Electricity is the movement of electrical charge through a circuit (usually, flowing electrons.)

The Greek word for "amber" is "elektron"

Women in ancient Greece noticed that rubbing their amber jewelry against silk caused it to accumulate a charge -which they used to shock small frogs at parties.

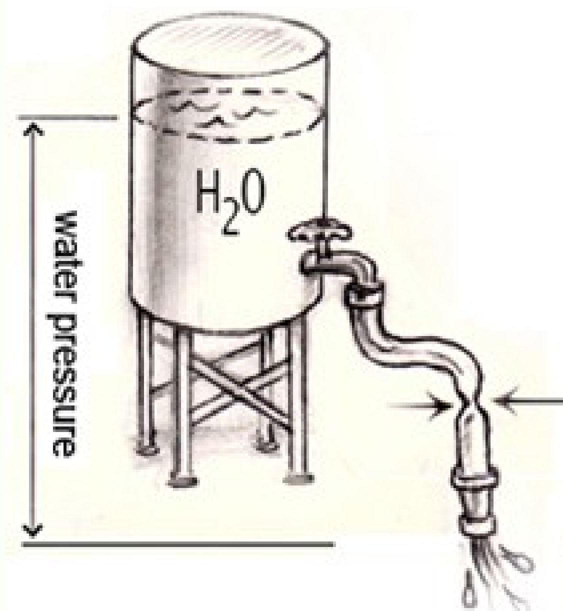
[video of “triboelectric effect”]

Benjamin Franklin (1705-1790) had ideas about electricity:
1. That Lightning was electricity.
2. The two types of electrical charge (at the time, referred to as two “fluids”: "resinous" and "vitreous") were in fact the result of the relative presence or absence of a “single fluid”, which he referred to as “positive electricity” and “negative electricity”, respectively.

Thinking about current:
The famous “water metaphor”

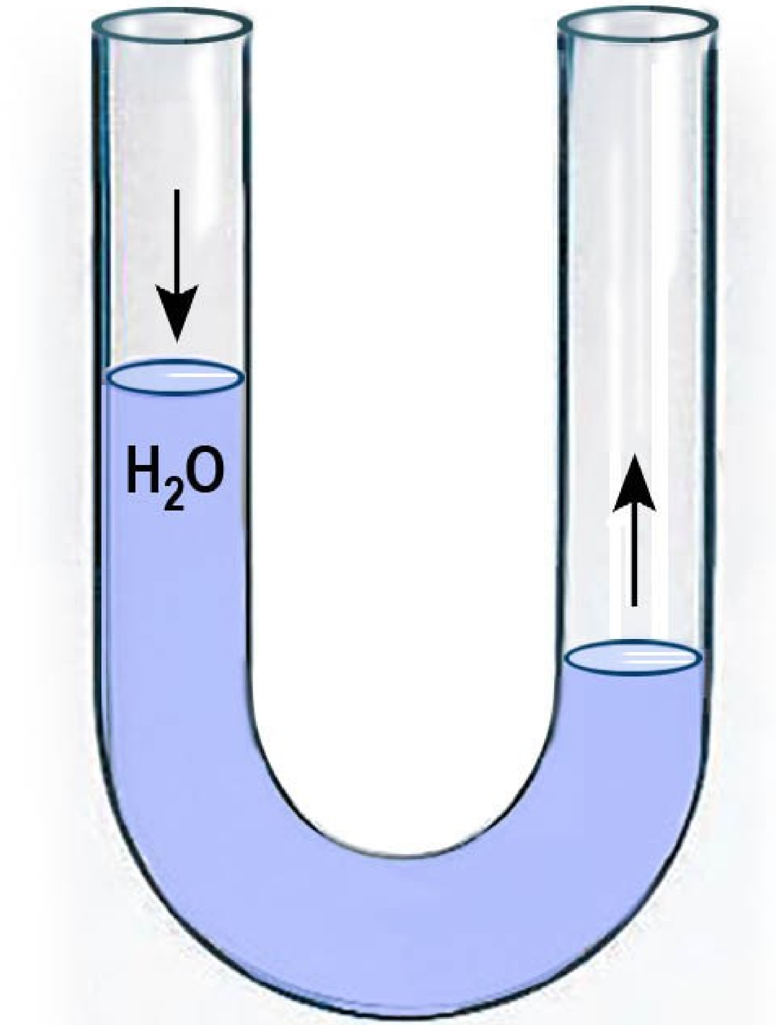
Electrical components called “resistors” slow down the flow of electrons, and are essential for controlling the flow of electricity in a circuit. The electrical energy lost when current goes through a resistor is transformed into heat. The property of impedance (resistance) in a resistor is measured in units called ***ohms***. In the metaphor, it's represented by pinching the water pipe.

