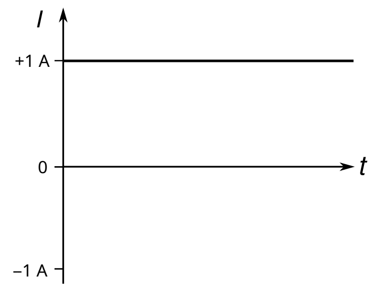
Prelab: Home Wiring

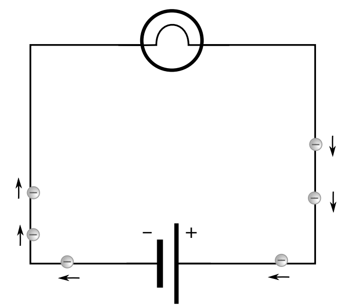
Everyday thing: A power outlet.

It's physics: There is quite a bit of physics and engineering on when it comes to electricity and the choices that went into designing the electric grid and the wiring and plugs in your home.

Alternating vs. direct current

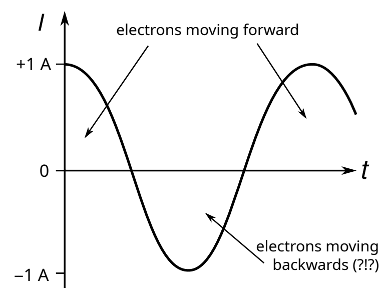
Every voltage source we encountered so far produces **direct current** (**DC**). This means there are two terminals, "–" and "+", and the electrons flow in a constant stream from the "–" to the "+" terminal. If we were to plot the current through a DC circuit over time, it would look something like the diagram on the top left – a constant in time.

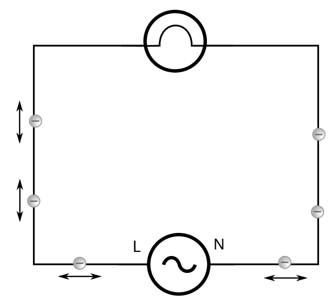




Basically every power outlet in the world is a source of **alternating current** (**AC**). For such a source, the plot current over time looks like the diagram on the bottom left: it **alternates** between positive current and negative current.

Negative current just means that the electrons are flowing in the opposite direction. Thus, instead of flowing from one place to another like in DC, the electrons just "rock" back and forth in the circuit.





And interesting consequence of this is that for an AC circuit, there is no dedicated "–" or "+" side, because the electrons move in both directions. One, somewhat arbitrarily, labels:

- one of the sides as "**Line**", "**L**" or "**Hot**", usually marked with a **black** wire,
- the other side as "**Neutral**" or "**N**", usually marked with a **white** wire.

It is important to note that despite their naming, both of these wires will carry current, and so **both** of them are **dangerous**.

You should recognize the shape of the AC current from the springs lab as an **oscillatory motion**. In the US, the period (the time it takes the current pattern to repeat) is:

$$T = 1/60\,\text{s} \approx 0.015\,\text{s},$$

so current oscillates very quickly. One defines the **frequency** as $1/T$ with the SI unit **Hertz** (**Hz**). So that means AC has a frequency of 60 Hz, in other words, the current repeats 60 times in a second.

