An Introduction to Electricity and Circuits

Materials prepared by Daniel Duke – 4th Sept 2013.

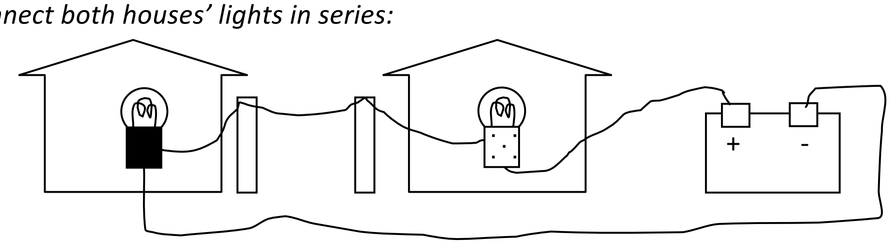
This course has been designed to introduce students to the basic concepts of electricity and electrical circuits with a focus achieving understanding through simple analogies and hands on demonstration. The intended results is not a complete understanding of the exact physics but a 'working' understanding that students can put to practical use, and a demystification of electricity.

1. DEMONSTRATION – ELECTRIC LIGHTS

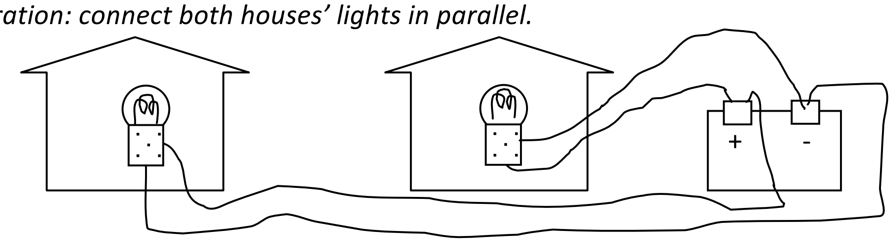
Electricity is a wonderful thing, because it provides the power that makes all kinds of nice inventions work. Some of those inventions are light bulbs that let you see when the sun goes down, electric motors than pump water with no need to do hard work, and electricity provides the power to charge up the batteries in phones, computers and other handy things, which themselves are just complicated electrical systems.

However, connecting up electricity to make things work is sometimes confusing. We have to understand the way it works in order to know how to make it work best for us.

Imagine I have two houses, each with two electric lights installed. How do I wire them up so that everyone gets a bright electric light? Electric current always travels over two wires – it flows through the wire like water flows through a pipe, coming in through one and going out through the other. You have probably noticed that electric batteries always have two ends or two connections for two wires. We call them "Positive" or "plus" and "Negative" or "minus" and we'll learn why later on. Let's wire them up so that the electric current flows into one house, then the next, then out to the battery. *Practical demonstration: Connect both houses' lights in series:*



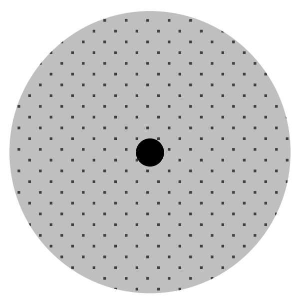
The lights are not very bright. What's more, if I cut the wire, both lights go out. Now what happens if I choose a different way to wire them up – in this case, I connect both straight to the battery at once? *Practical demonstration: connect both houses' lights in parallel.*



Now we get a brighter light! And if I turn off the lights in my house, my neighbor still has her light. We used more wires to do it this way, but the lights work much better. Why is it so? We will have to understand electricity to figure it out.

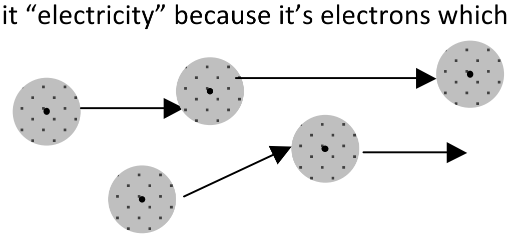
2. WHAT IS ELECTRICITY?

