BASIC ELECTRONIC COMPONENTS

DEPARTMENT OF COMPUTER SCIENCE

PHYSICAL COMPUTING 2025
2. SEPTEMBER 2025
SIMON HOGGAN CHRISTENSEN
LABORATORIEKOORDINATOR

WHO DIS?

Simon Hoggan Christensen

MSc IT-Product Development (2012-2017)
Lab Coordinator
Research and teaching environment and infrastructure
Technical teaching: ITPDP, PhysComp, ITWoT

Physical Computing:

Solo: 2019, 2023
Co-teaching: 2020, 2021, 2022, 2024

Email: simon@cs.au.dk

... BUT FIRST, SOMETHING VERY UNRELATED

BUYING YOUR OWN TOOLS - SUGGESTIONS

Soldering iron

https://www.av-cables.dk/loddekolbe-2/

https://arduinotech.dk/shop/ts100-soldering-iron-65w-digital-lcd-oled-programmable-controller/

https://dk.rs-online.com/web/p/loddestationer/2237521?gb=b

Hand tools –various, ifixittoolkits are pretty good

https://www.proshop.dk/Kabinet-Tilbehoer/iFixit-Essential-Electronics-Toolkit/2688175

https://www.proshop.dk/Kabinet-Tilbehoer/iFixit-Pro-Tech-Toolkit/2688173

DEPARTMENT OF COMPUTER SCIENCE

BUYING YOUR OWN TOOLS - SUGGESTIONS

Multimeters – buy an autoranging one

https://www.av-cables.dk/multitester/professionel-digital-multitester-mtm01.html

https://elektronik-lavpris.dk/p116581/dmt-2010-digital-multimeter/

Components, wires, soldering tin etc.

https://www.amazon.de/Elegoo-%C3%9CBERARBEITETES-Stromversorgungsmodul-Jumperkabel-Potentiometer/dp/B01M7N4WB6/ref=sr_1_6?keywords=arduino-set&qid=1566984170&s=gateway&sr=8-6

DEPARTMENT OF COMPUTER SCIENCE

OVERVIEW

Electricity

Electronic circuits and circuit diagrams

Basic Electronic Components

- Resistors
  - Types
  - Calculating resistance
  - Series and Parallel
  - Voltage Dividers
- Capacitors
- Crystals
- Transistors

DEPARTMENT OF COMPUTER SCIENCE

KEY CHARACTERISTICS OF ELECTRONICS

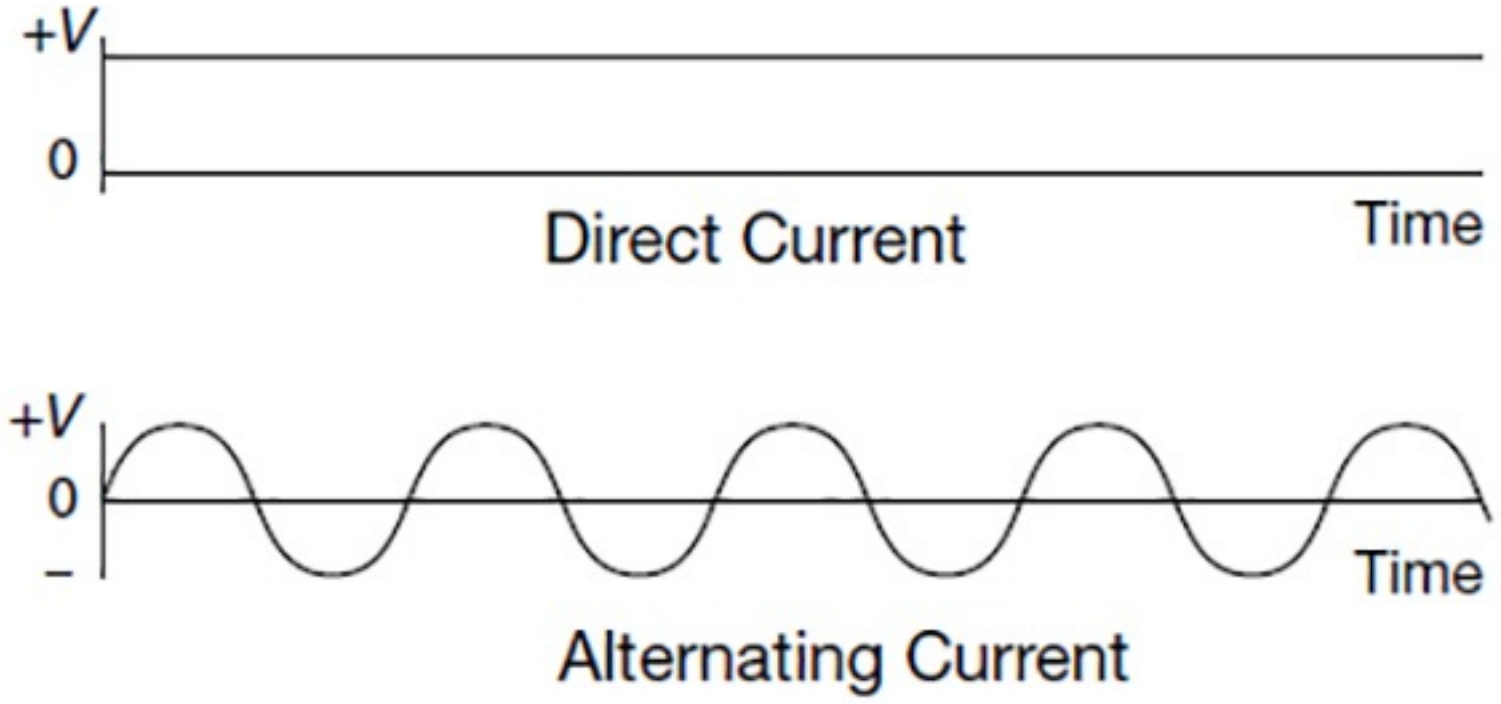
DEPARTMENT OF COMPUTER SCIENCE

FAIRLY ESSENTIAL REQUIREMENT

Electricity!

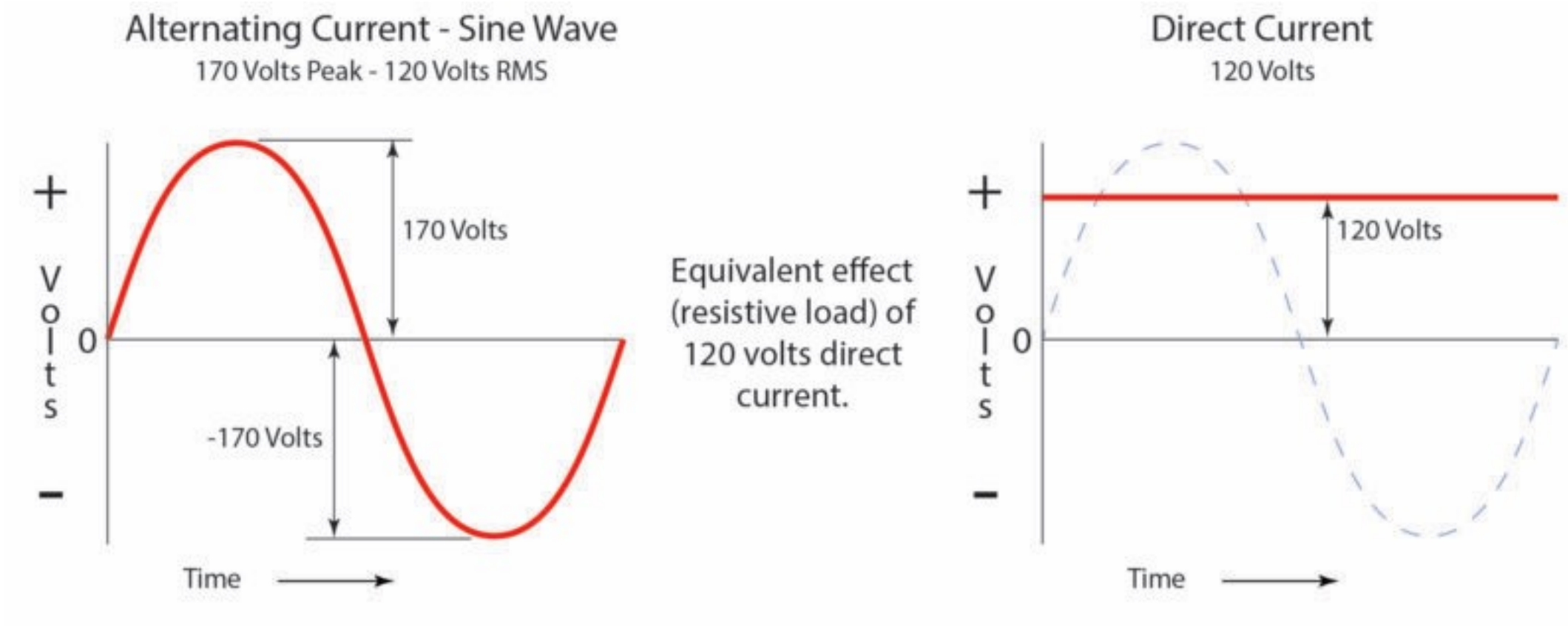
DEPARTMENT OF COMPUTER SCIENCE

ELECTRICITY



DEPARTMENT OF COMPUTER SCIENCE

ELECTRICITY



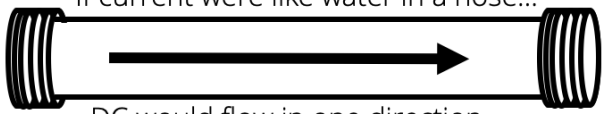
DEPARTMENT OF COMPUTER SCIENCE

ELECTRICITY

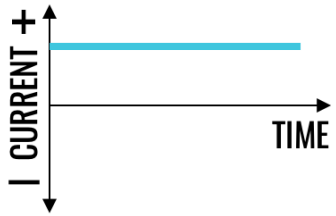
Alternating Current vs Direct Current

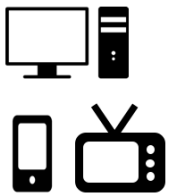
DC

If current were like water in a hose...



DC would flow in one direction...

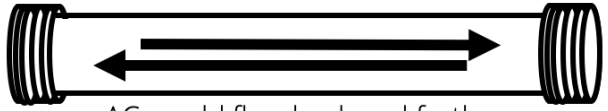




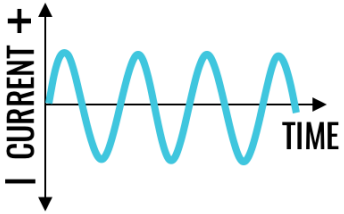
Things that use DC

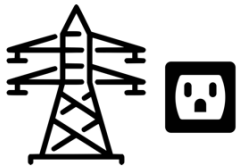
FREEING ENERGY

AC



AC would flow back and forth...

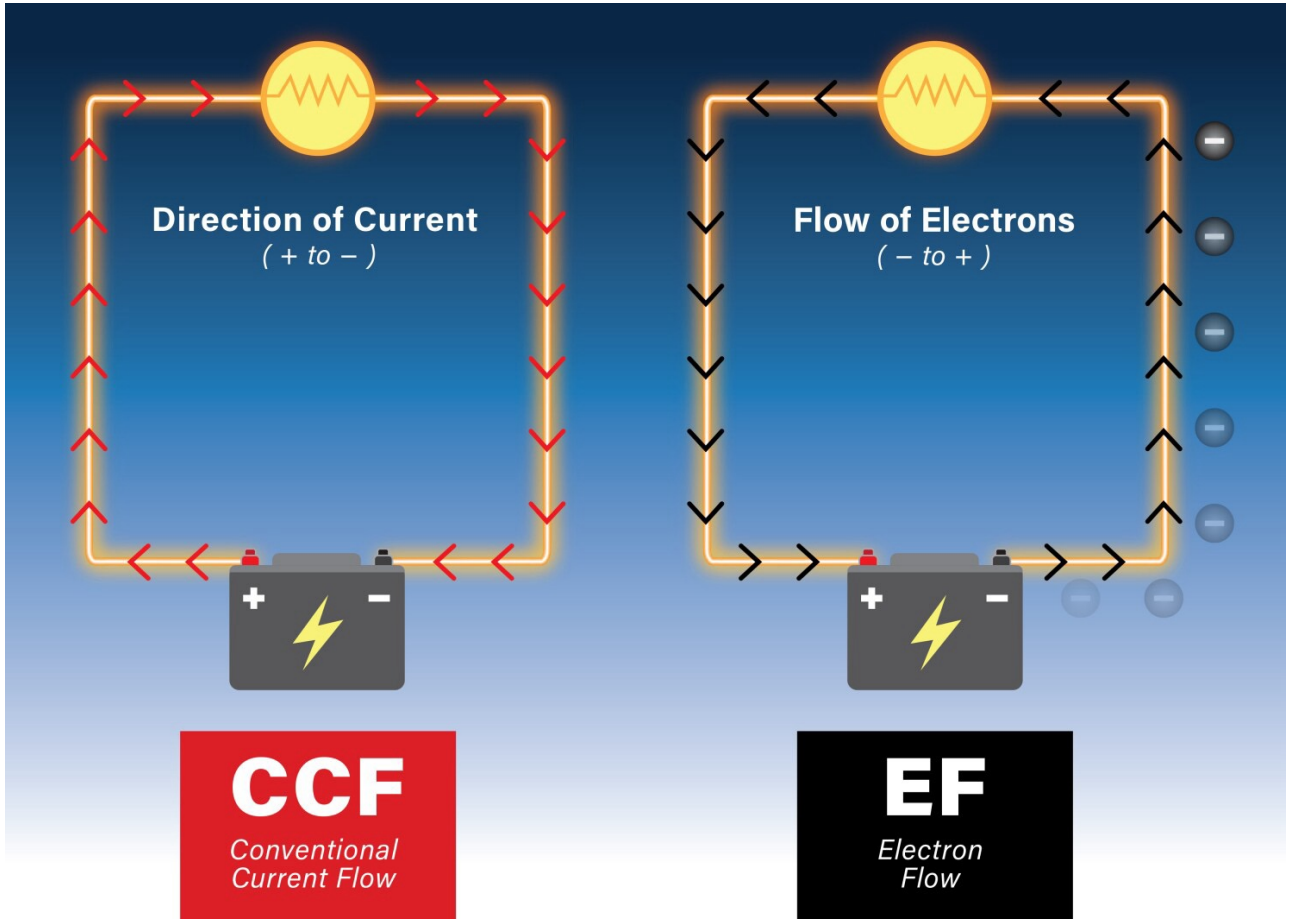




Things that use AC

DEPARTMENT OF COMPUTER SCIENCE

ELECTRICITY



DEPARTMENT OF COMPUTER SCIENCE

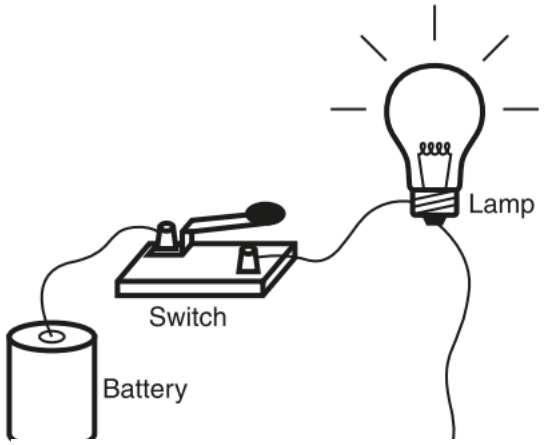
ELECTRICITY

DEPARTMENT OF COMPUTER SCIENCE

ELECTRONIC CIRCUITS

An electric circuit is a closed loop containing a source of electrical energy (a battery) and a load (a light bulb)

Using electrical energy to convert human action into other forms of energy -> switch



DEPARTMENT OF COMPUTER SCIENCE

KEY CHARACTERISTICS

Voltage: the relative level of electrical energy between any two points in the circuit (e.g. power and ground) -> measured in Volts (V)

Current: the amount of electrical energy passing through any point in the circuit -> measured in amperes or amps (A)

Resistance: the amount that any component in the circuit resists the flow of current -> measured in ohms (Ω)