The water pressure (measured between two points) is a metaphor for *electromotive potential,* measured in units called ***volts***.



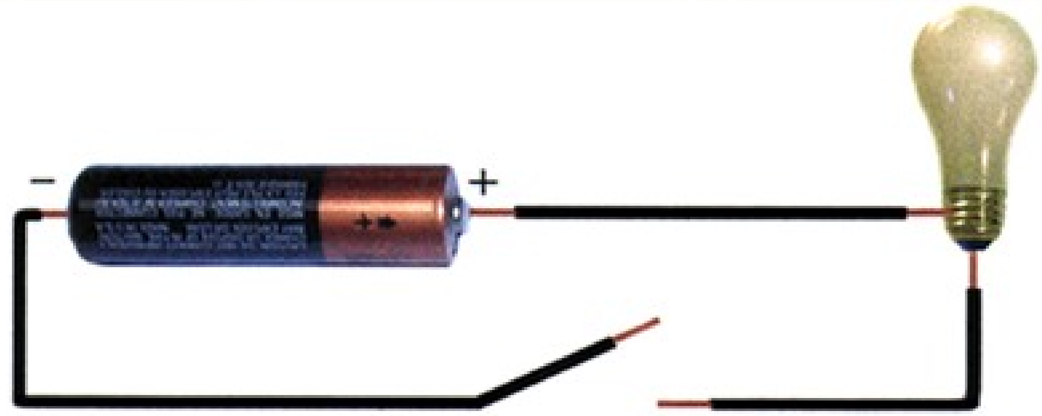
The diameter of the pipe (or volume of water flowing) is a metaphor for current. It is measured in units called ***amperes*** (***amps***.) One ampere = a volume of one coulomb per second. -A *coulomb* is a measure of charge equal to 6.24 * 10^{18} electrons.

“Volts” is a unit of measure of the difference in *electrical potential* between 2 points in a circuit.



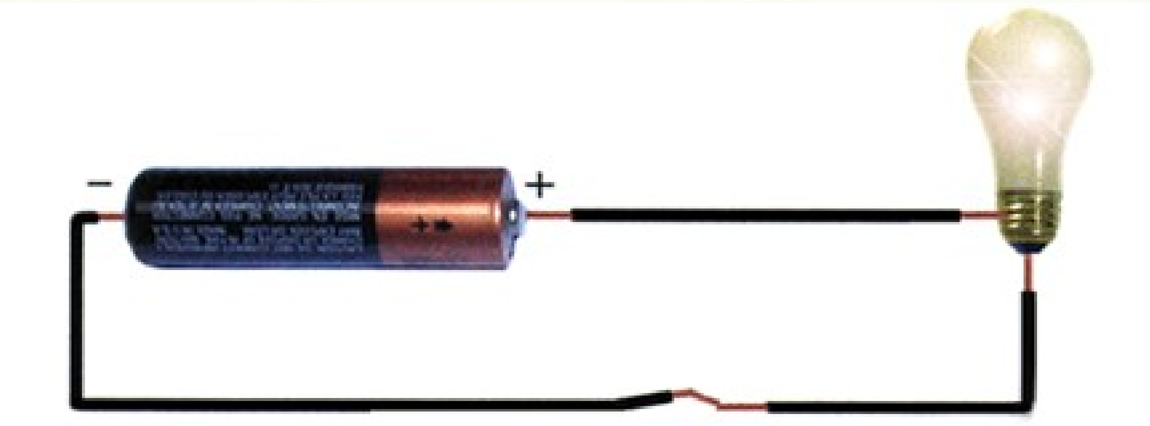
Metaphorical example showing “kinetic potential”...

Simple DC Circuits (open):



Here is perhaps the simplest circuit we could build. In this case the light bulb is the “load” in the circuit, controlled by a “single pole, single throw” (SPST) switch. (More about switches later.)