Thomas Edison vs. Nicola Tesla

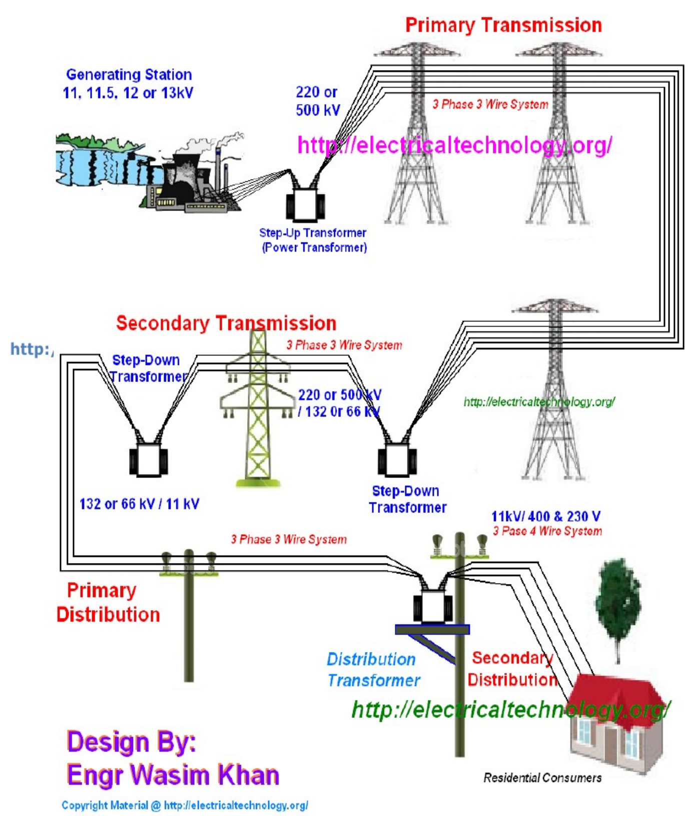
One of the most famous, and somewhat apocryphal, nerd rivalries in history, the fight between Thomas Edison and Nicolas Tesla over which type of current to use is worth revisiting, now that we know what current actually *is*.[1]

To understand the question whether to use AC or DC, one should answer the question: how can the electrons do work when they are not flowing from one place to another? The answer is that for a resistor or a light bulb, the important thing is not that they are flowing, but that they are **moving**, regardless of direction. Similar to a plane tool moving back and forth to smooth wood, the electrons are bumping against the atoms of the light bulb both on their forward and backward path, creating heat, which creates light.

Because the electrons alternate between moving forwards and backwards, there are periods in between where there is no or little current. Also, as we will learn later, some of the energy in an AC is spent producing a magnetic field. Thus, **AC is generally less efficient than a DC** voltage source. This was pointed out by Thomas Edison, who advocated for the adoption of DC as the standard.

There is one big problem with DC, though: it is very difficult to transform DC from one voltage to another. This is generally necessary, because:

- the power lost though the resistance of a wire is proportional to the square of the current I, so we want to transfer as little current as possible when transferring large amounts of power. Since $P = IV$, we can use a large voltage instead. This is why power lines have voltages of 100,000 V and more.
- Such large voltages would be incredibly dangerous in a household, however, so we need to transform it to something more manageable, e.g., 110 V in the US.



This is why Serbian polymath Nicola Tesla advocated for alternating current, because it turns out to be very **easy to transform AC from one voltage to another**. Ultimately, Tesla's argument won out.

(Both men also made – dubious – arguments that their form of current was safer. In fact, both large DC and large AC voltages are very dangerous: large AC voltage mess with the rhythm of electric signals in the heart and can cause fibrilation and death, while large DC voltages can cause the blood to boil – and death.)

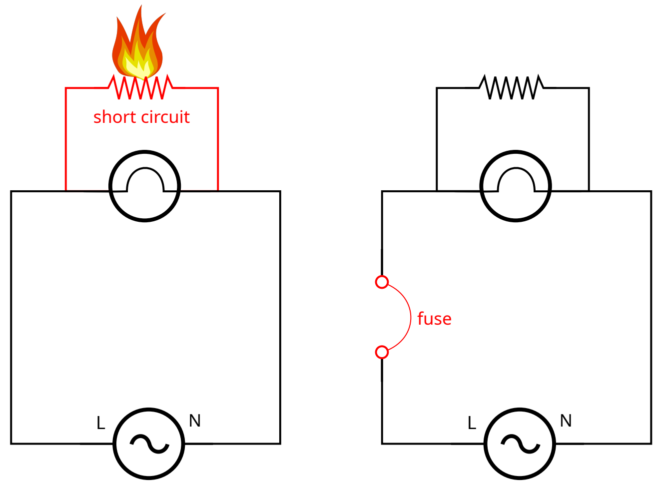
1 *See also: https://www.youtube.com/watch?v=gJ1Mz7kGVf0*

Safety

There are two main safety hazards with associated with large electric voltages: **fire** and **electric shock**.

