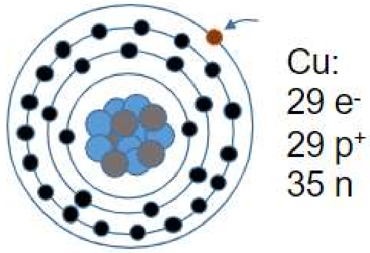
Voltage and current are the cornerstone concepts in electricity.

Charge

The concept of electricity arises from an observation of nature. We observe a force between objects, that, like gravity, acts at a distance. The source of this force has been given the name **charge**. A very noticeable thing about electric force is that it is large, far greater than the force of gravity. Unlike gravity, however, there are two types of electric charge. Opposite types of charge attract, and like types of charge repel. Gravity has only one type: it only attracts, never repels.

Conductors and insulators

Conductors are made of atoms whose outer, or valence, electrons have relatively weak bonds to their nuclei, as shown in this fanciful image of a copper atom. When a bunch of metal atoms are together, they gladly share their outer electrons with each other, creating a "swarm" of electrons not associated with a particular nucleus. A very small electric force can make the electron swarm move. Copper, gold, silver, and aluminum are good conductors. So is saltwater.



There are also poor conductors. Tungsten—a metal used for light bulb filaments—and carbon—in diamond form—are relatively poor conductors because their electrons are less prone to move.

Insulators are materials whose outer electrons are tightly bound to their nuclei. Modest electric forces are not able to pull these electrons free. When an electric force is applied, the electron clouds around the atom stretch and deform in response to the force, but the electrons do not depart. Glass, plastic, stone, and air are insulators. Even for insulators, though, electric force can always be turned up high enough to rip electrons away—this is called breakdown. That's what is happening to air molecules when you see a spark.

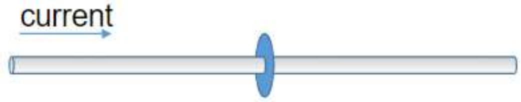
Semiconductor materials fall between insulators and conductors. They usually act like insulators, but we can make them act like conductors under certain circumstances. The most well-known semiconductor material is Silicon (atomic number 14). Our ability to finely control the insulating and conducting properties of silicon allows us to create modern marvels like computers and mobile phones.

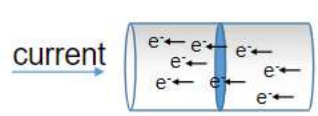
Current

Current is the flow of charge.

Symbol: I.   Measured: in amperes (A)

Current is reported as the number of charges per unit time passing through a boundary. Visualize placing a boundary all the way through a wire. Station yourself near the boundary and count the number of charges passing by. Report how much charge passed through the boundary in one second. We assign a *positive* sign to current corresponding to the direction a *positive* charge would be moving.





A few remarks on current

What carries current in metal? Since electrons are free to move about in metals, moving electrons are what makes up the current in metals. The positive nuclei in metal atoms are fixed in place and do not contribute to current. Even though electrons have a negative charge and do almost all the work in most electric circuits, we still define a positive current as the direction a *positive* charge would move. This is a very old historical convention.

Can current be carried by positive charges? Yes. There are lots of examples. Current is carried by both positive and negative charges in saltwater: If we put ordinary table salt in water, it becomes a good conductor. Table salt is sodium chloride, NaCl. The salt dissolves in water, into free-floating Na^++start superscript, plus, end superscript and Cl^--start superscript, minus, end superscript ions. Both ions respond to electric force and move through the saltwater solution, in opposite directions. In this case, the current is composed of moving atoms, both positive and negative ions, not just loose electrons. Inside our bodies, electrical currents are moving ions, both positive and negative. The same definition of current works: count the number of charges passing by in a fixed amount of time.

What causes current? Charged objects move in response to electric and magnetic forces. These forces come from electric and magnetic fields, which in turn come from the position and motion of other charges.

What is the speed of current? We don't talk very often about the *speed* of current. Answering the question, "How fast is the current flowing?" requires understanding of a complex physical phenomenon and is not often relevant. Current usually isn't about meters per second, it's about charge per second. More often, we answer the question "How *much* current is flowing?" all the time.

How *do* we talk about current? When discussing current, terms like *through* and *in* make a lot of sense. Current flows *through* a resistor; current flows *in* a wire. If you hear, "the current across ...", it should sound odd.

Voltage

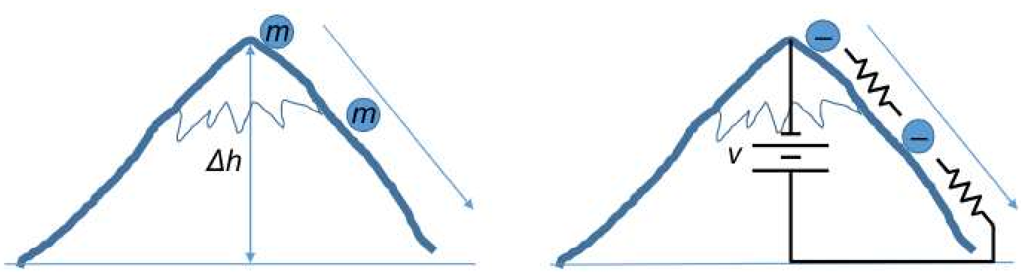
Symbol V. Measured in volts (V)

To get our initial toehold on the concept of voltage, let's look at an analogy:

Voltage resembles gravity

A ball at the top of the hill rolls down. When it is halfway down, it has given up half of its potential energy.

An electron at the top of a voltage "hill" travels "downhill" through wires and elements of a circuit. It gives up its potential energy, doing work along the way. When the electron is halfway down the hill, it has given up, or "dropped", half of its potential energy.



For both the ball and the electron, the trip down the hill happens spontaneously. The ball and electron move towards a lower energy state all by themselves. On the trip down, there can be things in the way of the ball, like trees or bears to bounce off. For electrons, we can guide electrons using wires and make them flow through electronic components —circuit design— and do interesting things along the way.