- All electrical devices resist the flow of current

DEPARTMENT OF COMPUTER SCIENCE

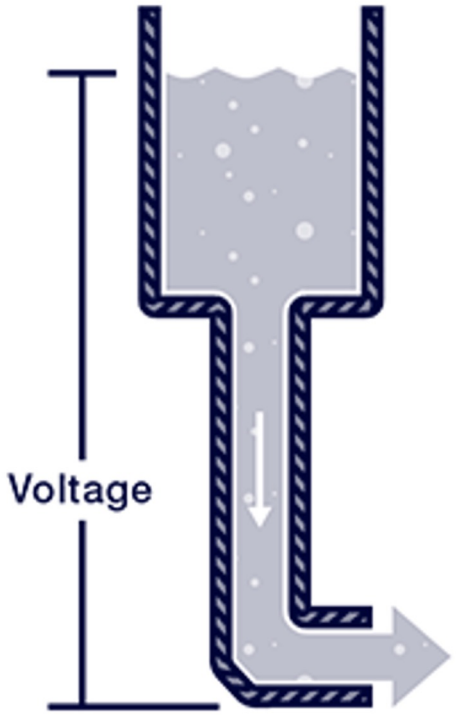
WATER ANALOGY

Water = Charge (coulombs)

Pressure = Voltage (volts)

Flow = Current (amps)

Hose width = Resistance (ohm)



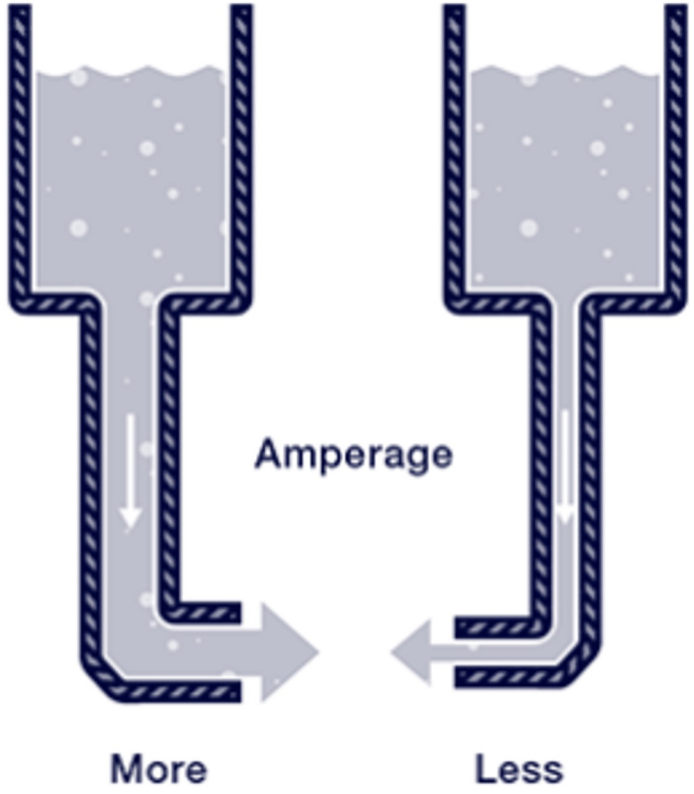
From Sparkfun

DEPARTMENT OF COMPUTER SCIENCE

CURRENT

The current through the narrower hose is less than the current through the wider hose.

If we want the flow to be the same through both hoses, we have to increase the amount of water (charge) in the tank with the narrower hose.



DEPARTMENT OF COMPUTER SCIENCE

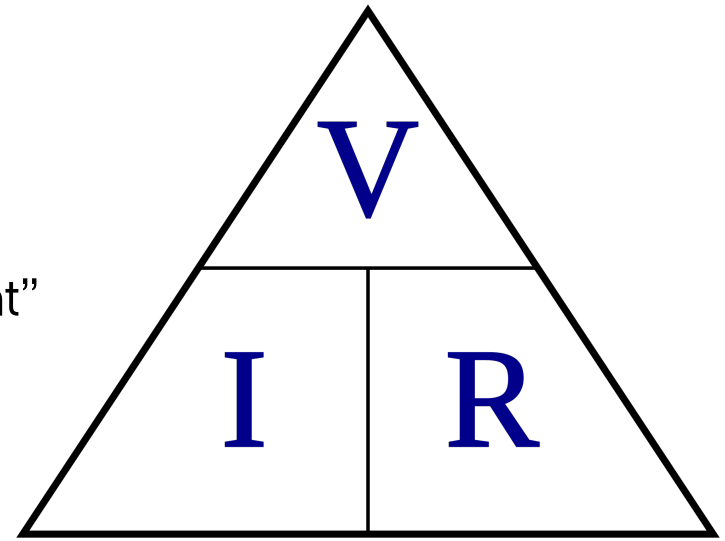
OHM'S LAW

How are voltage, current and resistance related? Ohm's Law!

Voltage(V)= current(I) x resistance(R)

- or I=V/R
- or R= V/I

- Current = I for "Intensität" and refers to "flow of current"



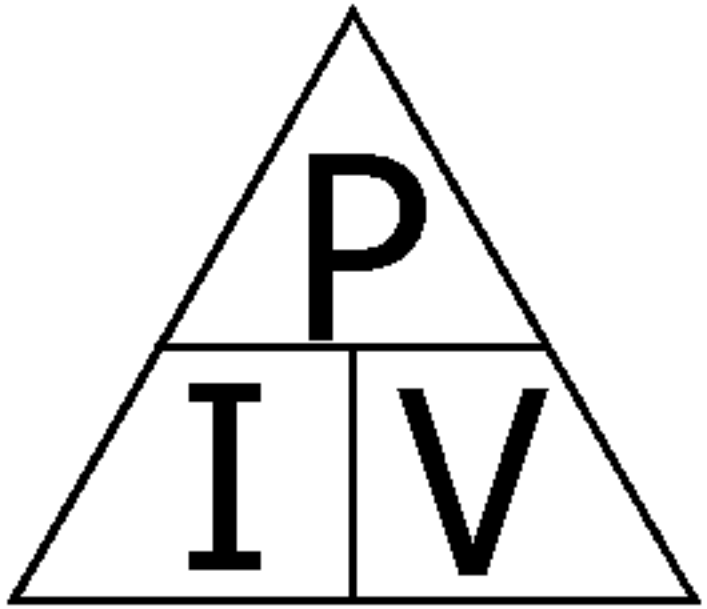
DEPARTMENT OF COMPUTER SCIENCE

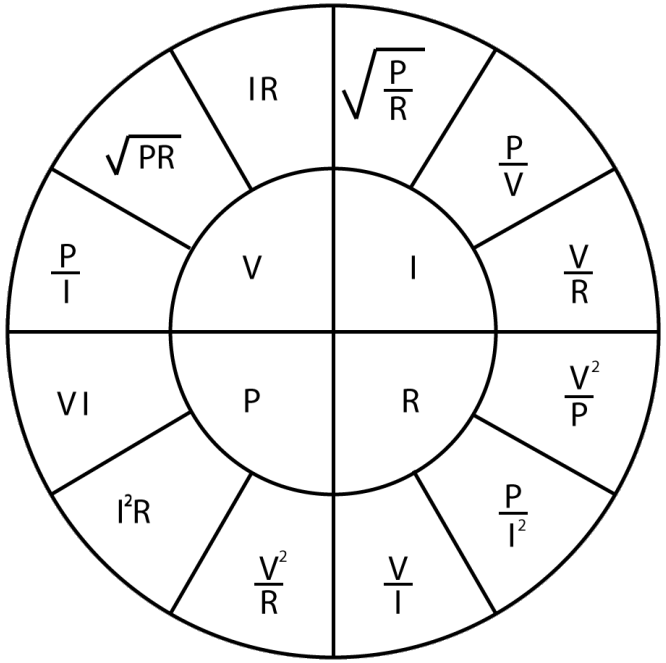
WATTS

P (watts) = V (volts) x I (amps)

$P = V^2 \div R\ (\Omega)$

$P = I^2 \times R$

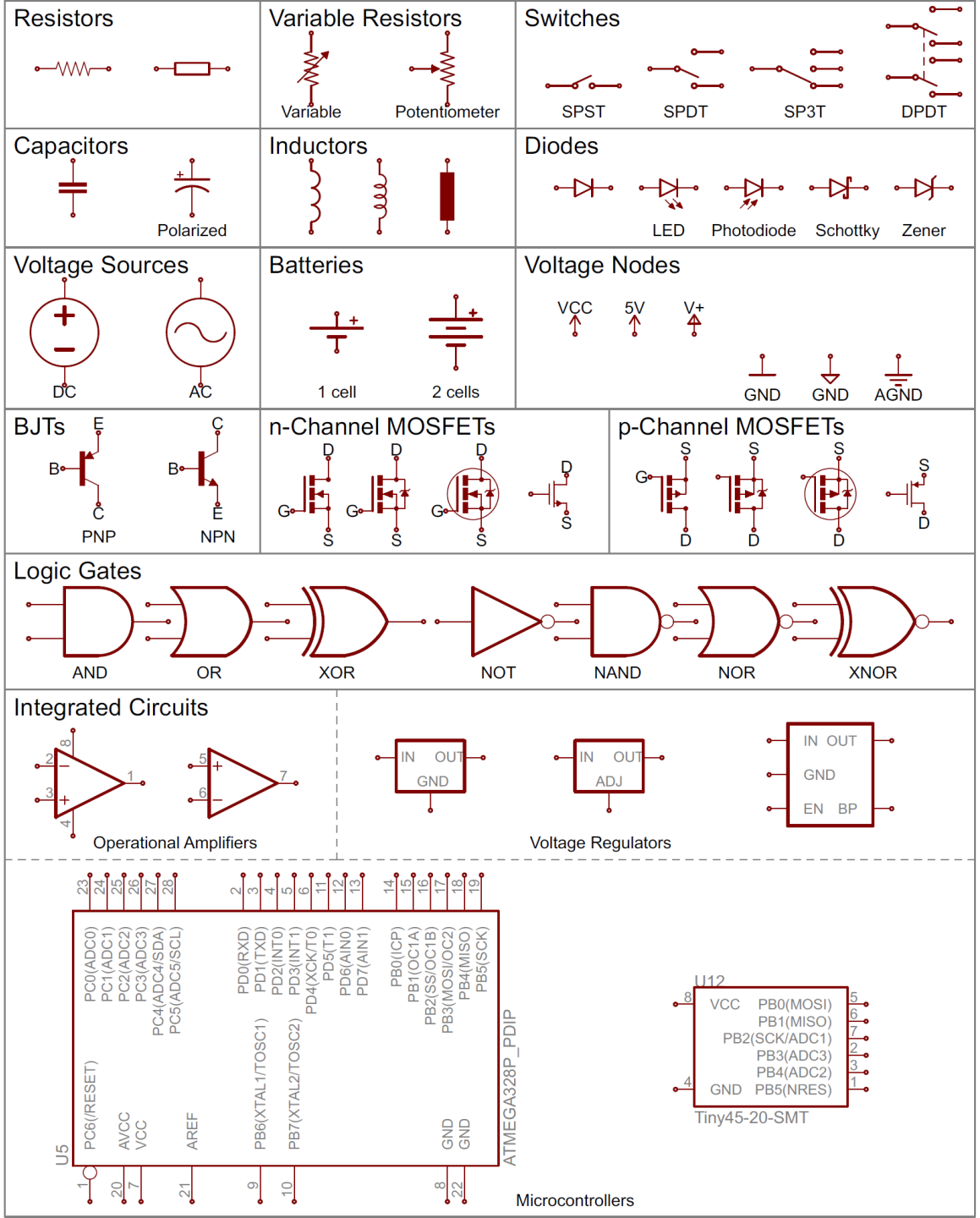




DEPARTMENT OF COMPUTER SCIENCE

BASIC COMPONENTS AND THEIR SYMBOLS

DEPARTMENT OF COMPUTER SCIENCE



https://learn.sparkfun.com/tutorials/how-to-read-a-schematic

DEPARTMENT OF COMPUTER SCIENCE

CIRCUIT DIAGRAMS

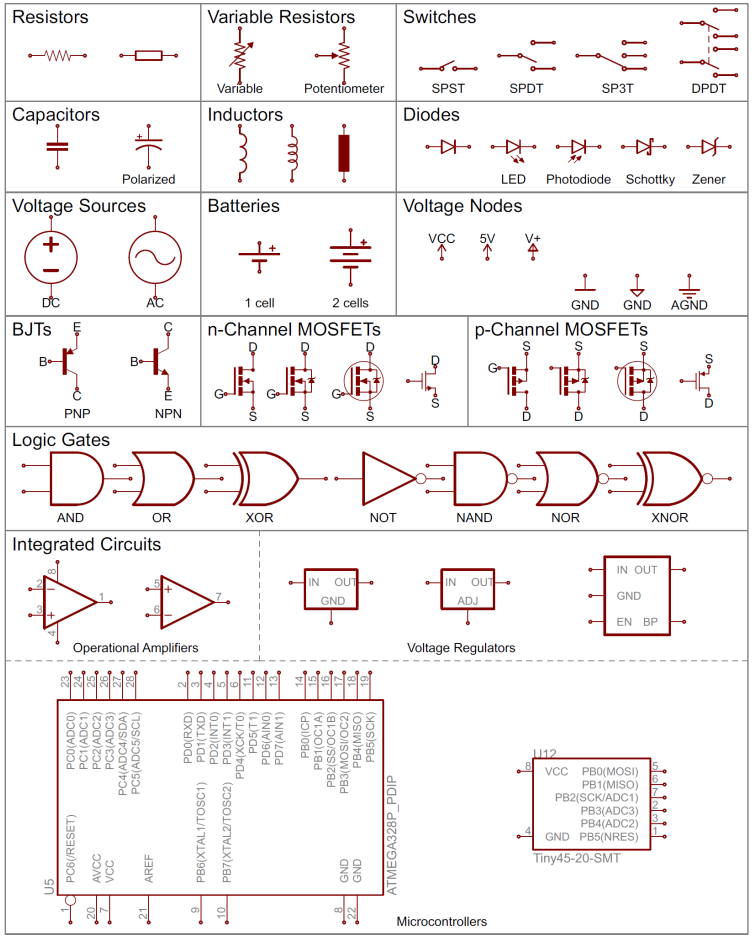
Each component is represented by a schematic symbol

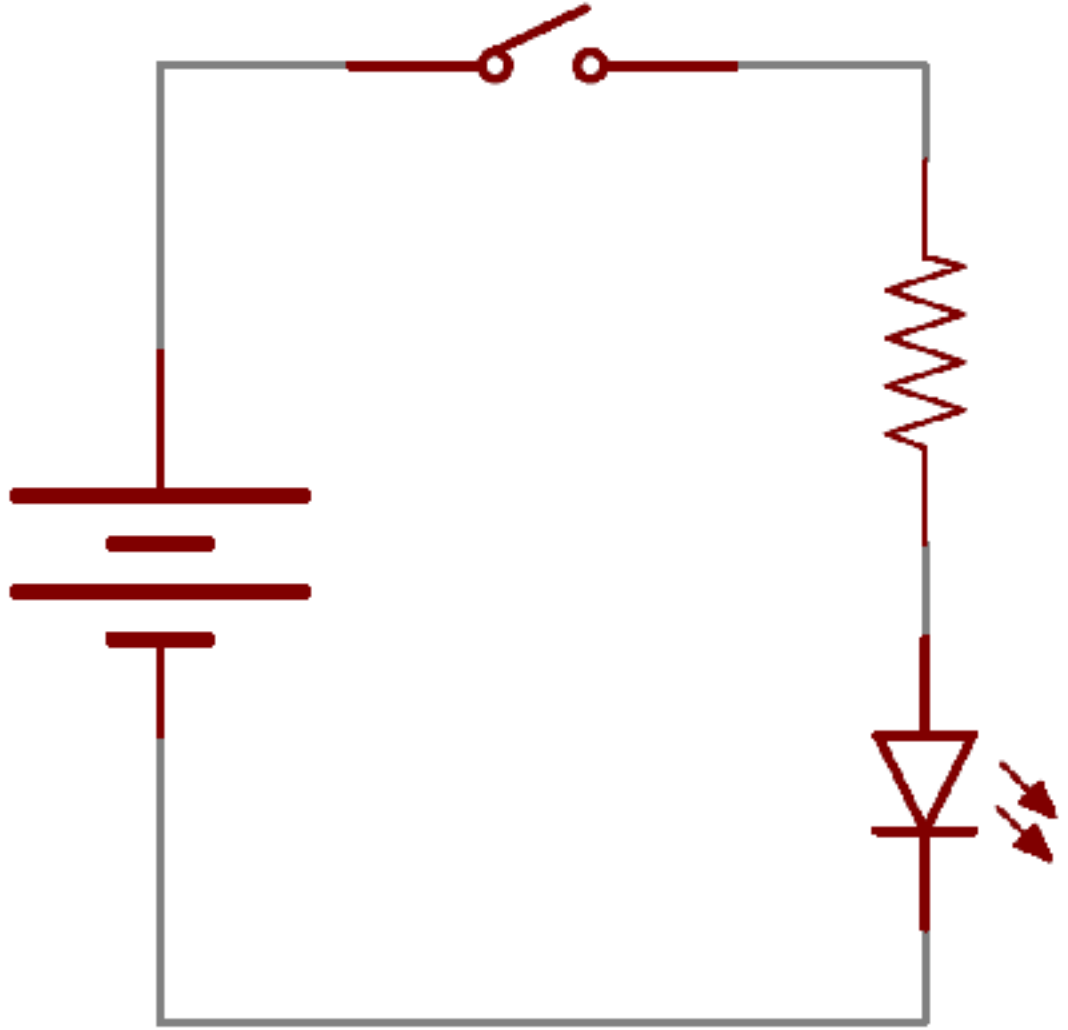
Layout Guidelines:

- The lowest voltage should be shown at the bottom, and the highest voltage at the top.
- The information should flow from left to right.
  - Sensors and other input devices on the left, and outputs such as motors, LEDs, on the right.