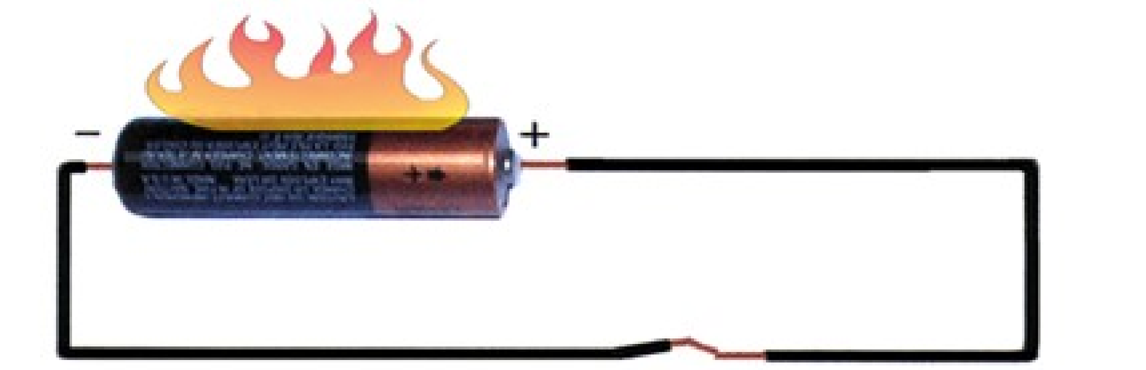
Simple DC Circuits: (closed)



Electricity flows from a source, where there is the greatest concentration of electrons (positive pole) to the place with a relatively lower concentration of electrons (negative pole, often also referred to as “ground”) through the path of least resistance.

DC (Direct Current) circuits harness the power of the electrical current flowing from a positive source, energizing a load of some kind as it passes through it to ground.

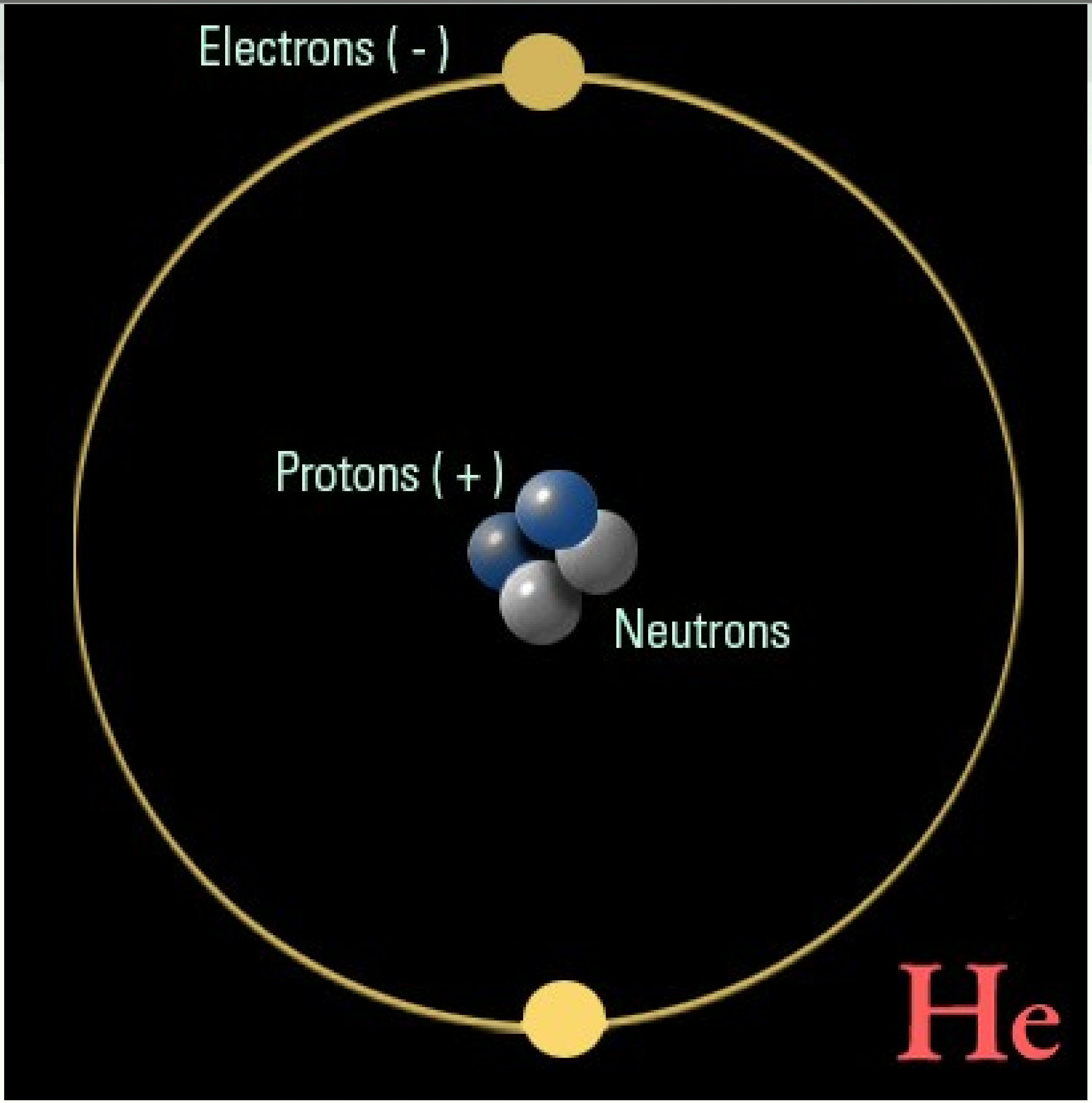
Simple DC Circuits: (short!)