Everything in the whole world is made of tiny little particles called atoms. They are so small, you can't even see them. Everything from the air, to your body, to the water you drink and the food you eat is made of atoms. There are many different kinds of atoms – we call them "elements", and you have probably heard their names. Iron, copper, carbon, oxygen, and so on. If we could see atoms at their tiny size, they would look like little soccer balls. That soccer ball is called the 'nucleus'. Around the nucleus is a whizzing cloud of even tinier particles called 'electrons'. Those electrons are usually stuck in 'orbits' around the nucleus, like the moon is stuck in orbit around Earth, but the difference is we are never quite sure where they are inside the cloud.



The important thing to remember about atoms, aside from the fact that they are very very small, is that the cloud of electrons is much bigger than the nucleus. If you can imagine the atom's nucleus the size of a soccer ball, the electron cloud around that atom would be the size of a mountain. And the next atom would be the next mountain nearby! And it takes millions of atoms to make up just the tip of a pencil.

Most of the time, electrons like to stay in orbit around the nucleus, but every now and then one of them escapes and flies away, until it bumps into another atom's cloud of electrons. When it does, it carries a little bit of energy from one atom to the next. Now imagine lots and lots of atoms, with lots and lots of electrons getting free of their orbits and they're all moving in the same direction at once, and bumping into other atoms. That's a whole lot of charge that's moving in one direction, even though the atoms themselves are not going anywhere. They're passing energy between each other in the form of little electrons. That moving of energy is called "electrical current" because it's caused by MOVING ELECTRONS. We call it "electricity" because it's electrons which are doing the work.



We describe the amount of electrons in motion as a “charge” with some number value. It has a unit of measurement like the meter or the kilogram. It is called the Coulomb (C).

Important thing to remember: Electricity is caused by moving electrons. Moving electrons in large groups have a “charge” measured in Coulombs.

3. WHY DO SOME THINGS CONDUCT ELECTRICITY AND OTHERS DON’T?

Electrical wire conducts electricity very well. Wood does not conduct electricity. Why is this so?

Before, we learned that there are many different kinds of atoms, called “elements”. Each of the elements has a different number of electrons orbiting its nucleus. Depending on how many electrons there are, and depending on how the atoms are connected to each other and lined up, sometimes the electrons are able to very easily move. This means electricity can flow very well. Some times, electrons have great difficulty moving, and so electricity has a hard time flowing.

Important thing to remember: Something that conducts electricity well is a ‘Conductor’. Something that does not is an ‘Insulator’.

The elements that conduct electricity very well are mostly metals. Copper and gold conduct electricity extremely well. The elements that usually conduct electricity poorly are those which make up a lot of everyday things – carbon, nitrogen, and oxygen – this is what wood, soil, and plastic are made of. However, some elements are very odd and will sometimes conduct electricity and other times not. For example, carbon in the form of wood will not conduct. But carbon in the form of a graphite pencil tip can conduct electricity quite well!

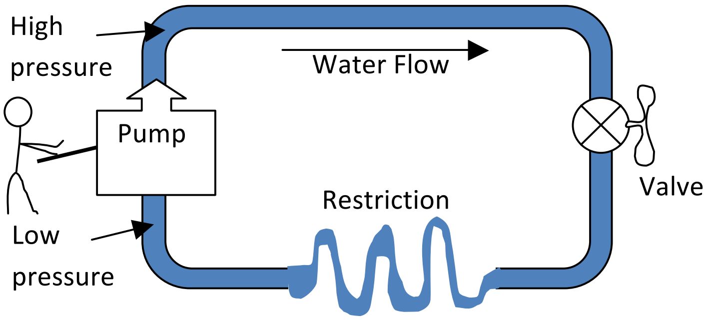
When we make electric wires, we have a conductor (ie. Copper or some other metal) surrounded by an insulator (like plastic). The purpose of the insulator is to protect us from an electric shock when we touch it. The human body is usually an insulator, but if our skin gets wet, or the electricity is strong enough, like in a lightning strike, we become conductors and can get hurt by electrocution as the electricity moves through us. So the insulator is important to keep us safe.