DEPARTMENT OF COMPUTER SCIENCE

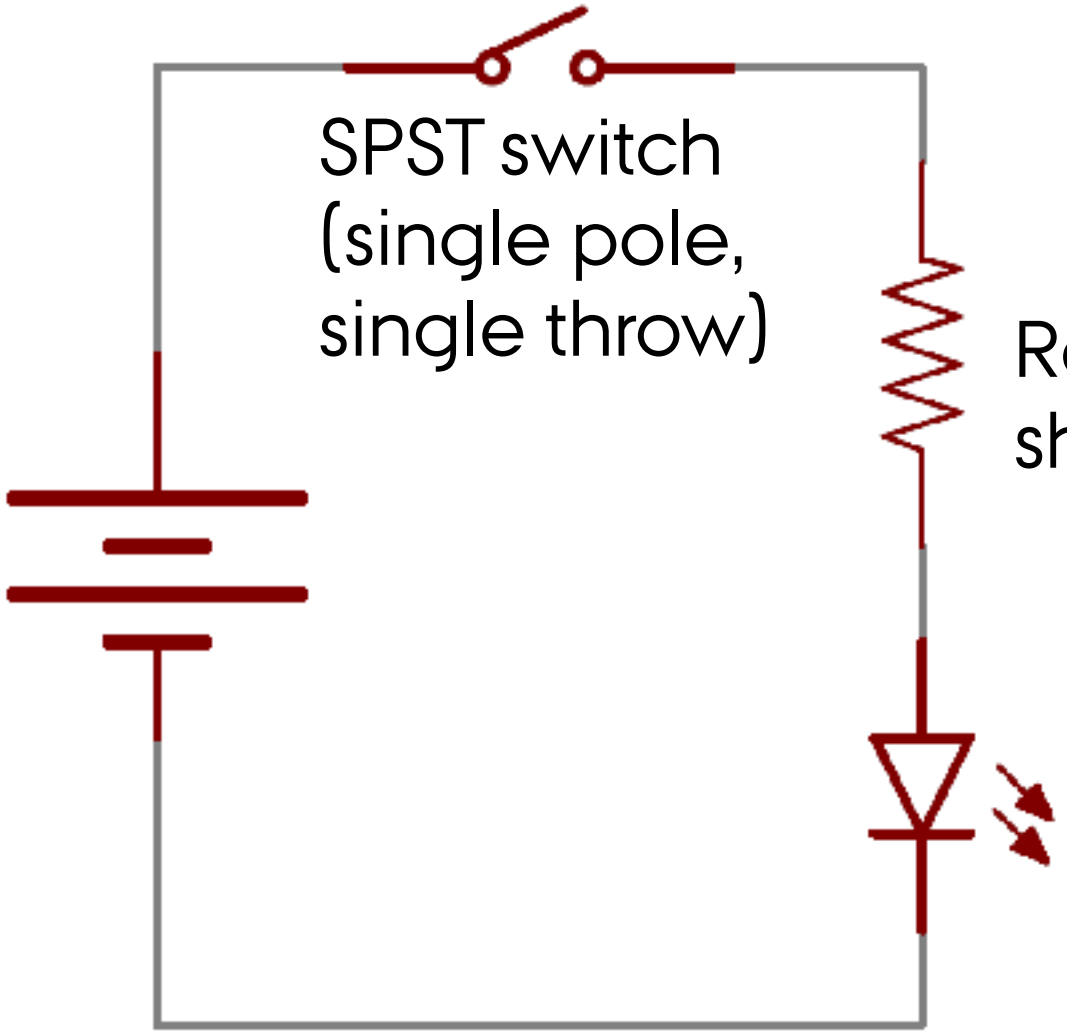
WHAT DOES THIS DIAGRAM REPRESENT?





DEPARTMENT OF COMPUTER SCIENCE

WHAT DOES THIS DIAGRAM REPRESENT?



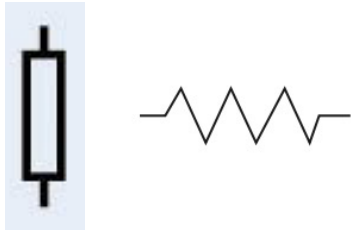
DEPARTMENT OF COMPUTER SCIENCE

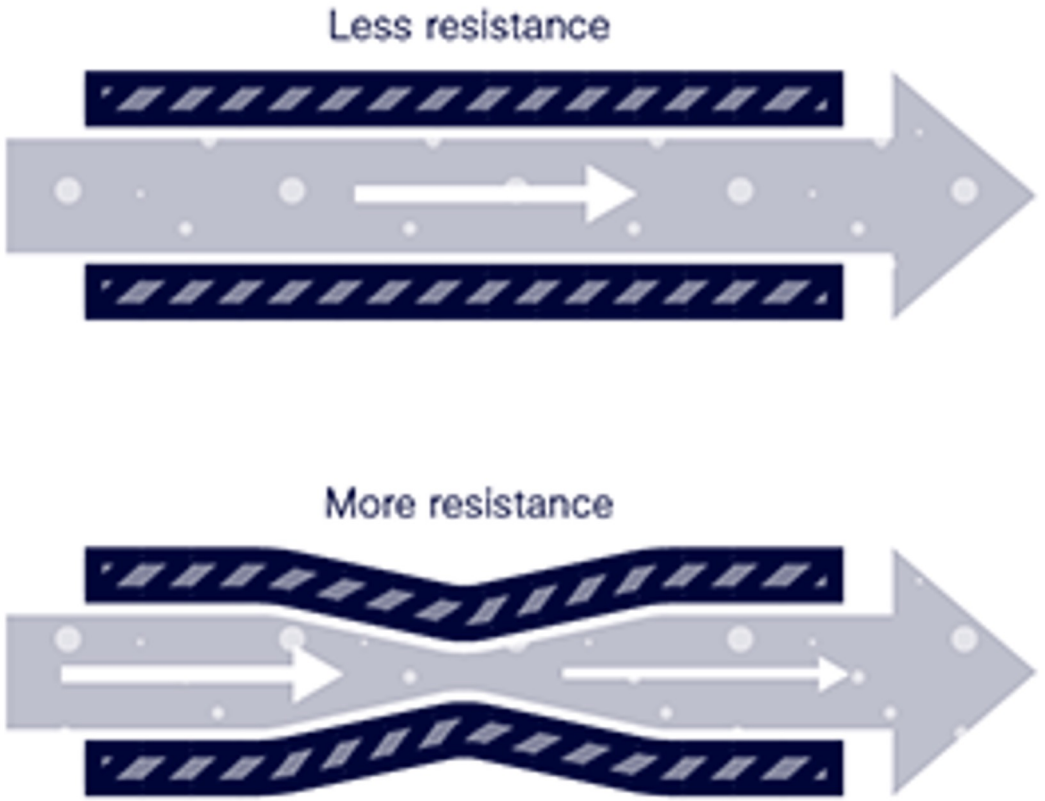
RESISTORS

DEPARTMENT OF COMPUTER SCIENCE

Can be used to limit the amount of current that will move through that circuit each second.

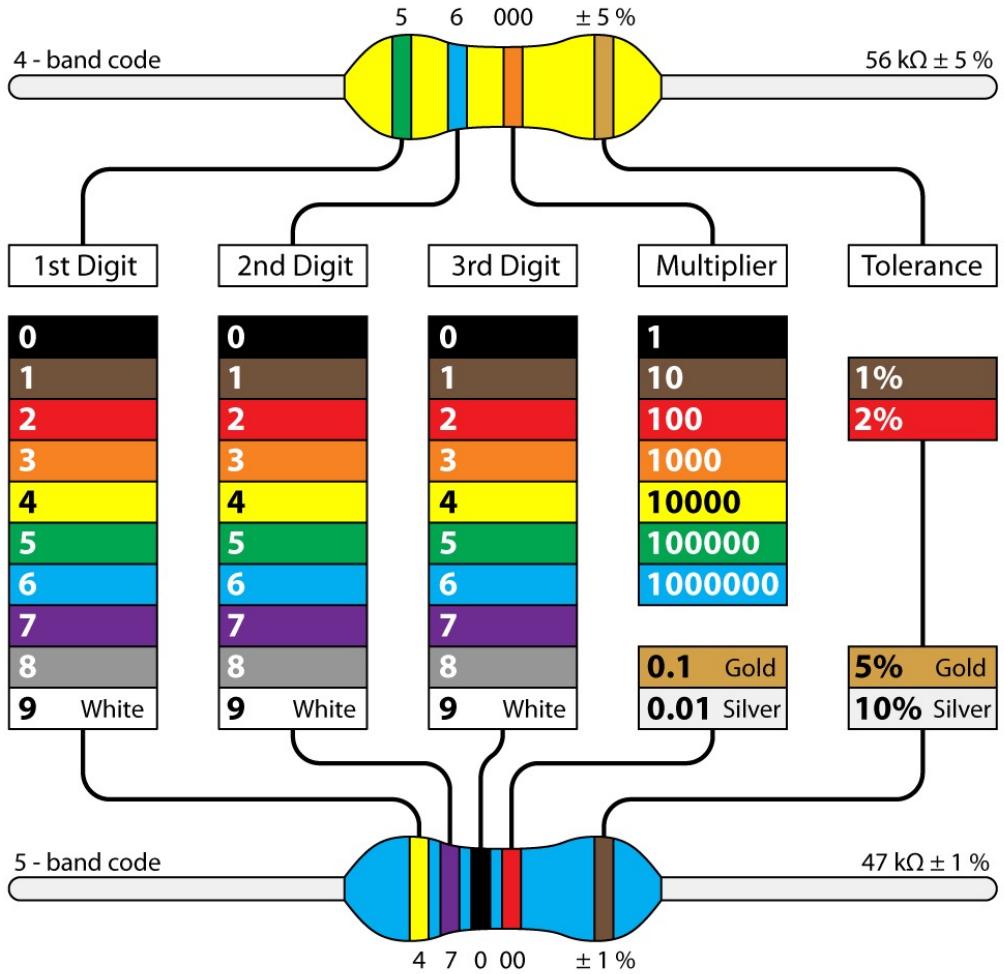
Unit – Ohms (Ω)





DEPARTMENT OF COMPUTER SCIENCE

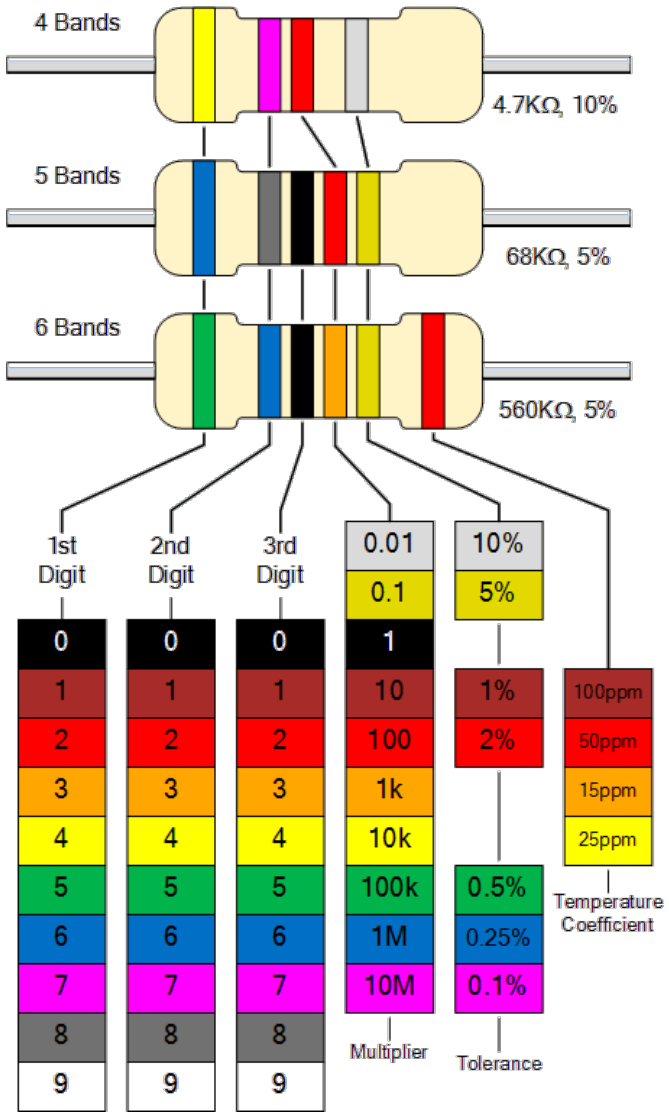
Resistor colour code



Digit, Digit, Multiplier = Colour, Colour x 10^{colour} in (Ω's)

http://www.imajeenyus.com/electronics/20120315_resistor_colour_code/index.shtml

DEPARTMENT OF COMPUTER SCIENCE



http://www.electronics-tutorials.ws/resistor/res_2.html

There are resistors with 4, 5 or 6 indicators bands

http://www.digikey.com/en/resources/conversion-calculators/conversion-calculator-resistor-color-code-6-band

Graphical Resistor Calculator

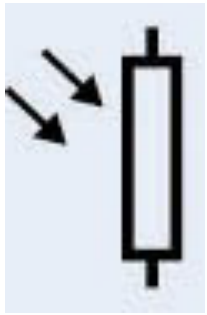
http://www.dannyg.com/examples/res2/resistor.htm

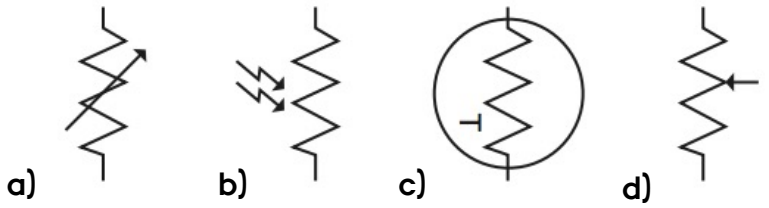
DEPARTMENT OF COMPUTER SCIENCE

TYPES OF VARIABLE RESISTOR

Schematics:

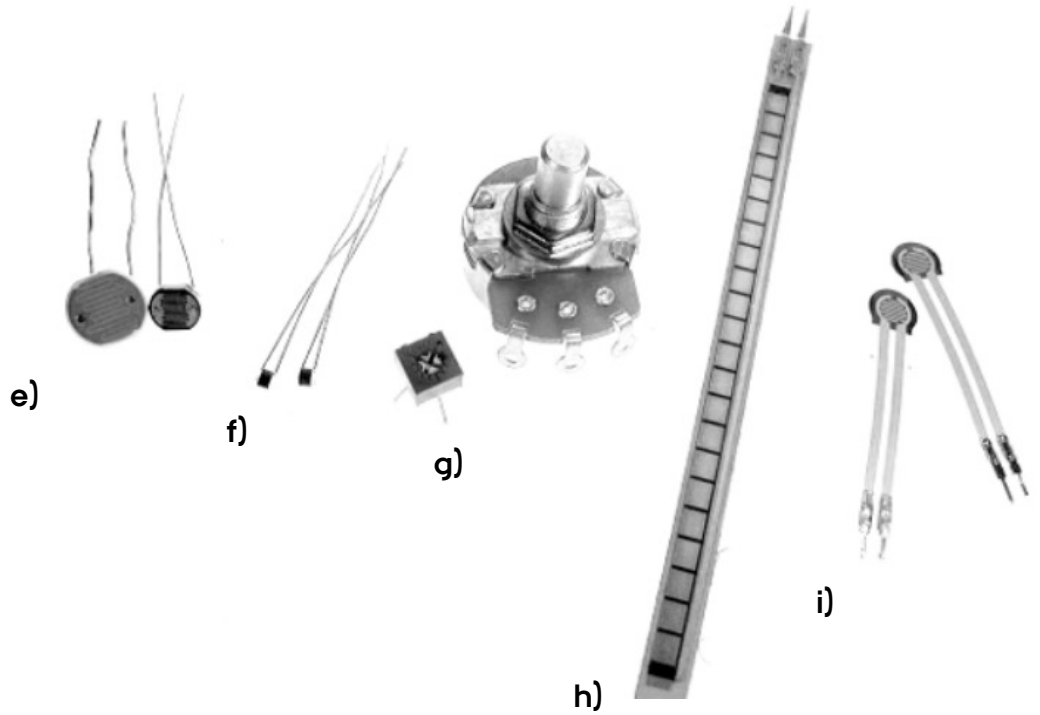
- a) Generic variable resistor
- b) Photocell
- c) Thermistor
- d) Potentiometer





