ Ohms

in series

$$R_{total} = R_1 + R_2$$

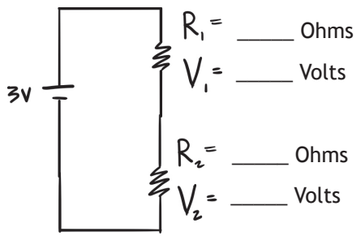
in parallel

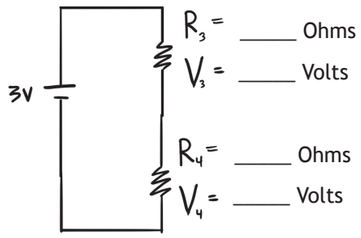
$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2}$$

The equations are a good reference when resistances vary in your circuit, but the key thing to remember is that
- in series, total resistance sums
- in parallel, total resistance divides

voltage dividers

Apply a voltage across the dividers. Use a multimeter to measure the voltage across each of the resistors. In a voltage divider, resistance and voltage are proportional to each other. The ratio of the resistors will determine the ratio of the voltages.





transistor power switch

Make your bend sensor activate the nichrome wire/ thermochromic ink!
Our MOSFET has something called a "Threshold Voltage." It is 1.5-2V.

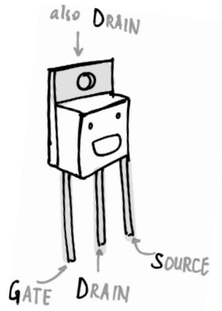
Find the resistance at which you'd like your bend sensor to "turn on" the nichrome wire.

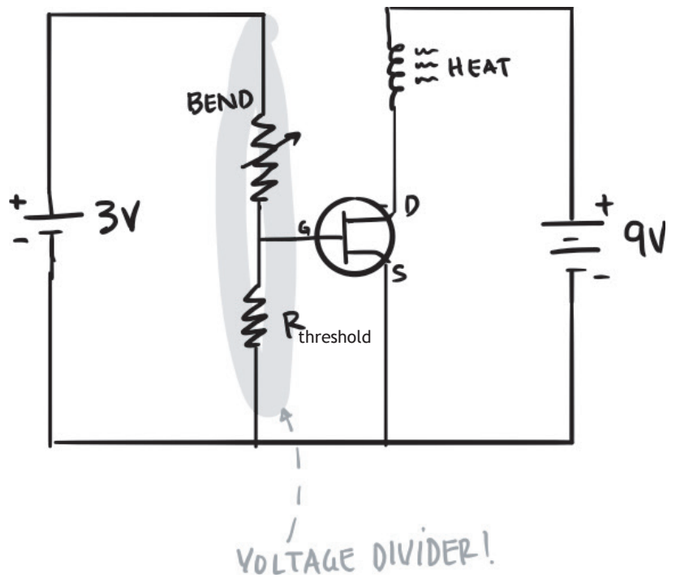
R_{bend} = _____ Ohms

$R_{threshold}$ = _____Ohms

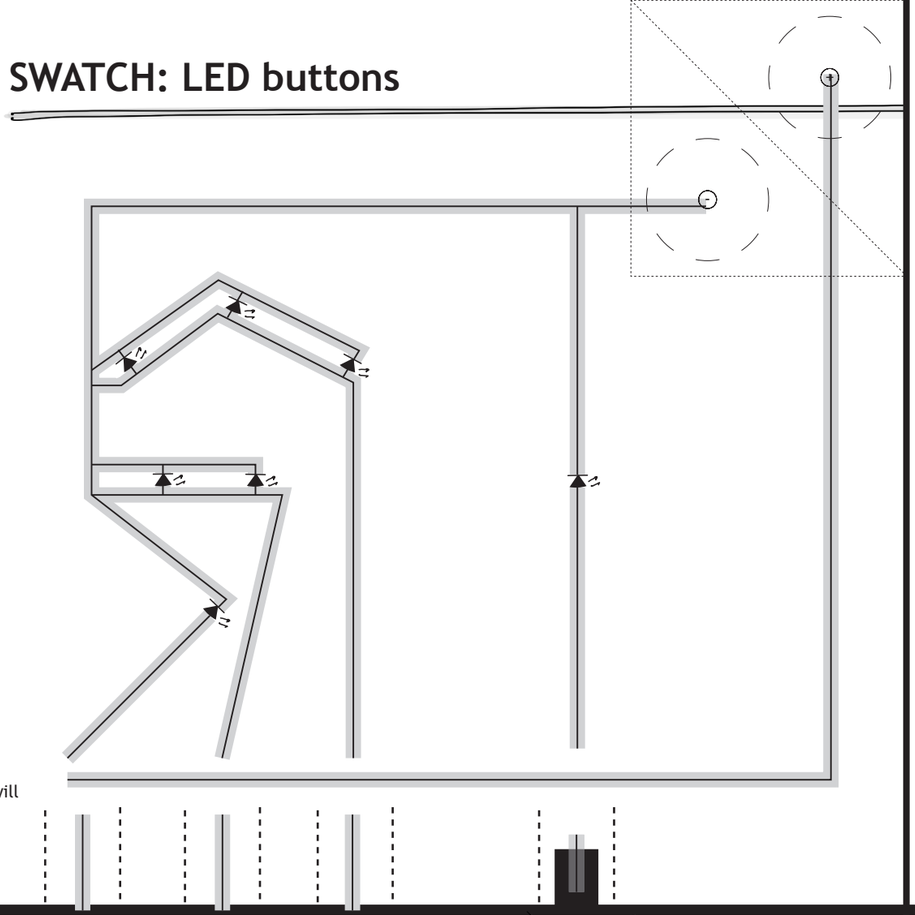
$$\frac{R_{bend}}{R_{threshold}} = \frac{V_{bend}}{V_{threshold}}$$

After you calculate the resistor you need, hook up the circuit!





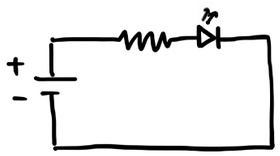
SWATCH: LED buttons



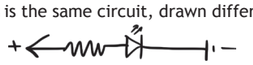
materials:
velostat
LEDs (same color in parallel)
copper tape
(ideally these should have resistors in it, but our LEDs will have a shorter lifespan)

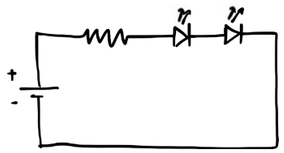
series and parallel

Make each of the circuits on the breadboard.

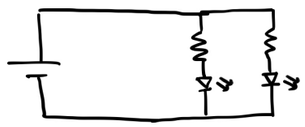


Simple LED circuit
- The battery, resistor, and LED are all in series!
- This is the same circuit, drawn differently!

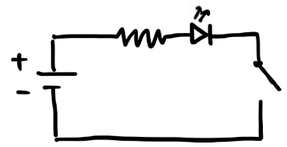




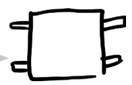
Two LEDs in series
- The total voltage is the sum of voltages across each component
- The current is constant throughout the circuit



Two LEDs in parallel
- The total current is the sum of currents thorugh each LED
- The voltage across components in parallel is the same



One LED + a button
Add a button component into the circuit.



Draw how the connections of the button look inside.

breadboard challenges

I want a circuit with two buttons. When I press one button, it turns on one red LED.
When I press the second button, it turns on two other red LEDs.
Can you draw this circuit?