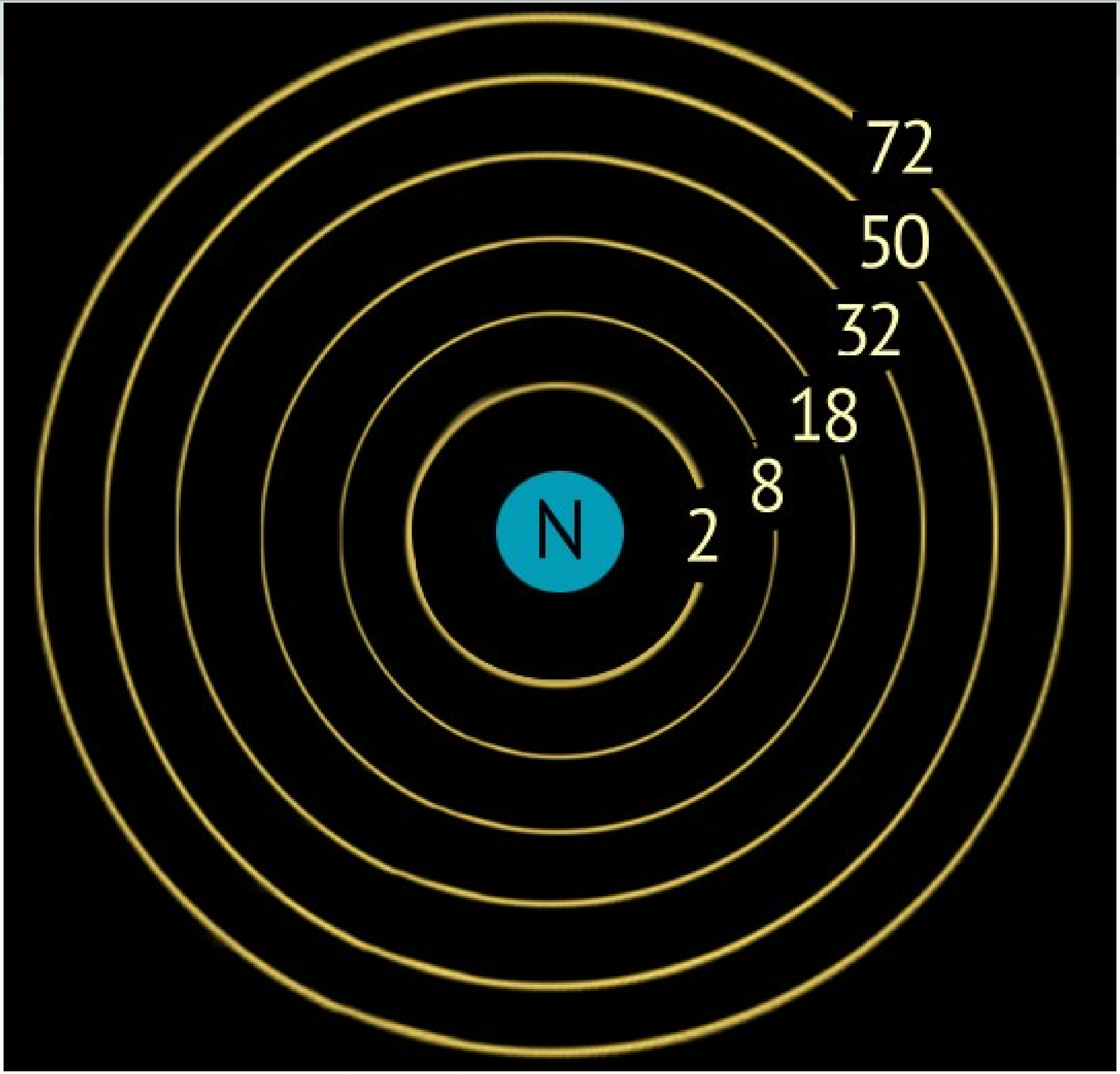
- Always make sure there is a load of some kind on the circuit. A path through a conductor directly from source to ground is called a ***short circuit*** (very bad.) It will cause the power source to over-heat and die. In this case it would cause the battery to get very hot and die. If this happens with AC current in your home it can cause catastrophic fires.