Images

- e) Photocell
- f) Thermistor
- g) Potentiometer
- h) Flex sensor
- i) force-sensitive resistor (FSR)



DEPARTMENT OF COMPUTER SCIENCE

PULL-UP AND PULL-DOWN RESISTORS

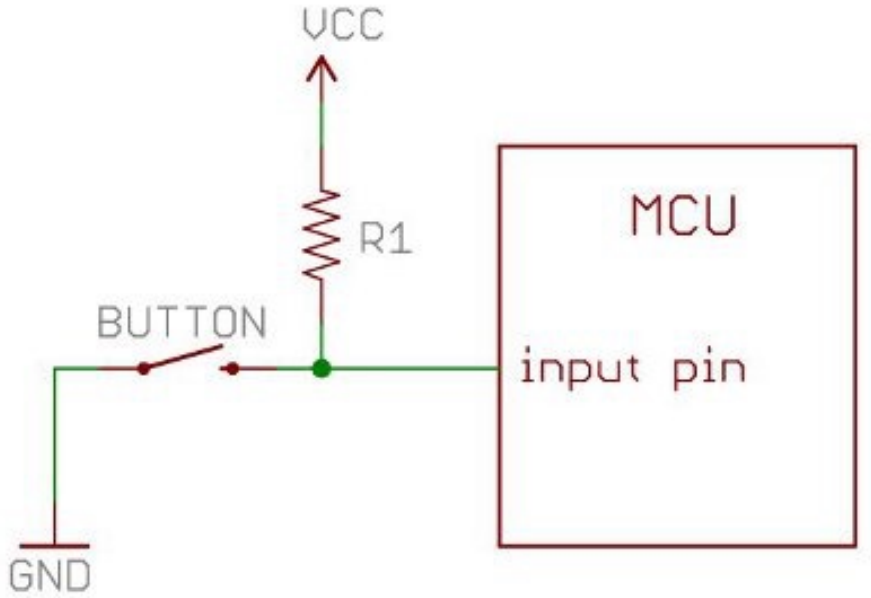
A pull-up or pull-down resistor can ensure that a pin is in a high or low state

- Often used with switches

A pull-up resistor is connected to VCC and a pull-down resistor is connected to ground.

Pull-up resistor:

- the input pin will read a high state when the button is not pressed - a small amount of current is flowing between VCC and the input pin (not to ground)
- When the button is pressed, it connects the input pin directly to ground. The current flows through the resistor to ground, thus the input pin reads a low state.



From https://learn.sparkfun.com/tutorials/pull-up-resistors

We usually use 10kΩ for pull-up

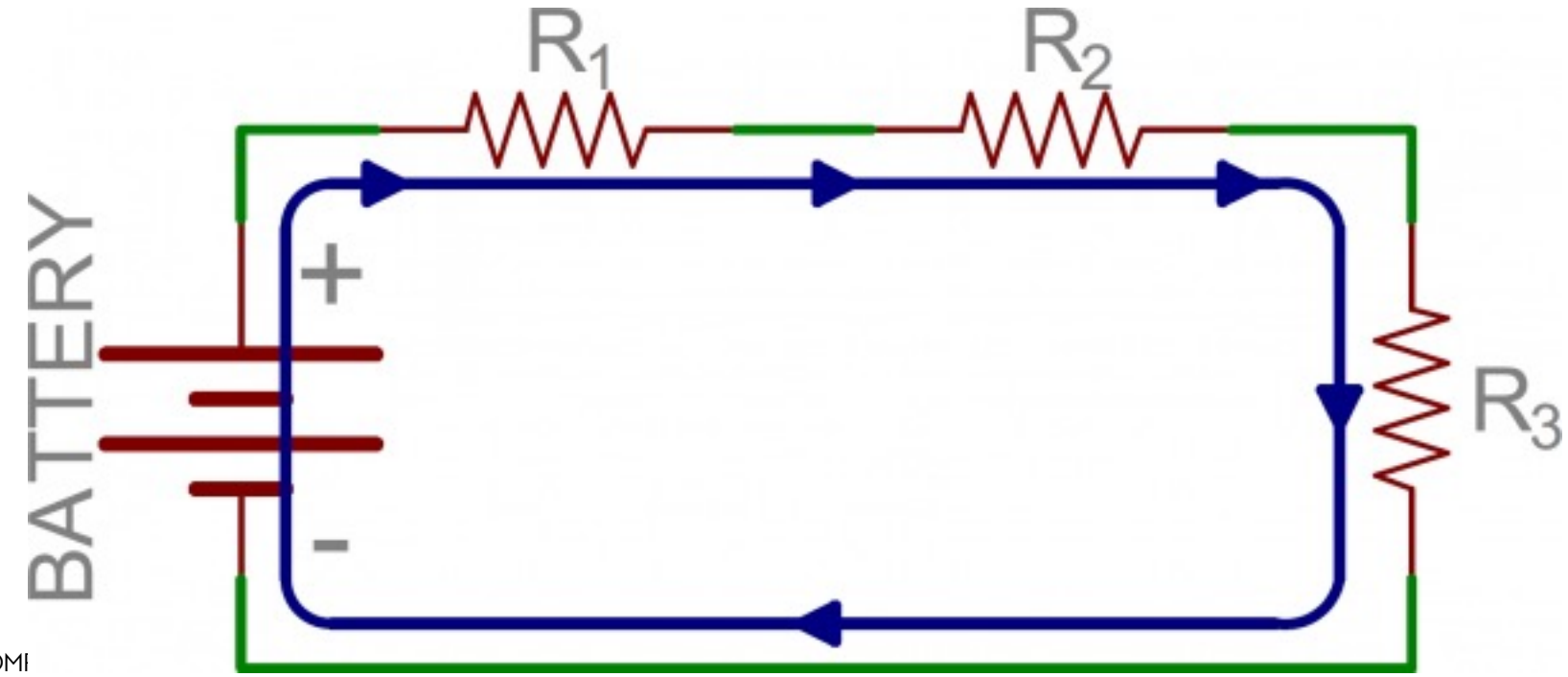
DEPARTMENT OF COMPUTER SCIENCE

SERIES AND PARALLEL CIRCUITS

DEPARTMENT OF COMPUTER SCIENCE

SERIES

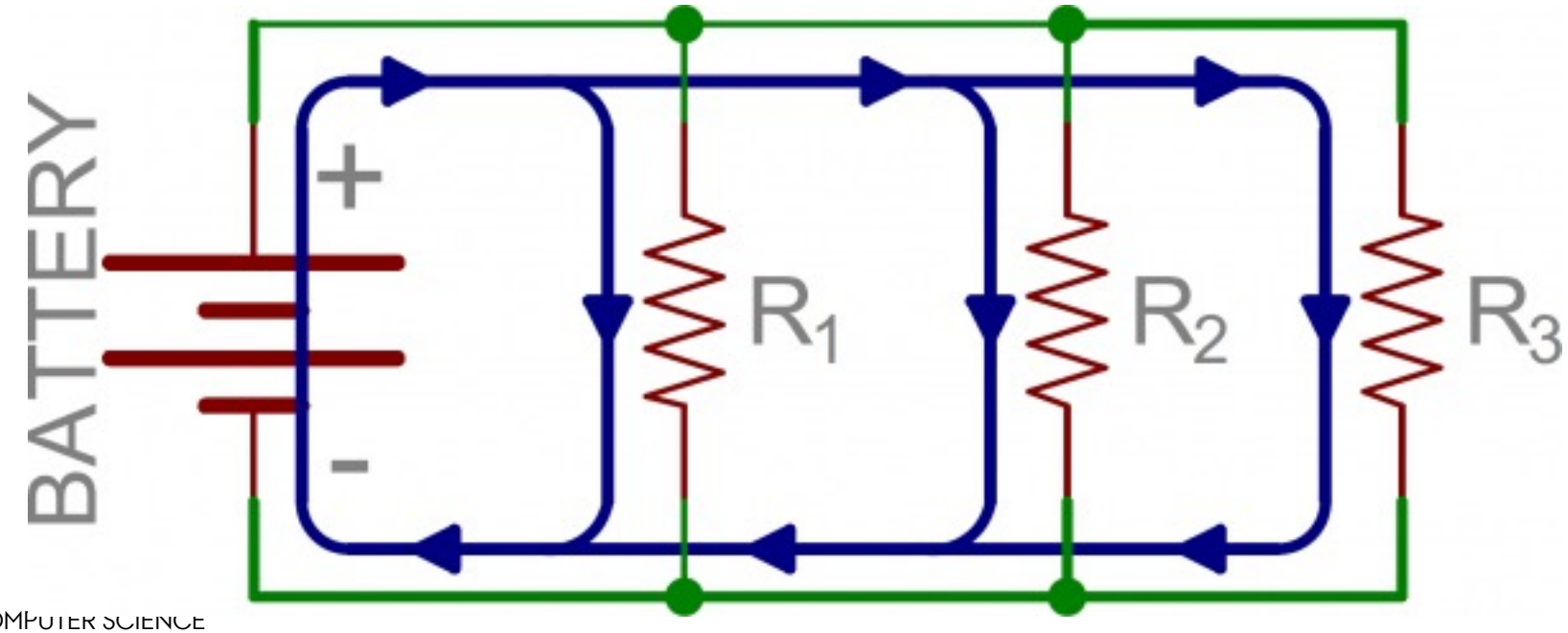
Two components are in series if they share a common node and if the **same current** flows through them.



PARALLEL

If components share two common nodes, they are in parallel.

Where series components all have equal currents running through them, parallel components all have the same voltage drop across them



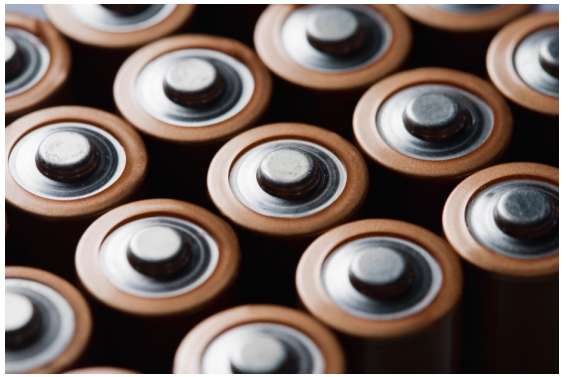
DEPARTMENT OF COMPUTER SCIENCE

BATTERIES?

When using batteries in parallel you bump the current value (in this case capacity)

When used in series you add the relative voltage.

Two 9v 600mAh batteries in series = 18v 600 mAh
Two 9v 600mAh batteries in parallel = 9v 1200mAh



DEPARTMENT OF COMPUTER SCIENCE

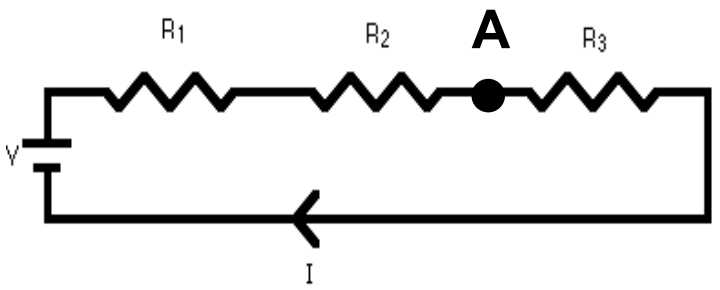
OHM'S LAW

DEPARTMENT OF COMPUTER SCIENCE

CALCULATING RESISTANCE

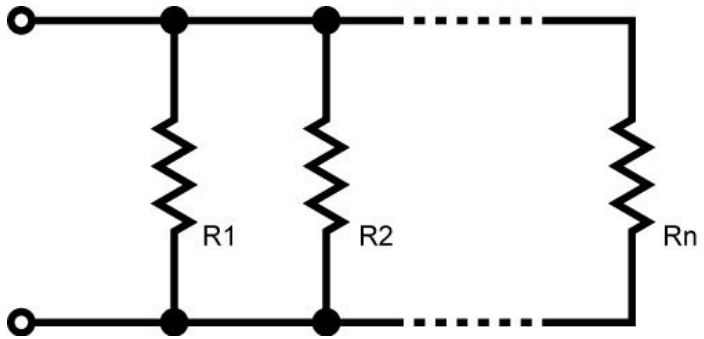
Series R (adds)

$$R_{total} = R_1 + R_2 + R_3$$

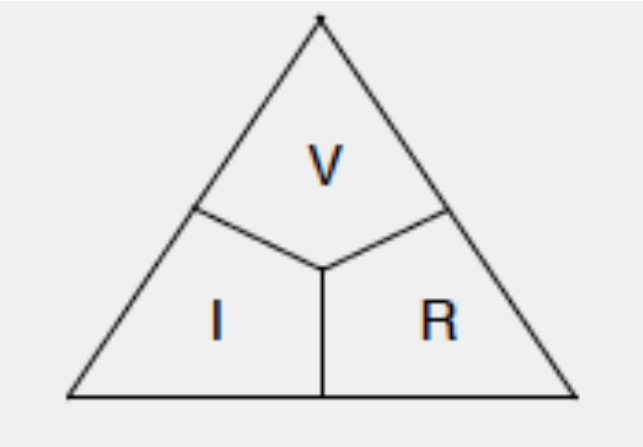


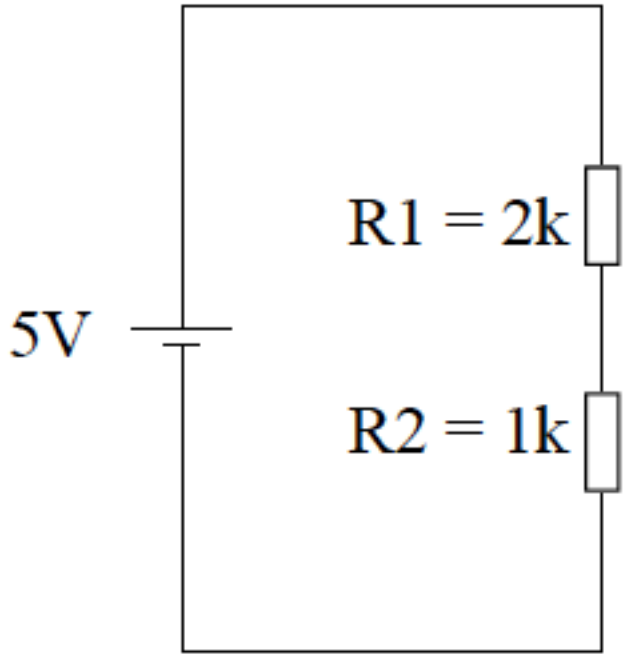
Parallel R (decreases)

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$



When you have only two resistors in parallel: $$R_{tot} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

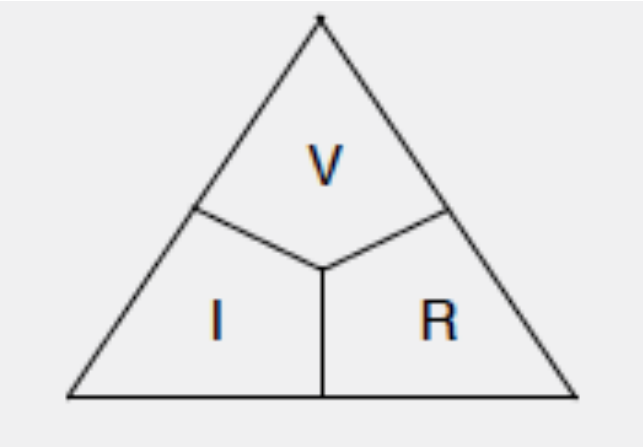


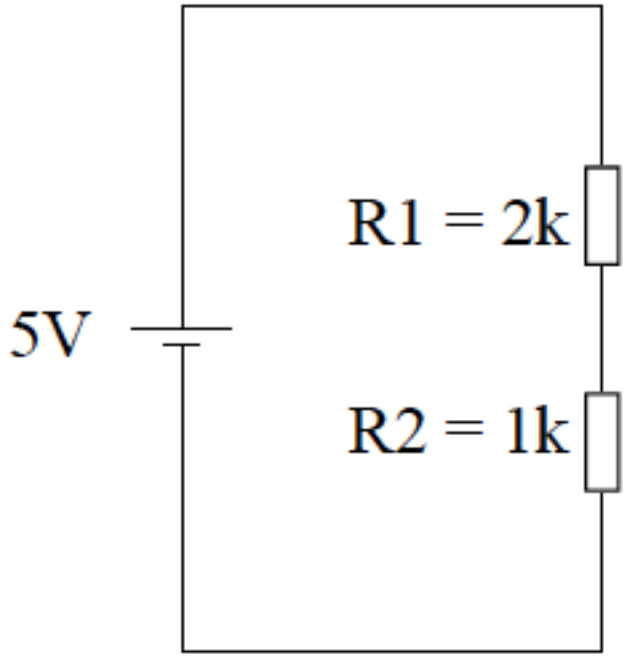


What is the total R in this circuit?

