**PHYSICS**

**Electricity**

Electricity is the flow of electric charge carriers: electrons (in most cases). Electrons are the negatively charged particles that whirl around the positively charged nucleus (core, plural: nuclei) of an atom. Electrons can move easily through metals, like copper, silver, gold ... We call these materials conductors. These materials have freely moving electrons. Materials like plastic, wood, glass, air ... don't conduct electricity very well. They are called insulators.  
They don't have moving electrons or other charge carriers. A piece of material that has more negative charges (electrons) than positive ones (nuclei with positive protons), is negatively charged. A piece of material that has less negative charges than positive ones, is positively charged. (Note that only the electrons can move, the positive nuclei are stuck in a grid.)

**Current**

Just like magnets, opposite charges attract each other: when you have one piece of material that has more electrons, and one piece that has less electrons, the electrons in the negative piece will be attracted to the positive piece. If there's a conductor in between these pieces, these electrons will 'flow' to the positive part: This is electric current. Current expresses the amount of charges that flow through a conductor per unit of time. Its unit is Amps (Ampère), and is defined as C/s, where C is Coulomb (charge) and s is seconds (time). Its symbol is I.

**Voltage**

A battery has a negative side that has more electrons, and a positive side that has fewer electrons. Like I said earlier, the electrons will try to reach the positive side, but they cannot go through the internal circuit of the battery itself. This gives the electrons potential energy. This is the energy that is released as light and heat in a bulb, as motion (kinetic energy) in a motor ... The difference in potential energy of a charge at the positive and a charge at the negative side, is called the voltage. The unit is Volts, and is defined as J/C, where J is Joule (SI-unit of energy) and C is Coulomb (SI-unit of charge). This expresses how much energy a certain charge (read: certain amount of electrons) releases.  
The symbol for Volts is V or U (from the German word 'Unterschied', difference, and refers to the potential difference).

**Power**

Power is the amount of energy that is released per unit of time. The SI unit is Watts, and is defined as J/s where J is Joules, and s is seconds. If you multiply current by voltage (C/s ∙ J/C) the C cancels out, so you get J/s. This means that voltage multiplied by current gives you the wattage.

In most schematics, the conventional current flow is used: arrows are drawn from the positive side to the negative side. In practice, however, only electrons can move, so the actual direction of the current flow is from the negative side to the positive side.

**Components**

### Resistors

Resistors are components with - as the name implies - an [electrical resistance](https://en.wikipedia.org/wiki/Electrical_resistance_and_conductance), in other words, they limit the flow of electrons, so they are often used to limit the current.

The SI unit of resistance is Ohms, often written as the Greek letter omega (Ω). They are often used with the unit prefixes kilo (k) and mega (M). E.g. 1.2MΩ = 1M2Ω = 1,200kΩ = 1,200,000Ω = 1,200,000E = 1,200,000R. (note that writing a digit after the unit prefix is the same as writing it after the decimal point. Also, in some schematics, E or R are used instead of Ω).

The value of a resistor is indicated by 4 (or 5) colored bands, using the resistor color code:  
The first 2 (or 3) bands are the 2 (or 3) first digits of the value, and the 3rd (or 4th) band is the power of ten that comes after those 2 (or 3) digits. This is also called the multiplier, and is just the number of zeros you have to add. The last band is the tolerance, and is mostly silver or gold.  
E.g. red red red gold = 22 x 100Ω = 2,200Ω = 22 x 10² Ω = 2k2Ω = 2.2kΩ, with a tolerance of 5%; green blue black brown red = 560 x 10Ω = 5,600Ω = 5k6Ω = 5.6kΩ, with a tolerance of 2%.

The relationship between resistance, voltage and current can be calculated using **Ohm's Law**.

**I = V/R**

where I is the current in Amps, V the voltage in Volts, and R the resistance in Ohms.  
This is a very, if not the most important formula in electronics, so try to remember it!

### Capacitors

A capacitor is an electrical component that can store electrical charge (in the form of electrons).  
Although they are fundamentally different, in some ways, it behaves like a small rechargeable battery.   
When a voltage is applied to a capacitor, the potential difference (a difference in number of electrons → the side with more electrons has a negative charge, compared to the other side) These electrons can flow out of the capacitor again, when the voltage is no longer applied, just like a battery.

Capacitors are used in filters, for example to filter out the 50/60Hz noise from your power supply, or to filter high frequencies out of your music when you turn on the low-pass filter, or turn the bass and treble knobs on your amplifier. In these cases, the capacitor charges and discharges really quickly.  
Another use for the capacitor, is filtering out DC voltage.

The SI unit of capacitance is Farad, or F. This is a very large unit, and most often, you'll see prefixes like pico (p), nano (n) or micro (µ).