Materials that have lots of “free electrons” in their atomic structure that move easily from and between their valence shells are referred to as **conductors** (e.g. copper, gold.) Conversely, materials with relatively few free electrons are called **insulators** (e.g. wood, rubber.) If the electromotive potential is great enough, just about anything can become a conductor, even the air in the sky (in the case of lightning.)

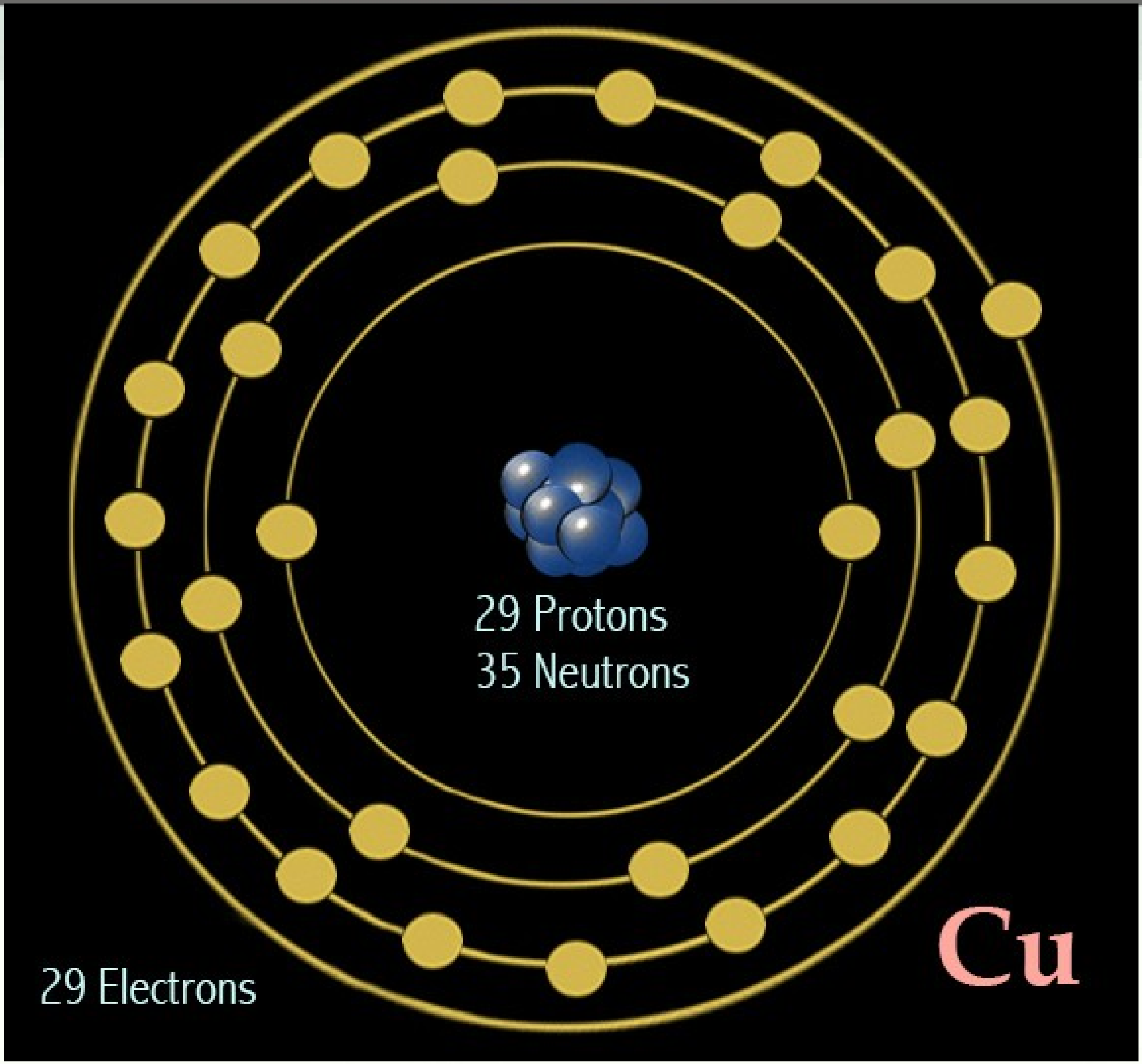
Electrons don't have to travel the entire length of a circuit in order for electrical conductance to happen.