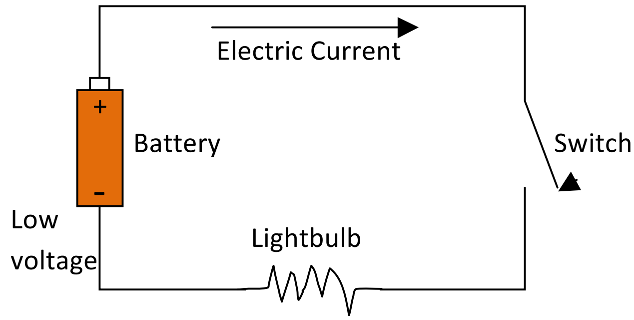
4. PARTS OF AN ELECTRIC CIRCUIT

When we wired up our houses for light, we have a few different parts. We have a battery – that’s the source of the electrical energy. We have a light – it turns the electrical energy into something useful. And we have wires, which are conductors that let the electricity flow to where we need it. This arrangement is called a ‘circuit’ because it has to be closed, like a racecar circuit. The end has to meet up with the beginning.

Important thing to remember: An electrical circuit has to be a closed loop for electricity to flow.

Electricity moves in a circuit like water moves through a pipe. This helps us understand how it works.





The battery behaves like a pump, which pushes the water. To make water move in a pipe, we pump it to give it "pressure". The equivalent for pressure in an electric circuit is called "Voltage". The battery pumps up the voltage from low on the negative side to high on the positive side. Like pressure in a pipe tells us how much potential energy is in a certain amount of water, voltage tells us how much potential energy is in a group of electrons. Voltage is measured in "Volts" and one Volt (V) is equivalent to one Joule of energy per one Coulomb worth of electric charge (remember those tiny electrons?) Sometimes, voltage is also called "potential", because a higher voltage has the "potential" to do some useful work for us.

The wires are just like pipes. The speed at which the electrical energy flows through the wires is called Current. In order for electricity to flow, there must be both an increase in voltage, and this will start a current flowing just like pumping up the pressure of water will start it flowing. Current also has a unit of measurement, the Ampere or Amp. Since current refers to speed, one Amp is equivalent to one Coulomb per second. The symbol for current is not "C" because we already use that to indicate the Coulomb, so we use the letter I instead.

In a water pipe, we might have a valve or tap to stop the flow. In an electric circuit, we have a switch – it breaks the circuit so that it is no longer a closed loop and the electricity cannot flow.

Along the pipe, there is a narrow, winding channel that the water has to work its way through. It is hard to push the water through this narrow space. As a result, the water pressure drops. This is like the light bulb. The electricity has to travel through a tiny, winding wire in the light bulb. It's hard to do it, and the wire gets so hot it glows and lights up the room. Voltage is lost as the electricity makes its way through the wire in the bulb, and that lost voltage has been turned into heat and light.

Important thing to remember: Electricity moves like water in a pipe. The battery provides a voltage, which is measured in Volts. This causes an electric current to flow, which is measured in Amperes.

5. RESISTANCE

We have described the flow of electricity as having several properties : a charge, a voltage (like pressure) and current (like the speed of flow). We also said that a light bulb is a very narrow winding path, which causes the electrical voltage to drop because it's difficult for the electricity to get through.

Some things are more difficult for electricity to flow through than others. How hard it is for electricity to flow is called "Resistance." You may recall that we defined some materials as being "conductors" and some as being "insulators."

Class question: If resistance represents the difficulty of electricity to flow, does a conductor have high or low resistance? Does an insulator have a high or a low resistance?

About 100 years ago or so, a scientist called Ohm discovered that the resistance of a circuit could be measured, and that the amount of voltage lost by an electric current moving through a resistant path could be always described by the current multiplied by the resistance:

$V=I*R$ ← we call it Ohm's law. Resistance is measured in Ohms,

We can also measure resistance in the classroom. We have a circuit which converts electric current into sound.

Demonstration of the Drawdio pencil, which plays a tone that rises as the resistance between the terminals drops.

If I touch both sides of the circuit with my fingers, a very small electrical current flows through my body and the device will convert that small current into a sound. If I draw with the pencil on paper, the electricity can flow through the graphite lead of the pencil and make a sound. The longer the path the electricity travels, the lower the sound, so if I move the pencil around I can play a tune!