What is the I (in ampere)?

DEPARTMENT OF COMPUTER SCIENCE





What is the total R in this circuit?

TOTAL R= 3KΩ

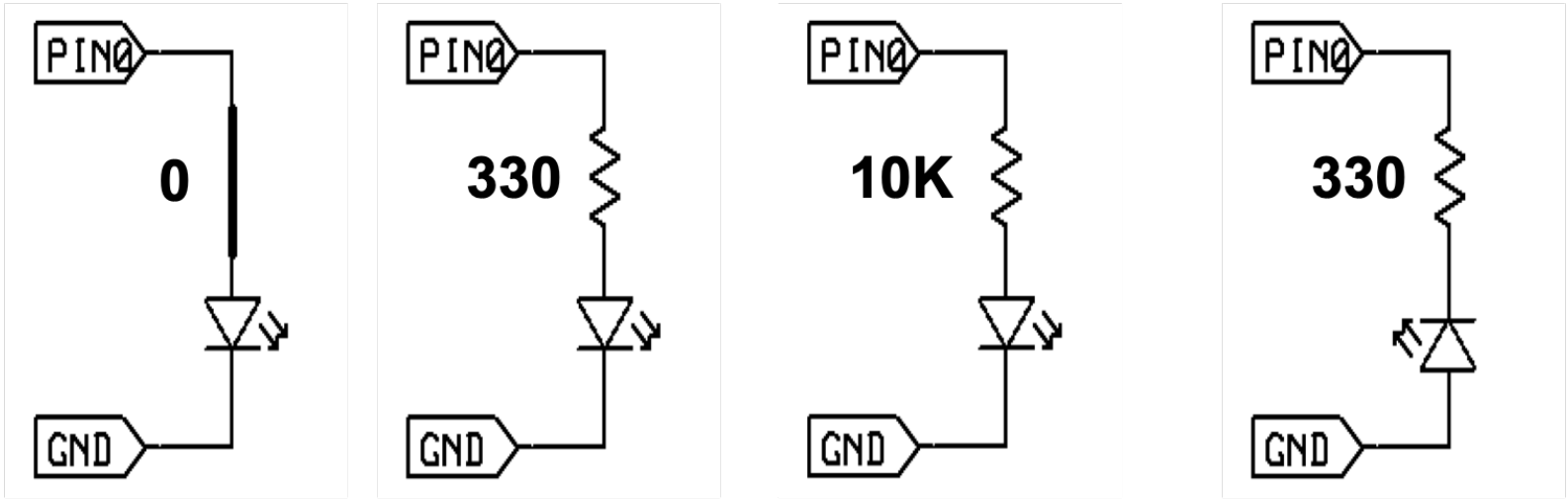
What is the I (in ampere)?

I=5V/3000Ω = 0,00167 A = **1, 67 mA**

Current name	*Meaning*	*Value*	*Symbol*
amp	—	10^{0} A	A
milliamp	one thousandth of an amp	10^{-3} A	mA
microamp	one millionth of an amp	10^{-6} A	µA
nanoamp	one thousand millionth of an amp	10^{-9} A	nA
picoamp	one million millionth of an amp	10^{-12} A	pA
femtoamp	one thousand million millionth of an amp	10^{-15} A	fA

DEPARTMENT OF COMPUTER SCIENCE

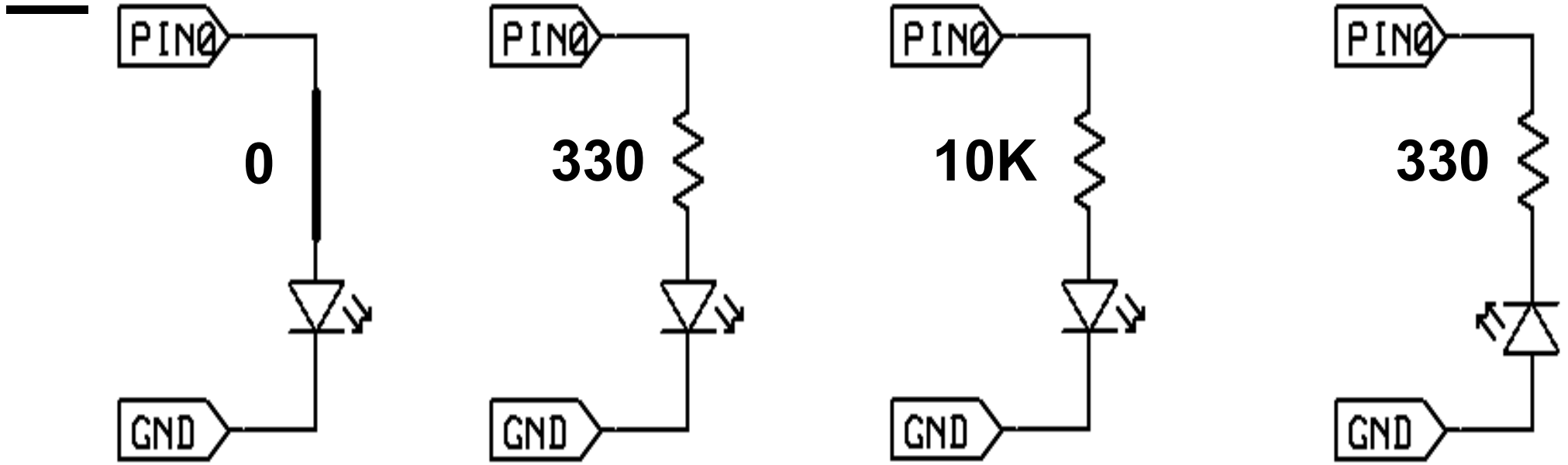
Which of These Work?



Assume Vin of 5V, 5mA, and you want 3.4V to go to the blue

DEPARTMENT OF COMPUTER SCIENCE

Which of These Work?



Assuming voltage of 5 and you want a current of 5milli amps, and you want 3.4 volts to go to a blue led.
We use Ohm's law to calculate the wanted voltage drop before the (sensitive) component.

R = 1.6 (wanted Vdrop) / 0.005 (mA) = 320 ohm.
Closest fixed resistor value = 330.

DEPARTMENT OF COMPUTER SCIENCE

VOLTAGE DIVIDERS

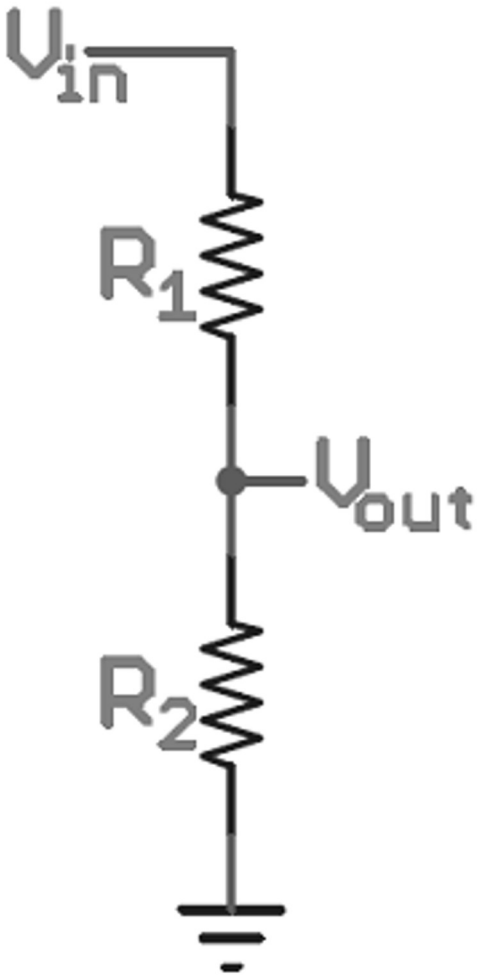
DEPARTMENT OF COMPUTER SCIENCE

VOLTAGE DIVIDERS

Can be used to turn a large voltage into a smaller one, by using 2 resistors in series

If R1 was 1.7kΩ and R2 was 3.3kΩ

- a 5V input could be turned into 3.3V at Vout.



$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

DEPARTMENT OF COMPUTER SCIENCE

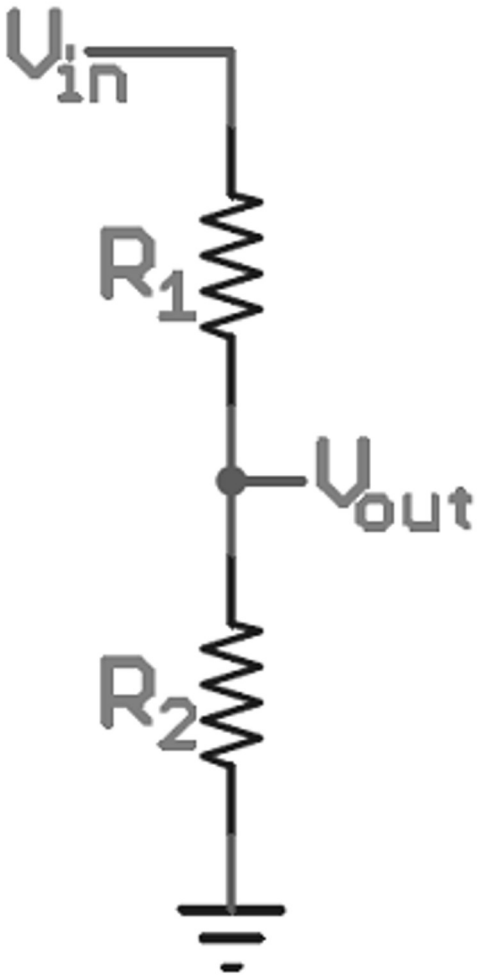
VOLTAGE DIVIDERS

You need two resistors for a voltage divider to divide the input voltage into two different sections and values, creating a specific output voltage at the junction due to voltage drop.

With two resistors in series, the total voltage from the source is divided proportionally (depends on value) across each resistor.

One resistor defines the voltage drop to ground, and the other resistor establishes the point from which the output voltage is measured, allowing you to achieve a desired lower voltage.

A single resistor (without load) is not enough – it would just impact I in Ohm's law, but not result in a voltage drop.



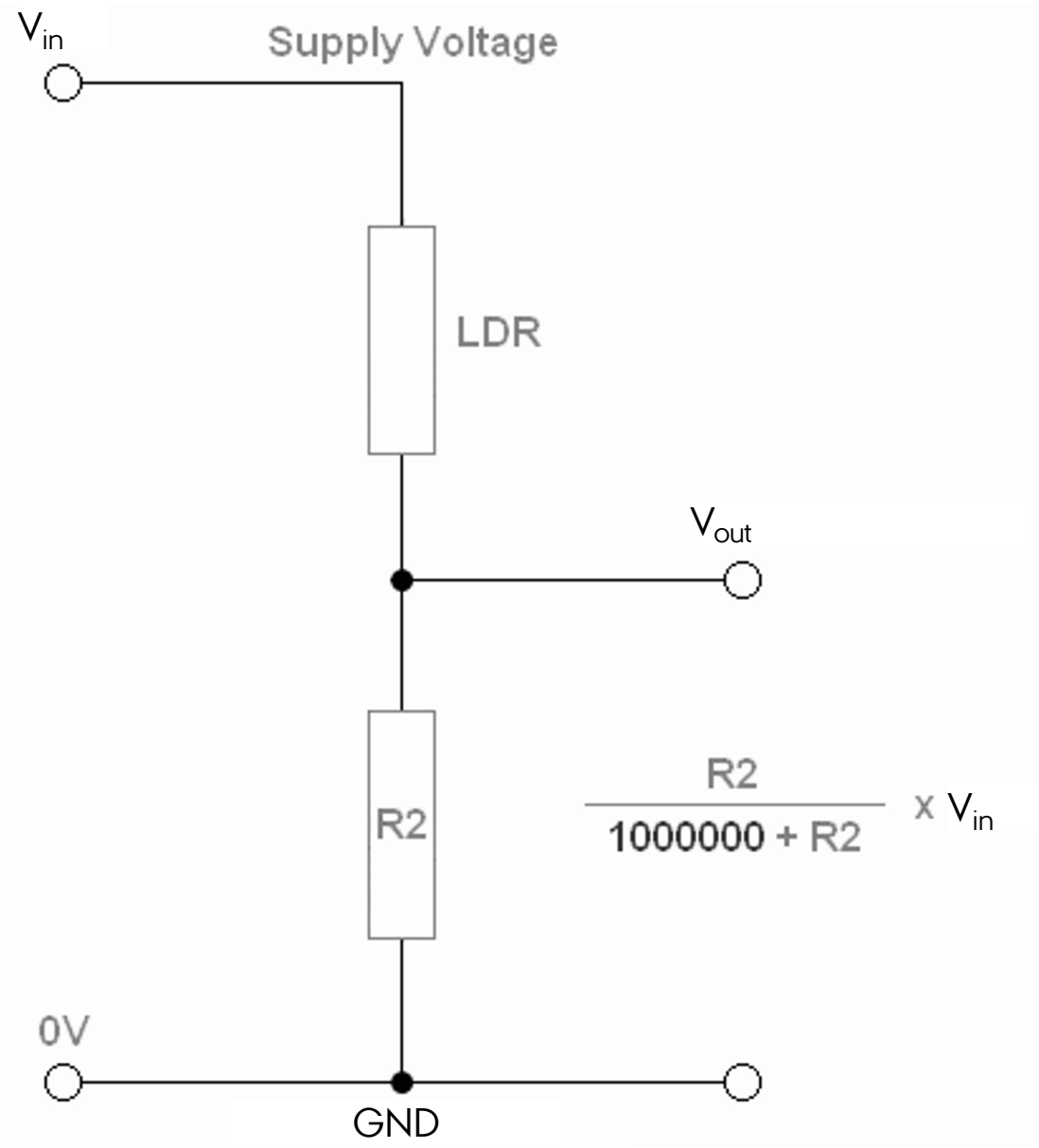
DEPARTMENT OF COMPUTER SCIENCE

LDR VOLTAGE DIVIDER

A Light Dependent Resistor (photocell) can be used as a light sensor because its resistance changes in varying light levels.

Usually, the LDR has 1 MΩ resistance in total darkness and approximately 5.4 kΩ in bright light.

DEPARTMENT OF COMPUTER SCIENCE

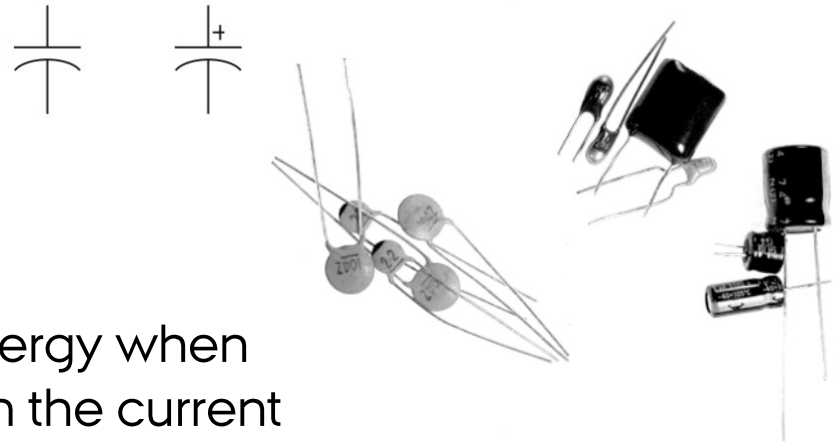


DEPARTMENT OF COMPUTER SCIENCE

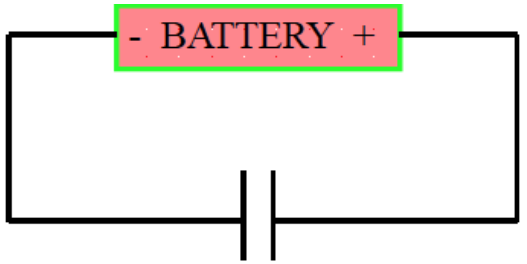
CAPACITORS

DEPARTMENT OF COMPUTER SCIENCE

CAPACITORS



A capacitor is a bit like a savings account. This element stores energy when times are good and electricity is flowing into the capacitor. When the current is removed, the capacitor releases its charge until it is got no charge left.

