Electricity & Electronics

v1.1

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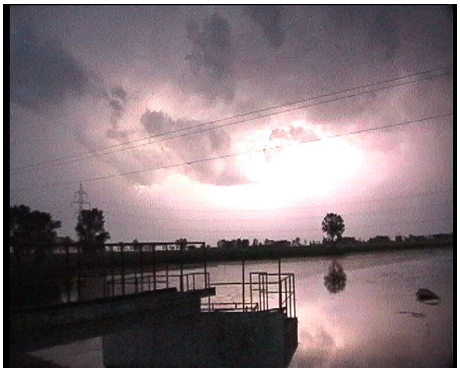
Electricity

Electricity is a flow of electrons. It is measured with *voltage* and *current*. Electricity occurs naturally in lightning and some fish produce electricity to stun their prey. Our bodies use electricity to control our muscles.

Static electricity (like you hear when pulling off a fleece jersey) is electricity that has high voltage but very little current. The word “static” means non-moving and refers to the lack of current of static electricity.

Electricity can be dangerous. Never put anything into a light socket or wall outlet that shouldn’t be put there. Be extremely careful when using high voltages or high current.



Lightning over a water reservoir near Timisoara, Romania

Voltage

Voltage is the grunt behind the electricity – the electro-motive force.

Two common ways of increasing voltage are connecting multiple batteries in *series*, or using a *transformer* to step the voltage up. (However, transformers are normally used to step voltage down. See *inductors* for details on transformers.)

Current

Current describes how many electrons are flowing. The more current, the more electrons are flowing. Current is measured in amps (also called amperes). The symbol for amps is A, but just to confuse things, the symbol for current is I (see *Ohm’s Law*). To confuse things even more, **conventional current** flows from positive to negative. Electrons are negatively charged and actually flow in the opposite direction, from negative to positive.

Alternating current (like the mains power in our homes) keeps changing the direction in which it flows. This happens many times a second. **Direct current** always flows in the same direction.

Resistance

Resistance is the opposition of an object to current passing through it, resulting in a change of electrical energy into heat or other form of energy. The greater the resistance, the less current is let through. Resistance is measured in ohms, with the symbol Ω (omega, the last letter of the Greek alphabet).

Ohm’s Law

Ohm’s Law is a formula used in electronics to calculate an unknown amount of voltage (V), current (I), or resistance (R). It was named after the German physicist Georg Simon Ohm (born 1787, died 1854). The formula can be rewritten several ways.

$$V = I \times R$$
$$I = V \div R$$
$$R = V \div I$$

Ohm’s Law is useful because we can use it to calculate the required value of components in an electronic circuit. This means (for example) that a resistor for an LED torch can be chosen so the torch can work as brightly as possible without risking burning out the LED.

Batteries, Cells

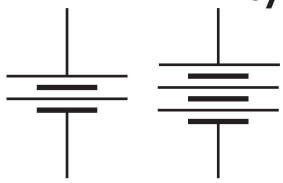
A **battery** is a self-contained device that converts chemical energy to electrical energy, delivering it on demand. A battery is made up of one or more *cells* and produces *direct current*.

A **cell** is a building block of a battery. Multiple cells may be used in a battery to make up the required battery voltage. Typical cell voltages range from 1.2 volts to 2 volts depending on the materials and chemicals used. Some common voltages:

• Ni-Cd (nickle cadmium) rechargable = 1.2V.
• Carbon-zinc or alkaline = 1.5V (actual voltage in use 1.2V).
• Lead-acid (eg, car battery) = 2V (6 cells in a 12V battery).

Cells within a battery are normally connected in *series* to increase the total voltage. Cells can also be connected in parallel to increase a battery's capacity. Batteries can be connected in *parallel* or *series*.

Symbol



The long line indicates the positive side of the battery. It doesn't matter how many pairs of lines the battery has - normally two or three pairs are drawn.

A rechargeable battery made from three cells.