Classroom activity: Make a circuit by having people hold hands. If someone breaks the chain, we have no circuit and the sound stops. If someone makes a short-circuit, does the pitch go up?

6. SERIES AND PARALLEL

Now that we know a bit more about electricity, we can go back to our original problem of wiring up lights for houses, and figure out why one arrangement is better than the other. If we wire up the houses one after the other, we call it “series”. It just means, “all in a line”. If we wire each house directly to the battery, we call it “parallel”. It just means “several things at once.”

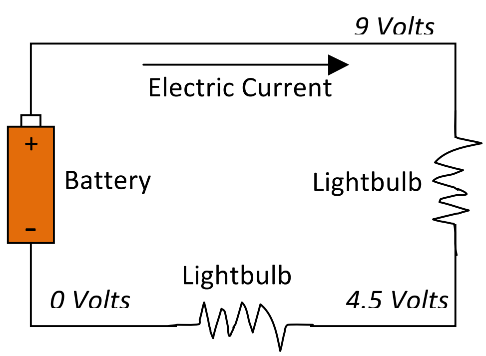
Important thing to remember: Electrical devices connected one after another are said to be “in series.” Electrical devices connected to the same power source directly at once are said to be “in parallel”.

We know that the parallel arrangement gives a brighter light. Why is it so?

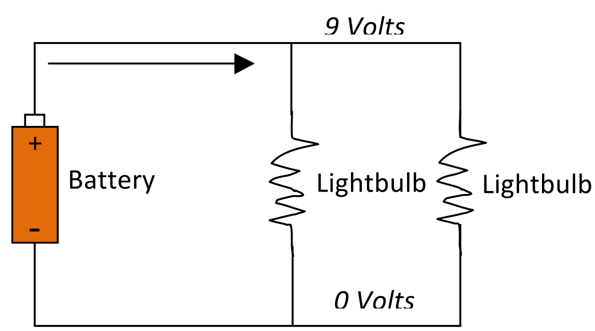
The battery puts out a constant voltage – it pumps up the energy of the electrons always to 9 volts, but the current flow can be anything we like.

If we wire our lights in series, then that 9 volts has to be shared between both bulbs, and each will see the same electric current flowing through the wire. So each bulb gets 4 and one-half volts, and the voltage is back down to zero by the time we come to the negative end of the battery

If we wire our lights in parallel, then each bulb sees the whole 9 volts, and each gets one half of the current flow. Because there are now two paths for the electrical current to take, the resistance to electrical current flow is overall lower, like the water having two pipes to flow through. Ohm’s law tells us that if the voltage at the battery stays the same and the resistance reduces, the current must increase. This compensates for the fact that the current has to split and travel half in each wire. The voltage on each light is now higher, and it glows brighter.



SERIES CIRCUIT



PARALLEL CIRCUIT

7. ADVANCED TOPIC – POWER CONSUMPTION

Those of you who are thinking about the series and parallel arrangement might ask "if I wire my lights in parallel, do I get more brightness for free?" The answer is no – the battery is working harder in the parallel case and will run out sooner. Why is it so?

Each light bulb consumes a certain amount of "Power." Power, in electricity, is defined as the voltage change over the bulb, multiplied by the current flow through the bulb:

$P = V * I$ ← Power is measured in Watts. One Watt is one Joule of energy per second.

When our circuit is in series, each bulb sees 4.5 volts. If the current flow through the wire is 1 amp, then 4.5 Watts of power are consumed in each bulb (9 Watts total).

When our circuit is in parallel, each bulb sees 9 volts. We mentioned before that because there are now two paths for the electric current to take, resistance is reduced and more current can flow according to Ohm's law. For argument's sake, lets' say we now have 1.5 amps of current flowing from the battery because of this lower resistance. It has to split two ways in each wire, so 0.75 Amp flows in each wire. Each bulb sees 9 volts * 0.75 Amp = 6.75 Watts (13.5 Watts total). So more power is now being consumed, the lights are brighter, and the battery runs out faster.