Short circuits

If a device is faulty, either by wear and tear and some other sort of problem, it can happen that instead of going through the device, line and neutral directly touch, producing a **short circuit**.



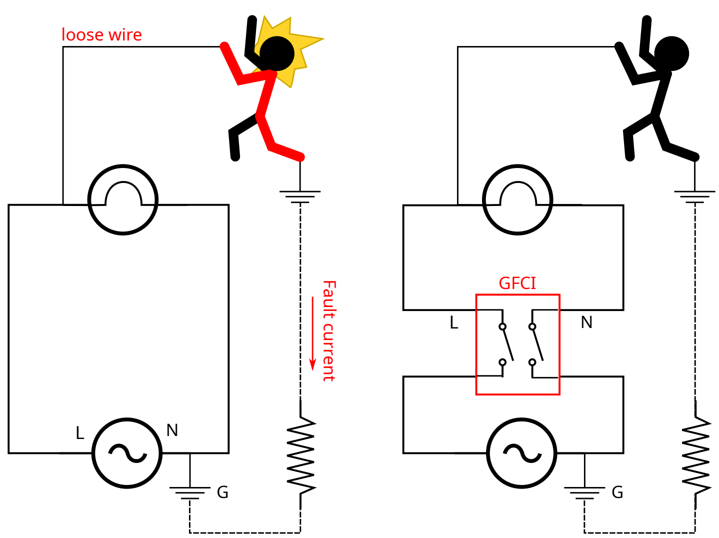
As we know from the simulator, in this case a lot of current is flowing through the circuit. The short circuit is usually not perfect, equivalent to a resistor with a low resistance. As large currents pass through that contact, it will heat up, and may ignite either the wire or stuff around the appliance.

To prevent this, one uses either a **fuse** or a **circuit breaker**. Both of them are essentially switches that break the circuit once the current through it becomes too large, usually 10 A, 15 A or 20 A. A fuse needs to be replaced once it fires, while a circuit breaker can be reset.

A **fuse or circuit breaker will not prevent electric shock**: your body has a resistance of about 1000 ohms, which means if you happen to close a 110 V circuit with your body, the current will be less than 1 A and the circuit breaker will not save you.

Electric shock

Suppose something in the appliance breaks and we suddenly have a loose wire somewhere (or the outer metal body is suddenly “live”). If we touch that wire and the ground, the current can travel through our body and the ground back to the voltage source.



A **ground fault circuit interruptor** (**GFCI**) detects this by comparing the current through L and N. If they are not equal, that means some current is “lost” to the ground somewhere (called **fault current**), potentially taking a harmful path. The GFCI will then interrupt the circuit.

GFCI switches **rely on a good ground connection** (third pin in your plug) to detect fault currents, otherwise the resistance through the ground may be too large. This is why it is important to connect all your equipment to the ground to shorten the distance between the next good ground connection.

If somebody gets caught in a live circuit

It's unlikely, but where there is electricity, there is always the risk of electric shock.

A person getting electric shock may manifest itself in a variety of symptoms: the person may have obvious muscle spasms, or be completely still. If you suspect somebody is caught in a live circuit:

- **Never touch a person currently caught in a live circuit**: you will form a parallel circuit with your own body.
- **Interrupt the circuit**, if possible: if you are close to a circuit breaker, voltage source, plug, or emergency off switch, interrupt the circuit.
- Otherwise, **use an insulating object** (chair, wooden board, etc.) to "bat" the person away from the circuit.
- Afterwards, give **first aid** and **call 9-1-1** if necessary.