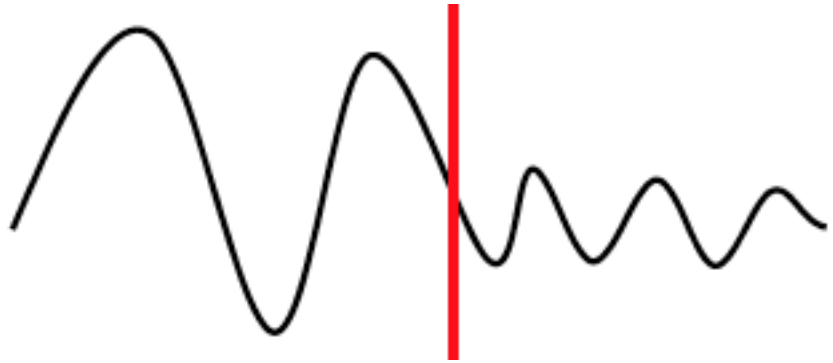


Capacitance (C) measured in Farads (F)

- E.g. microfarads (μF) or picofarads (pF) or nanoFarads (nF)

DEPARTMENT OF COMPUTER SCIENCE

USING CAPACITORS



If the voltage for a microcontroller drops briefly (while you're running a program), the microcontroller restarts.

The capacitor can supply power for the microcontroller when the voltage drops so that the microcontroller doesn't restart.

Capacitors and resistors can be combined to create filters that target specific frequencies.

- E.g. sub-woofer

DEPARTMENT OF COMPUTER SCIENCE

DECOUPLING CAPACITORS

DEPARTMENT OF COMPUTER SCIENCE

DECOUPLING CAPACITORS

Decoupling capacitors supress high-frequency noise in power supply signals

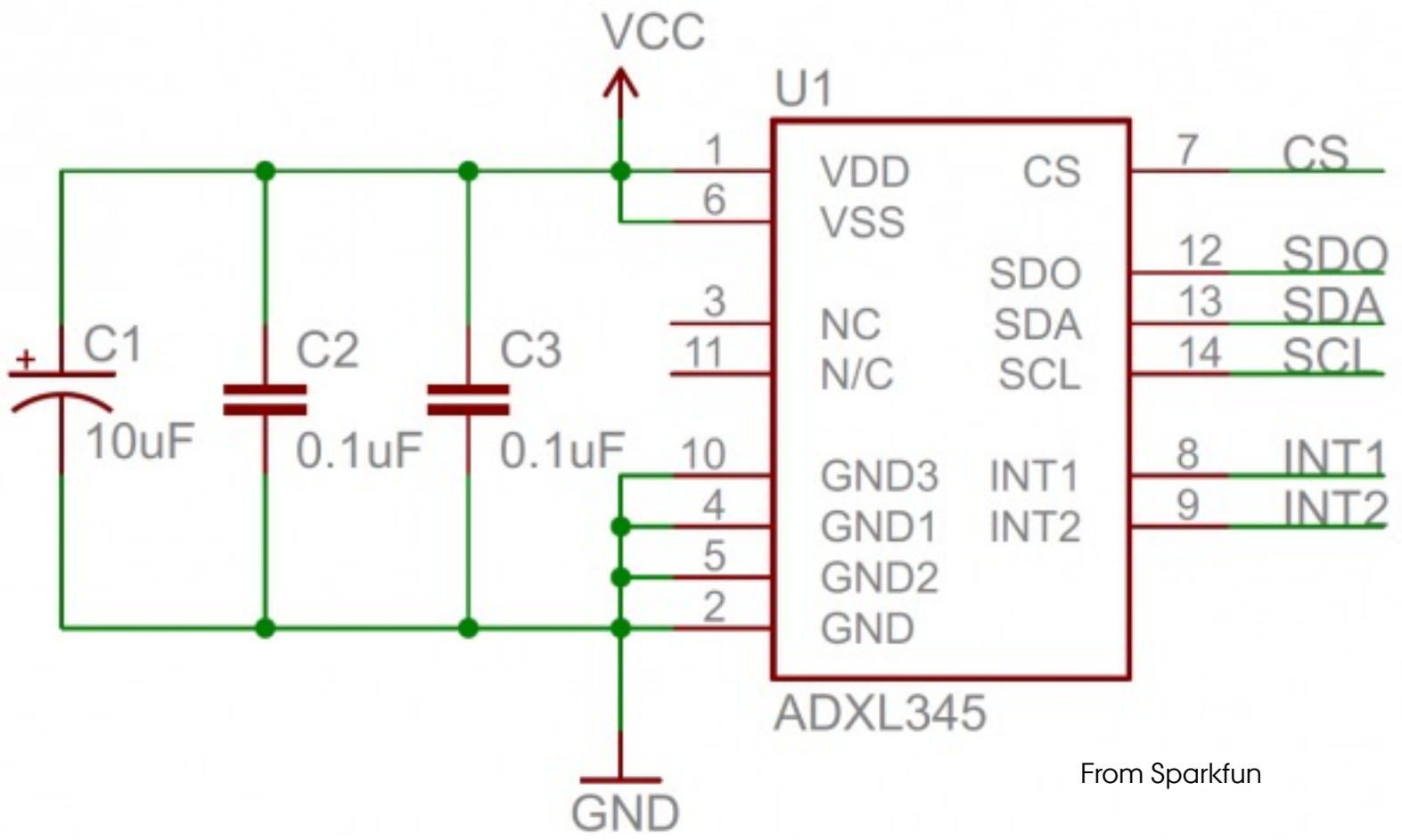
If the power supply temporarily drops its voltage, a decoupling capacitor can briefly supply power

How to Use

- Place the capacitor between the VCC and GND
- Should always be located as close as possible to the IC
- Try using a 10µF and 100nF

DEPARTMENT OF COMPUTER SCIENCE

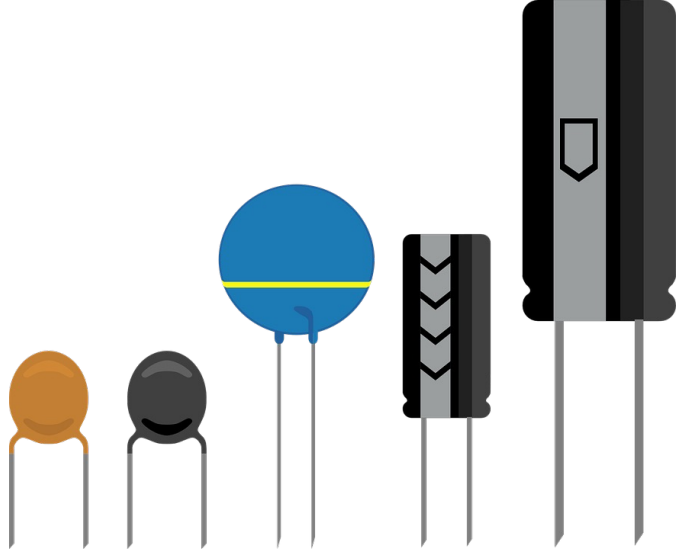
DECOUPLING CAPACITORS



From Sparkfun

DEPARTMENT OF COMPUTER SCIENCE

POLARIZED CAPACITORS



It's very important not to mix their polarity up.

Ceramic capacitors are not polarized, so you don't need to worry

Electrolytic capacitors are polarized.

Applying the wrong polarity will block your circuit and destroy the capacitor!!!

DEPARTMENT OF COMPUTER SCIENCE

CHOOSING A CAPACITOR

All capacitors have a maximum voltage rating.

- a capacitor should be selected so that its working voltage should be at least 50 % greater than the highest voltage to be applied to it.

Ceramic capacitors have values ranging from a few picofarads to one or two microfarads, (μF) but their voltage ratings are generally quite low.

Electrolytic capacitors are generally used when very large capacitance values are required.

Follow datasheet or suggested capacitors for context (online sources). Calculating capacitor value is beyond scope of this course.

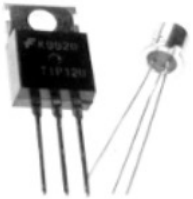
DEPARTMENT OF COMPUTER SCIENCE

TRANSISTORS

DEPARTMENT OF COMPUTER SCIENCE

TRANSISTORS

Solid semiconductor elements that are switching devices



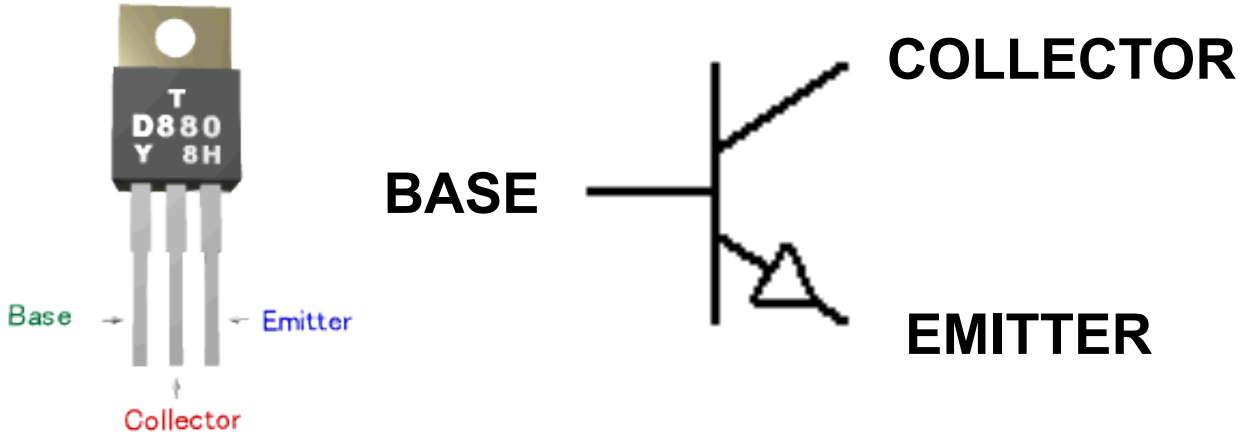
They can be thrown by an electronic signal e.g. from a microcontroller

They can be used for amplification, voltage stabilization, signal modulation and many other functions

DEPARTMENT OF COMPUTER SCIENCE

TRANSISTORS

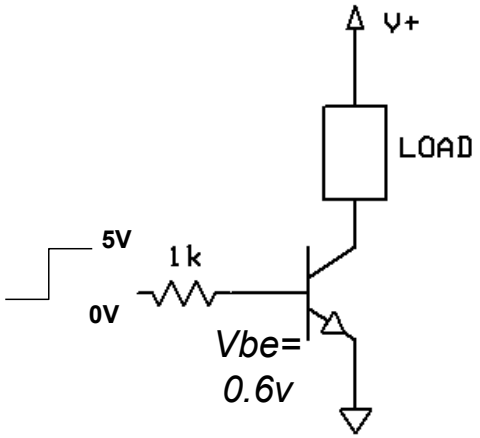
A small current flowing into the *base* and down to GND through the *emitter* of the transistor will switch a much larger current flowing from the *collector* to the *emitter*.



DEPARTMENT OF COMPUTER SCIENCE

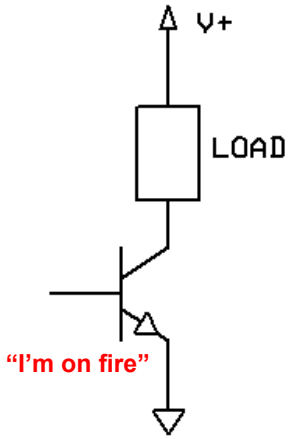
TRANSISTORS REQUIRE A RESISTOR

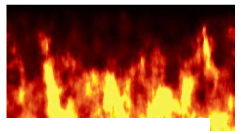
I_b = (5-.6)V /1KΩ
= 4mA



OK

I_b = (5-.6)V/ 0 Ω
= ∞ A





DEPARTMENT OF COMPUTER SCIENCE

TRANSISTORS

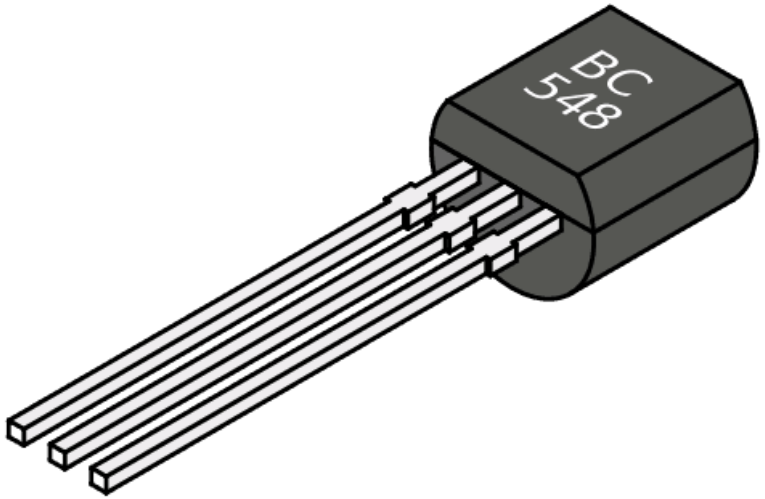
Like an electronic switch.

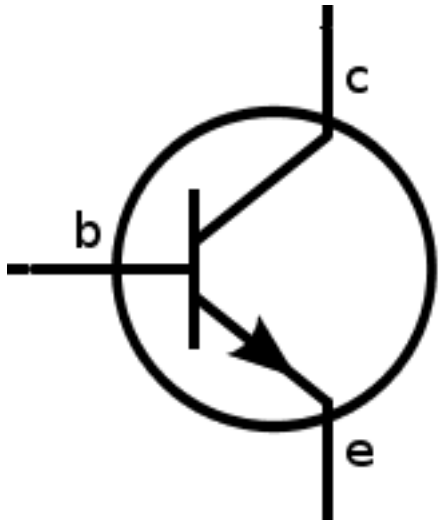
- It can turn a current on and off.

A common transistor is the “bipolar junction transistor” or “BJT”.

3 pins: Base (b), collector (c) and emitter (e).

NPN or PNP.