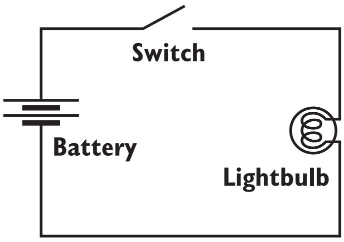
Circuits

A **circuit** is a collection of a power source (eg, a *battery*), a load, and some sort of conductor (like a wire) connecting them. A circuit may or may not have a switch.

An **open circuit** is when something breaks the circuit so that the flow of electricity stops. This might be because a switch is opened, a lightbulb burns out, etc.

A **short circuit** is when a loop is made from positive to negative without any load such as a lightbulb or resistor. This can be quite bad for the power supply or battery because the circuit tries to draw huge amounts of current. This is why homes have fuses.

Circuit Diagram



Example circuit

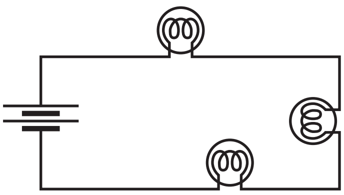
A **circuit diagram** is a simplified drawing of a circuit using symbols to represent components and the electrical connections between them. The actual components may be physically arranged quite differently to the circuit diagram.

Series & Parallel

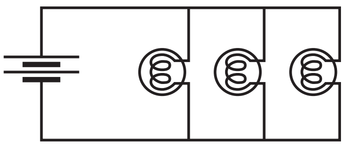
Components are in series when electricity passes through one component then the next one.

Components are in parallel when electricity splits to flow through the components. Electrically speaking, the components are side by side, even if they're not next to each other physically.

Circuit Diagram



Lightbulbs in series



Lightbulbs in parallel

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Resistors

A resistor can be anything that resists the flow of electricity, but when we talk about electronic circuits a resistor is a particular item that only does one thing - resists. It doesn't light up, store charge, etc.

Resistors are probably the most common electronic component. They are handy when using *LEDs*, or when wanting to change the speed at which a *capacitor* charges. A **variable resistor** can have its resistance easily adjusted. One particular kind of variable resistor is called a potentiometer or trimpot. An example is a volume control on a radio. A **light dependent resistor** changes its resistance depending on how much light is falling on it.

The value of a resistor is marked on the side of it with coloured stripes (normally four of them). The last stripe is spaced a bit further apart than the others are. The first two stripes are the first two figures of the resistance value. The third stripe is a multiplier - basically the number of zeros. The last band is the tolerance, or how accurate the value is. Gold = within 5%, silver = within 10%.

Symbol

Resistor

- **0 Black**
- **1 Brown**
- **2 Red**
- **3 Orange**
- **4 Yellow**
- **5 Green**
- **6 Blue**
- **7 Purple**
- **8 Grey**
- **9 White**

orange
orange
black
gold
"3, 3, no zeros"
33Ω ±5%

red
purple
orange
gold
"2, 7, three zeros"
27kΩ ±5%

Capacitors

A capacitor is an electronic device that stores charge. Capacitance is measured in farads (F) but since a farad is a very large charge, in practice microfarads (μF), nanofarads (nF) or even picofarads (pF) are normally used. Really big capacitors might have a value in millifarads (mF).

A capacitor is made from two metal "plates" (eg, aluminium foil) kept separated by a dielectric (eg, waxed paper). A dielectric is a material that is a good insulator (incapable of passing electrical current), but is capable of passing electrical fields of force.

Symbol

Capacitor

Polarised capacitors are indicated by a little + next to the symbol which indicates which way round the capacitor needs to be connected.