On some smaller capacitors, the capacitance is written using a three-digit number. The first two digits are the first two digits of the value, and the third digit is the power of ten to multiply it with. The unit of the value you get is picofarad.  
E.g. 104 = 10 x 10⁴ = 100,000 pF = 100 nF = 0.1 µF (= 0.0000001 F)

Larger capacitors, the electrolytic type, (mostly the cylindrical ones) have a polarity, marked by a grey line. If you connect them the wrong way around, they can explode, be careful!

### MOSFETs

Another type of transistor is the MOSFET, acronym for Metal Oxide Semiconductor Field Effect Transistor.  
The MOS just stands for the materials it is made of, and FET signifies that the amount of current that is let through is controlled by a field, an electric field, more specifically. Physics tells us, that the higher the voltage, the stronger the electric field, so we can control the current using a voltage, whereas the normal (Bipolar Junction Transistor or BJT) uses current to control the current.

A MOSFET also has three pins: a gate (G), a drain (D) and a source (S).  
The source is where the electrons come from, and they flow to the drain. This flow is controlled by the voltage at the gate (and its accompanying electric field). By analogy with the transistor, the gate can be compared to the base, the source to the emitter, and the drain to the collector.

An advantage of a MOSFET over a BJT is the higher efficiency: when fully turned on, a MOSFET has a D-S resistance of a few tens of milliohms. This results in much less power (heat) dissipation when driving high-current loads.   
Also, no current flows from the gate to the source.

A disadvantage though, is that you need about 10v on the gate for most MOSFETs to be fully on. This is 2-3 times higher than the voltage of an Arduino output pin, for example.

### Diodes

Just like a transistor, a diode is a semiconductor device. One of the interesting properties of a diode, is that they only conduct electricity in one direction.   
For example, Arduino boards have a diode in series with their power input jack, to prevent you from reversing the power, and damaging the chip.

Diodes have a forward voltage drop ranging from 0.5v to 0.7v. This means that if you measure the voltage before the diode, it will be about 600mV higher than after the diode.

Of course, a diode has its limits: if the reverse voltage is too high, it will break, causing it to let current pass in the wrong direction. In some diodes, this is done in a controlled way. These diodes are called zener diodes. They will only conduct if the voltage is higher than a certain value, specific to the zener.  
This value is constant, so zener diodes can be used as a reference in voltage regulators.

### LEDs

An LED, acronym for Light Emitting Diode, is like a normal diode, but they emit the energy (that is lost because of their forward voltage drop) as light, instead of heat. Their voltage drop is higher than a normal diode: ranging from 1.2v for an infrared LED, up to 3.5v for blue, white and ultraviolet LEDs.

If the current going through the LED is to high, it will die. To prevent this, a resistor in series is used.   
Always do this, otherwise, you'll kill the LED within a second.

### Relays

A relay is a mechanical current-controlled switch. It consists of a coil, next to a piece of metal, that is pulled back by a spring. When current flows through the coil, it generates a magnetic field that attracts the piece of metal and makes a connection.

The advantage is that you can control very high-current or AC loads, and they add virtually no extra resistance.  
The disadvantages are that relays are slow, since they have to move physically, they are more fragile, due to the moving parts, and they can create sparks.

(To prevent sparks and interference when switching heavy loads, you should use a [snubber circuit](https://en.wikipedia.org/wiki/Snubber).)

### Other Parts

Of course, there are countless other components you can use in your Arduino projects:

**Microphones and speakers:** Dynamic microphones have a coil and a magnet to convert the vibrations of the air to electrical signals. Similarly, speakers use a coil that moves in a permanent magnetic field to generate those vibrations, when fed with an AC signal. Electret microphones translate air movement to changes in capacity. Piezo disks convert vibration to voltage, and vice versa, so they can be use as both a mic and a small speaker.

**Switches:** switches are easy input devices for your Arduino, they exist in all shapes and sizes.

**Variable resistors or potentiometers:** this is just circular resistive trace, and a wiper, connected to a turning shaft, that changes the resistance as it moves along the trace.  
Small versions without a shaft are called trim pots.

**ICs and chips:** There's an immensely wide variety of ICs available, like voltage regulators, microprocessors, op-amps, amplifiers, logic gates, memory, timers, and so on.

**Sensors:** You can find a sensor for virtually anything, light sensors, temperature sensors, distance sensors, alcohol sensors, even GPS modules, cameras ... Other variants are optointerrupters, reed (magnetic) switches ...

**Rotary or optical encoders:** they convert movement to a series of pulses, like the volume knob in your car, or knob on your microwave oven.

**Displays:** LCD displays can be used (some with touchscreen), or simple 7-segment LED displays, even small OLED displays are available.

**Fans, coils and motors:** computer fans, solenoids, DC motors, stepper motors, servos, and so on.