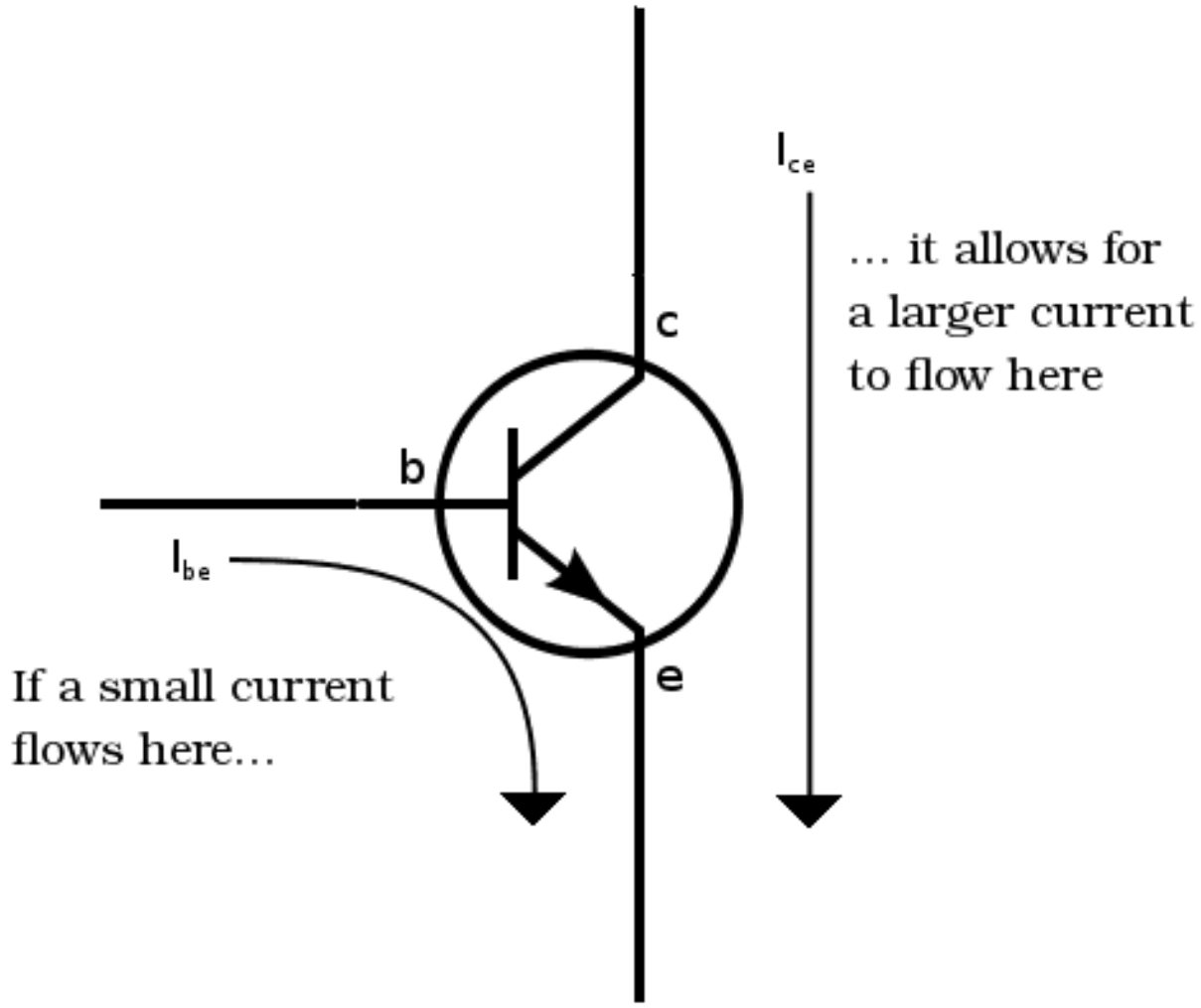
DEPARTMENT OF COMPUTER SCIENCE

CURRENT FLOW

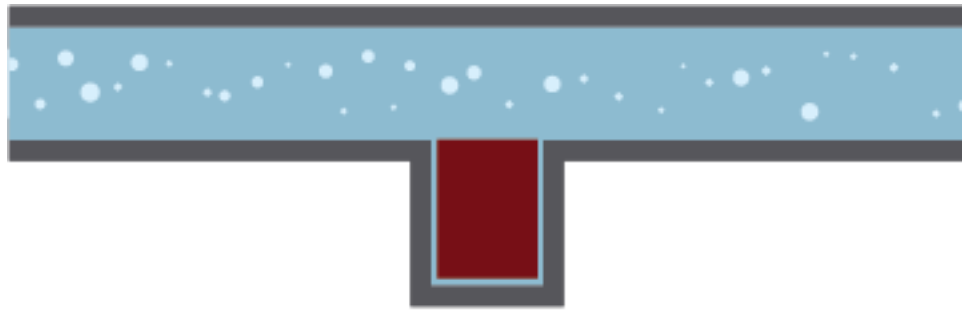
A current flowing from the base to the emitter "opens" the flow of current from the collector to the emitter.

Amplification: a transistor can be anywhere in between "fully on" and "fully off".

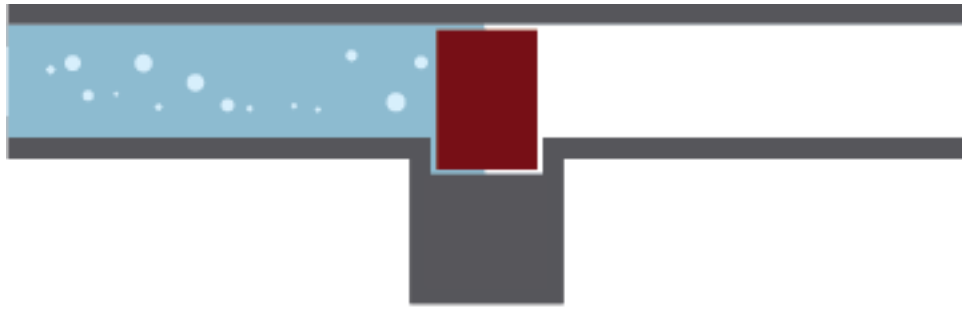
- A small control current can then control how big the main current is.



DEPARTMENT OF COMPUTER SCIENCE



Transistor On



Transistor Off

Flow Control

DEPARTMENT OF COMPUTER SCIENCE

From Sparkfun

NPN AND PNP

NPN: positive voltage to the collector terminal and positive voltage to the base
PNP: positive voltage to the emitter terminal and a negative voltage at the base terminal

In an NPN transistor, output current flows from the collector to the emitter.
In a PNP transistor, output current flows from the emitter to the collector.

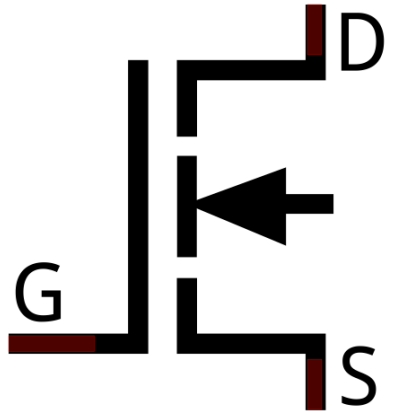
Transistors (PNP vs NPN) https://www.youtube.com/watch?v=F-Cv7CMHoGM

DEPARTMENT OF COMPUTER SCIENCE

MOSFETS

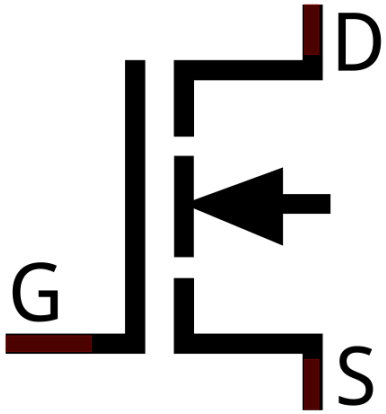
Metal- oxide-semiconductor field-effect transistor (MOSFET)

Will turn on as long as the voltage at its “gate” connection is greater than a certain threshold (voltage thrown as opposed to current thrown).



DEPARTMENT OF COMPUTER SCIENCE

MOSFETS AND BJTS



A MOSFET has a gate, drain, and source

- the drain is equivalent to the collector of a BJT.

BJTs are current-controlled devices

- BJTs are switched on by a current going through the base of the transistor.

MOSFETs are voltage-controlled. Voltage, not current, either turns the transistor on or off.

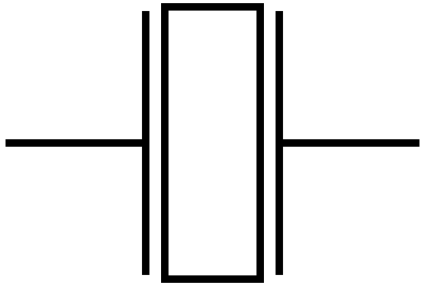
- MOSFETs have such high input impedance that they practically draw no current into the gate terminal.

DEPARTMENT OF COMPUTER SCIENCE

CRYSTALS

DEPARTMENT OF COMPUTER SCIENCE

CRYSTALS



Provides a clock input to your microprocessor.

Measured in Hz

When a voltage source is applied to a small thin piece of quartz crystal, it changes shape (aka the Piezo-electric effect).

This shape change produces mechanical vibrations or oscillations which can be used as a waveform for a clock.

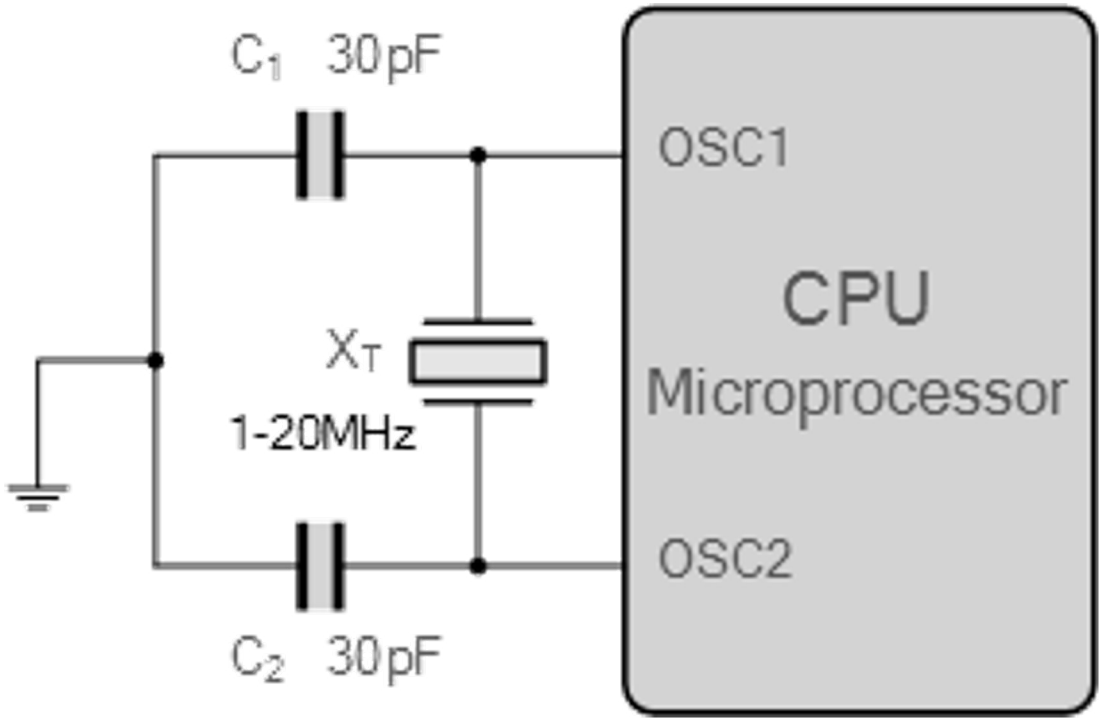
DEPARTMENT OF COMPUTER SCIENCE

https://commons.wikimedia.org/w/index.p

CRYSTALS

For a microprocessor clock waveform, you need a crystal and 2 ceramic capacitors with values between 15 to 33pF

Most microprocessors have 2 pins (OSC1 and OSC2) to connect to an external quartz crystal circuit



DEPARTMENT OF COMPUTER SCIENCE

DIODES

DEPARTMENT OF COMPUTER SCIENCE

DIODES

A diode is like one-way street allowing electricity flow in only one direction

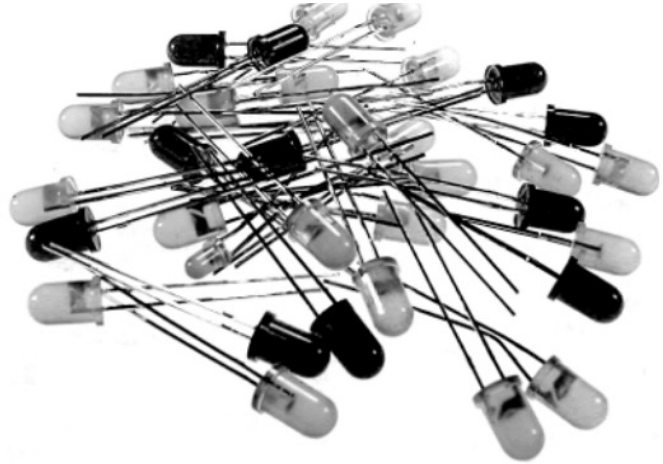
Polarized

- Two sides: cathode (-) and anode (+)
- Electricity flows from + -> -

Most diodes start to work when the voltage exceeds 0.7 Volts

LEDs can be found in all sort of devices

General purpose diodes e.g. 1N4002

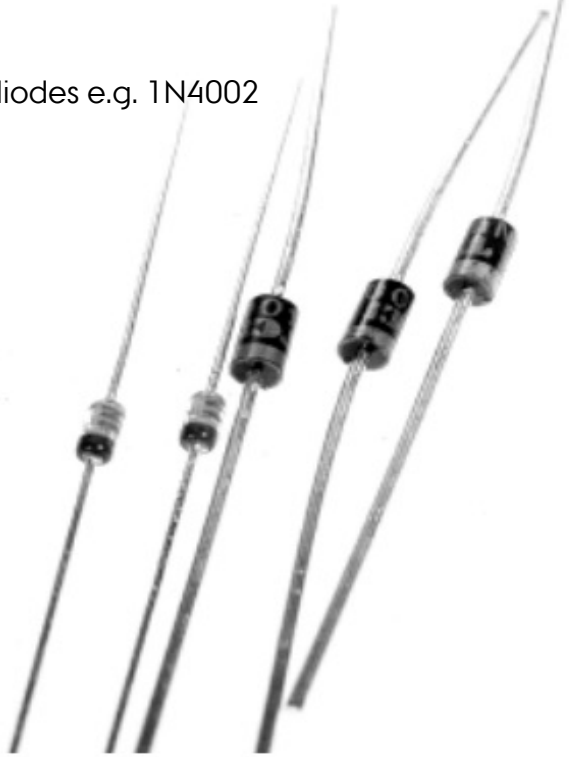


LED (Light Emitting Diode)

DEPARTMENT OF COMPUTER SCIENCE

DIODES

General purpose diodes e.g. 1N4002



Rectification:

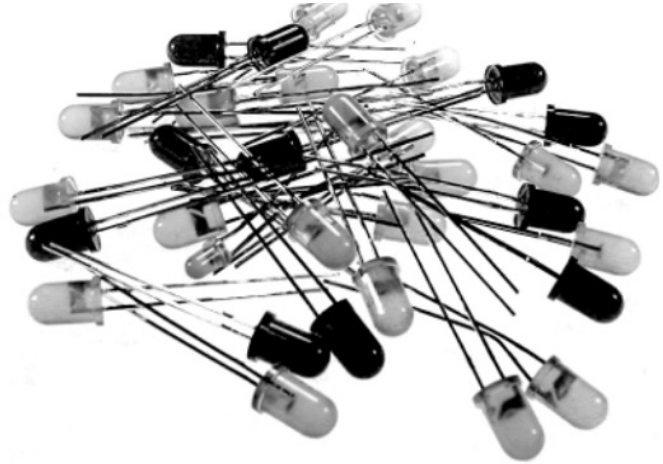
Diodes can be used to convert AC, that periodically reverses direction by design, into DC which flows in one direction. This is vital for powering most electronic devices, and a part of transformers.

Circuit Protection (!!!):

Diodes protect circuits and their components from damage caused by reverse voltage, overcurrents, and voltage spikes.

Flyback Diode in Inductive Loads (!!!):

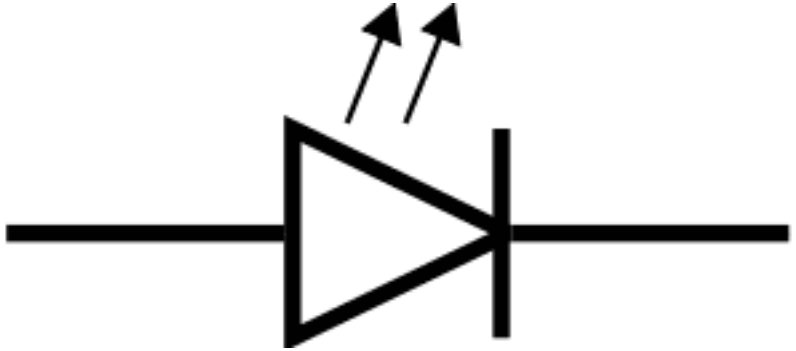
In devices with inductive components (like relays and motors), a diode is placed across the coil to provide a path for the large voltage spike created when the current is interrupted, preventing damage to the control transistor (and the rest of the circuit).