Some dielectric materials include vacuum, air, various ceramics, glass, mica, oil, paper, polyetheylene (thin plastic sheet), and waxed paper. A capacitor will often have a voltage rating printed on it. This is the amount of voltage that the capacitor can cope with. If the voltage across a capacitor's plates gets too much for the dielectric the dielectric is said to "break down" and it lets a spark across. For example, air breaks down at about 3,000 volts per millimetre of separation (3kV/mm). If the applied voltage and current is great enough the spark(s) from the plates can cause the capacitor to explode, resulting in a really bad smell and little bits of the capacitor everywhere. Note: It can be very dangerous to deliberately make a capacitor explode.

When a capacitor is uncharged, electricity can flow through it because electrons are "stored" in one plate at the same time that they are released by the other plate. As the plates charge up (one positive, one negative), the current flow through the capacitor decreases (quickly or slowly, depending on the size of the capacitor) until the capacitor is fully charged.

Capacitors can be used to remove voltage spikes or provide simple timing, such as the length of a siren noise, etc. Variable capacitors can be used for fine-tuning a radio.

Questions: What similarity is there between the sparks from static electricity and the sparks across a capacitor's dielectric when it breaks down? (Hint: Take a look at the list of dielectric materials.) How could you work out how much voltage static electricity has?

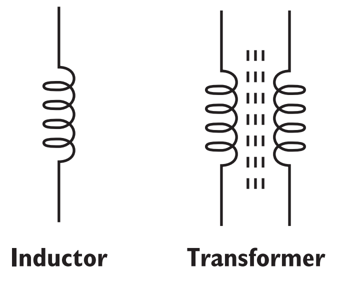
Inductors

An inductor is basically just a coil of wire, and so is often called a coil.

A **solenoid** is an inductor that uses the magnetic field created by the coil to create movement in a rod positioned in the middle of the coil. They are used in remote control cars, doorbells, and some stereos.

A **transformer** converts voltage by using two coils wound together. The magnetic field created by the current in the first coil forces a current to flow in the second coil. The voltage is changed by the ratio of the number of loops in each coil.

Symbol



Semiconductors

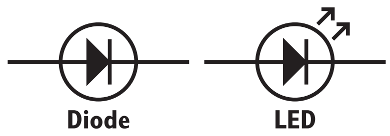
A semiconductor is an electronic device that does not conduct in a simple way. Semiconductors include *diodes*, *transistors*, integrated circuits (also called silicon chips), etc.

Diodes, LEDs
Semiconductors

A diode is an electronic device that allows electricity to flow through it in one direction only. This means it is a *semiconductor*.

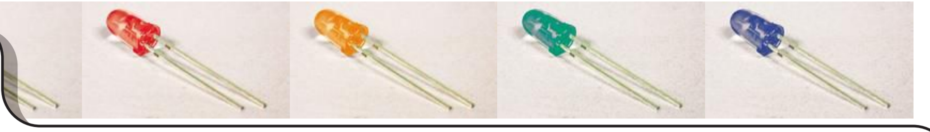
A **light emitting diode**, or LED, is a particular kind of diode that also gives off light when it is conducting. An LED must be connected the right way round in a circuit for it to give off light.

Symbol



The only difference between the symbol for a normal diode and an LED is the arrows, which indicate the light being emitted. The arrow within the diode symbol points in the direction of conventional current.

Warning: An LED should be used with a resistor or dedicated LED driver to limit the current through the LED. An LED needs a certain number of volts before it starts to work, but then its resistance starts to drop quickly and the current the LED draws will increase quickly for a small increase in voltage. (This is like pushing on a door that is jamming. When you push hard enough the door suddenly flies open and you and all your friends can go charging through.) As an LED heats up it decreases in resistance, so at the same voltage will draw more current, which can lead to thermal runaway. (This is different from a light bulb filament which will increase in resistance as it heats up.)



Transistors
Semiconductors

A transistor is what allows amplifiers to work. When a small current flows between two of the transistor's terminals, a much larger current flows between a different pair of terminals. This allows signals to be amplified many hundreds of times.

An **integrated circuit** contains many transistors in a single small package. Some ICs contain thousands of transistors.

Symbol