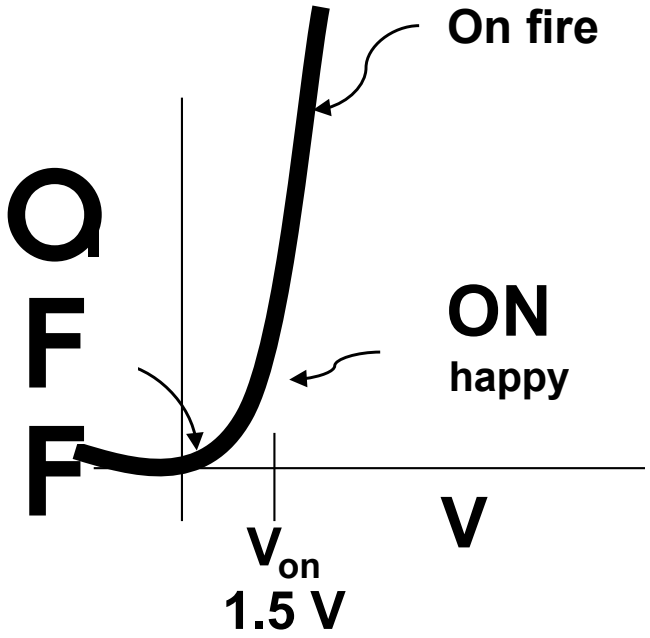
LED (Light Emitting Diode)

DEPARTMENT OF COMPUTER SCIENCE

LEDS



Only allows current in one direction

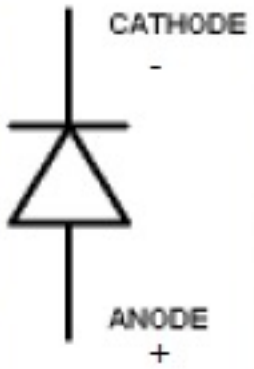


http://www.seeedstudio.com/depot/8mm-RGB-Led-lamp-common-anode-10-PCs-p-621.html

DEPARTMENT OF COMPUTER SCIENCE

How to recognize the cathode (-) and the anode (+) in different types of diodes

sign:	+	–
polarity:	positive	negative
terminal:	anode	cathode
wiring:	red	black
pinout:	long	short
interior:	small	large
shape:	round	flat
marking:	none	stripe



DEPARTMENT OF COMPUTER SCIENCE

SUMMARY

Electronic circuits

Basic components – Resistors

- Types
- Calculating resistance
- Series and Parallel
- Voltage Dividers

DEPARTMENT OF COMPUTER SCIENCE

SUMMARY

Circuit diagrams

Capacitors

Transistors
- BJTs
- MOSFETs

Crystals

Diodes

DEPARTMENT OF COMPUTER SCIENCE

EXAMPLE EXAM QUESTIONS

DEPARTMENT OF COMPUTER SCIENCE

EXAMPLE EXAM QUESTIONS

On a diode, what would be indicated by a grey marking at one end?

- Anode
- Tolerance of 10%
- Cathode

What is the function of a capacitor?

How does a resistor prevent damage to components in a circuit?

Which of the following could be used to make a voltage divider?

- A resistor and a capacitor in series
- Two resistors in parallel
- Two resistors in series

DEPARTMENT OF COMPUTER SCIENCE

EXAMPLE EXAM QUESTIONS

Two resistors with resistance values 1.2 kilo-ohms and 2.2 *kilo-ohms* are connected in series.

- Determine the total resistance of the network.

Two resistors are combined in parallel. If they have values of 100 ohms and 1.2 kilo-ohms, determine the value of their combined resistances.

DEPARTMENT OF COMPUTER SCIENCE

FURTHER READING

https://learn.sparkfun.com/tutorials/how-to-read-a-schematic

https://learn.sparkfun.com/tutorials/resistors

DEPARTMENT OF COMPUTER SCIENCE

USEFUL VIDEOS

Basic water analogy (series and parrallel circuits):
https://www.youtube.com/watch?v=7_7NO2Np5-s

Resistors: https://www.youtube.com/watch?v=VPVoY1QROMg

DEPARTMENT OF COMPUTER SCIENCE

FURTHER READING AND USEFUL VIDEOS

https://learn.sparkfun.com/tutorials/capacitors

https://learn.sparkfun.com/tutorials/diodes

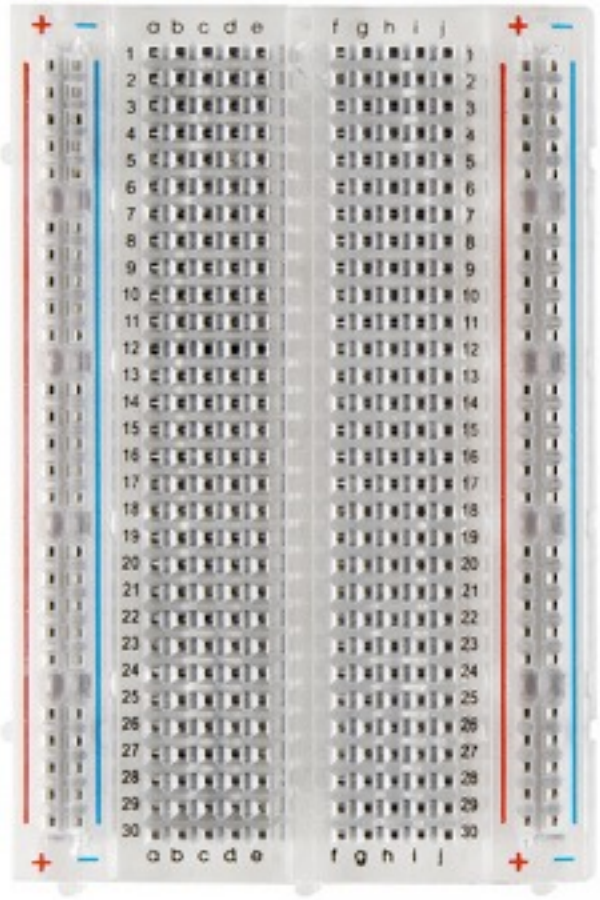
Diodes: https://www.youtube.com/watch?v=BXOS5czCb3Q

Capacitors: https://www.youtube.com/watch?v=otQGdPLyF3w

Transistors: https://www.petervis.com/GCSE_Design_and_Technology_Electronic_Products/Transistor_as_a_Switch/Transistor_as_a_Switch_Using_LDR.html

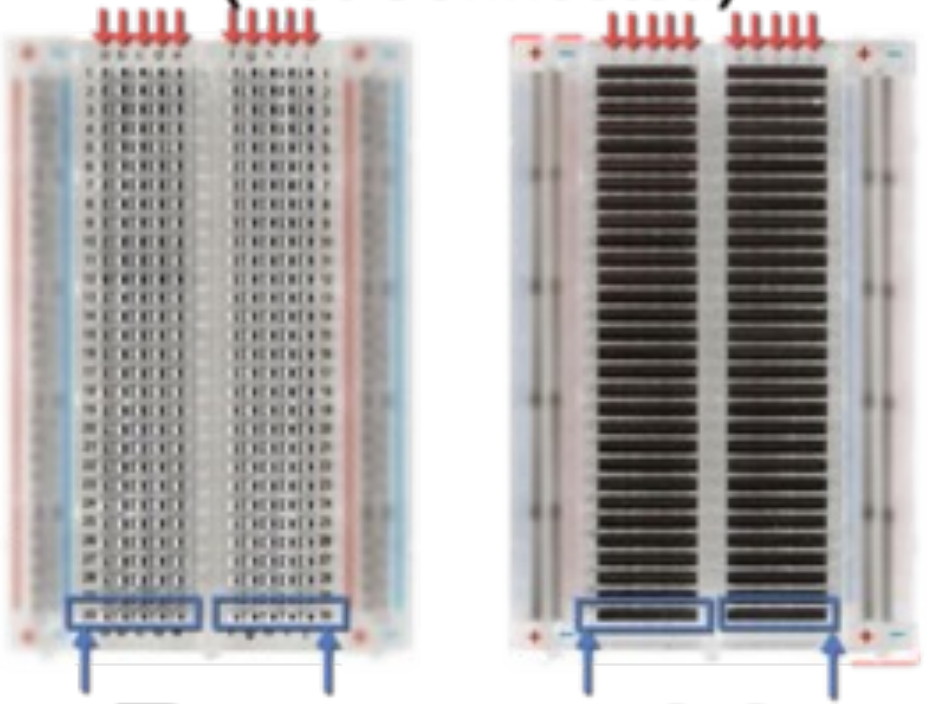
DEPARTMENT OF COMPUTER SCIENCE

BREADBOARDS



Columns a-f

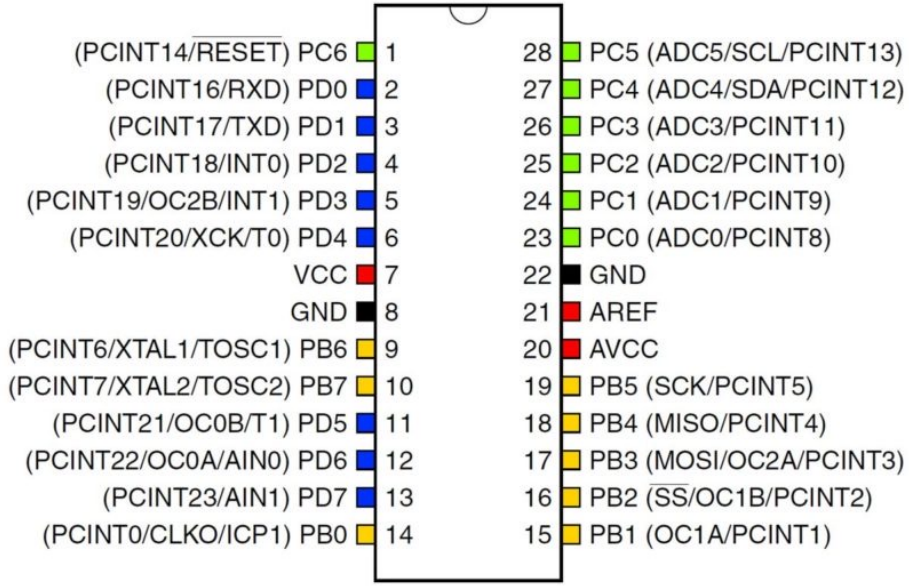
(Not Connected)



Rows 1-30

(Connected)

ATMEGA 328PU

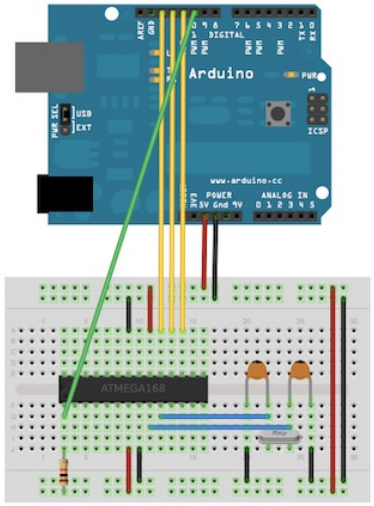


TASK 1 – BURN BOOTLOADER

Update to latest Arduino IDE

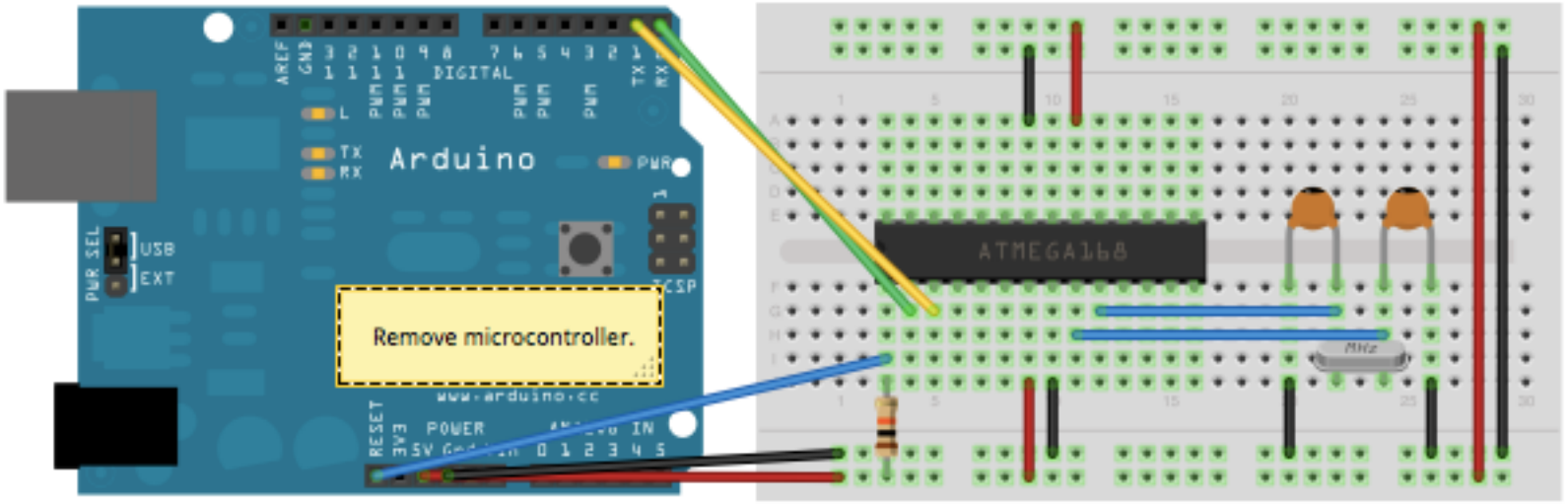
Follow the instructions here:

- https://docs.arduino.cc/built-in-examples/arduino-isp/ArduinoToBreadboard/



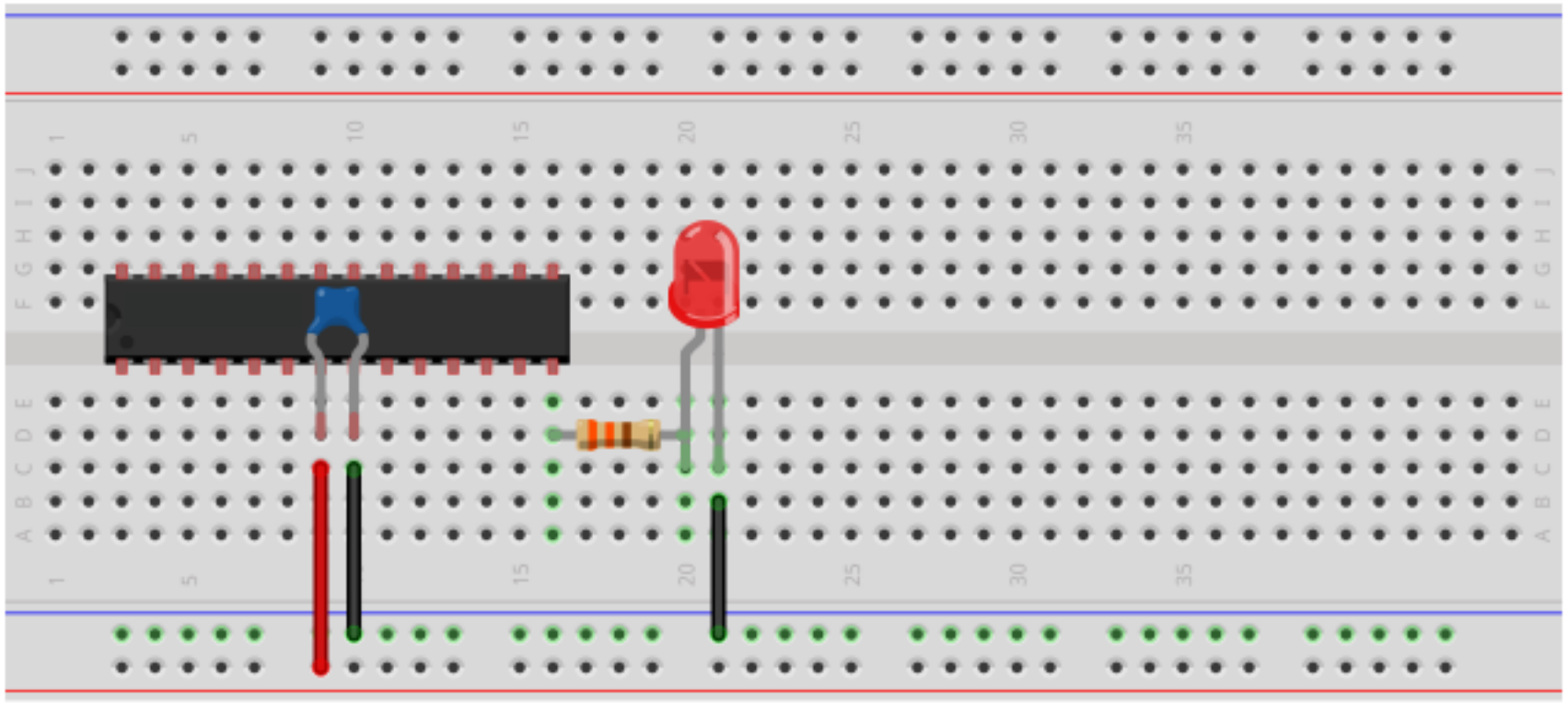
TASK 2 - UPLOAD

- https://docs.arduino.cc/built-in-examples/arduino-isp/ArduinoToBreadboard/



TASK 3 – BLINK LED

https://www.arduino.cc/en/Tutorial/Blink



HOW TO ”PASS” THE PRACTICAL EXERCISES

A quick demonstration of working prototype/finished practical exercise should be shown to Eve, Simon, or a TA.

Preferably during Study Café or lab session

Deadline: 09/09/2025

If you’re unable to attend at some point, so you can’t demonstrate, please write an email to Eve.

DEPARTMENT OF COMPUTER SCIENCE

DEPARTMENT OF COMPUTE