The classic "Rutherford-Bohr" model of the atom.
Niels Bohr developed it in 1913. It has since had numerous amendments to account for discoveries in *quantum mechanics.*



Bohr discovered that electrons could only exist in specific "quantized" orbits, with only a certain number of electrons allowed in each orbit or "shell". The outer "valence" shell was key in how the atom interacted with other atoms.



The element copper has 29 electrons in 4 energy levels, with only ***one lonely electron*** in it's fourth (valence) shell.

Series and Parallel:

Batteries in series.

When connected “in series”, DC voltage sources are <u>added</u>. In the above example, two AA batteries (1.5 volts each) wired in series supply 3 volts to the circuit. (1.5 + 1.5 = 3.)

Batteries in parallel.

When connected “in parallel”, batteries' voltages are unaffected, but the current (measured in *amperes*) is increased. In the above example, two AA batteries (1.5 volts each) wired in parallel supply 1.5 volts to the circuit, but can do so for a longer time than a single battery alone.

What's going on inside a resistor?

If you break one open, and scratch off the outer coating of insulating paint, you might see an insulating ceramic rod running through the middle with copper wire wrapped around the outside. A resistor like this is described as wire-wound. The number of copper turns controls the resistance very precisely: the more copper turns, and the thinner the copper, the higher the resistance.

In smaller-value resistors, designed for lower-power circuits, the copper winding is replaced by a spiral pattern of carbon. Resistors like this are much cheaper to make and are called carbon-film. Generally, wire-wound resistors are more precise and more stable at higher operating temperatures.

Resistor Color Codes

Resistance values:

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

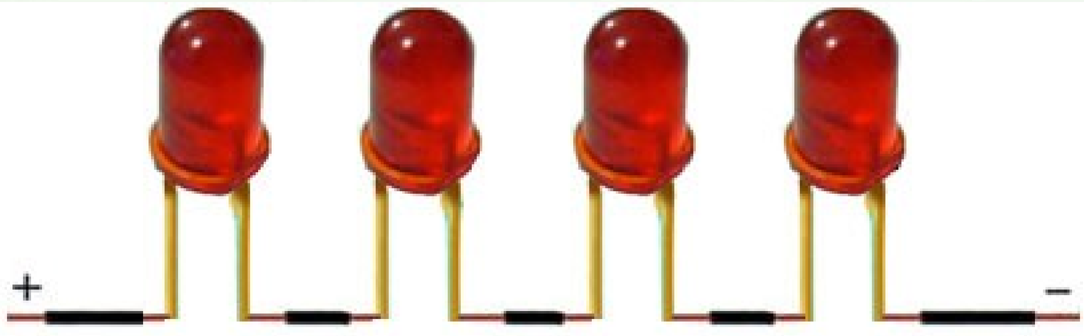
Tolerance values

- Brown ± 1%
- Red ±2%
- Gold ±5%
- Silver ± 10%

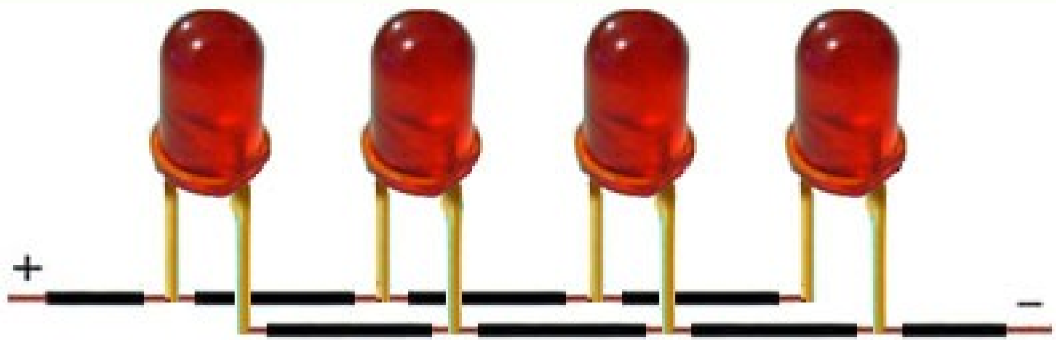
On most resistors, you'll see there are three rainbow-colored bands, then a fourth band usually colored gold, or silver.

The first two of the rainbow bands tell you the first two digits of the resistance. Suppose you have a resistor like the one shown here, with colored bands that are brown, black, and red and a fourth golden band. You can see from the color chart below that brown means 1 and black means 0, so the resistance is going to start with "10". The third band is a decimal multiplier: (how many zeros to add on the end.) Red means 2, so we multiply the 10 we've got already by 10 × 10 = 100 and get 1000. Our resistor is 1000 ohms.

Series and Parallel load:



series circuit



parallel circuit

The concept of being “in series” or “parallel” also applies to electrical components which are wired as the load of the circuit.

Some Definitions:

– The name for the property of having a “positive” and “negative” polar orientation is called “**polarity**.” Magnetic polarity and electrical polarity are inextricably linked.

- When a magnetic field is moved through a coil of wire, it causes electrons to move through the wire (electricity) in a process called “**induction**.” The moving magnetic field “induces” electrical current.

- **Direct Current** (**DC**) occurs when electrons flow in one direction continuously along a conductor. This is the kind of current obtained from batteries and is generally safe to work with at low voltages, and is the main kind of current we will be working with in our circuit constructions.

- **Alternating Current**(**AC**) occurs when the direction or polarity of the current alternates direction. AC is better suited for transmission through long distance power lines. Household (wall plug) current in North America delivers 110-115 volts, alternating at 60 times a second (60 Hz). A wire carrying AC will induce a current in nearby wire.

- “Wall current” (110-115 VAC) is a dangerous, potentially life-threatening energy source. **<u>Do not use it</u>** in the circuits you build without the advice and oversight of faculty and staff who can assure the work is done safely.

Some Definitions:

– Electricity (electrons flowing through a circuit) has two principle properties: voltage and current.

- **Electromotive potential** *(symbol: V, or sometimes the more archaic E)* is the difference in potential energy between two points in a circuit. It is measured in units called ***volts*** (after Alessandro Volta, inventor of the battery.) In the metaphor of water and plumbing often used to visualize electrical charge flowing in a circuit, voltage would be thought of as water pressure.

- **Current**: *(symbol: I for "intensité")* Current is the rate of flow, or volume of electrical charge through a circuit. The unit of measure is the ***ampere***, usually shortened to "***amp***" (after French physicist André-Marie Ampère.) It's a measure of how many electrons go past a given point in a circuit per second. (In the water metaphor, current can be thought of as the diameter of the pipe.)

- **Power** *(symbol: W)* Volts and amps multiplied together equals the total amount of electrical power in the circuit, measured in units called ***watts*** (after James Watt, Scottish inventor and engineer.)

- **Resistance** *(symbol: Ω -Greek letter for omega)* Also called **impedance**, is measured in units called ***ohms*** (after German physicist, Georg Ohm.)

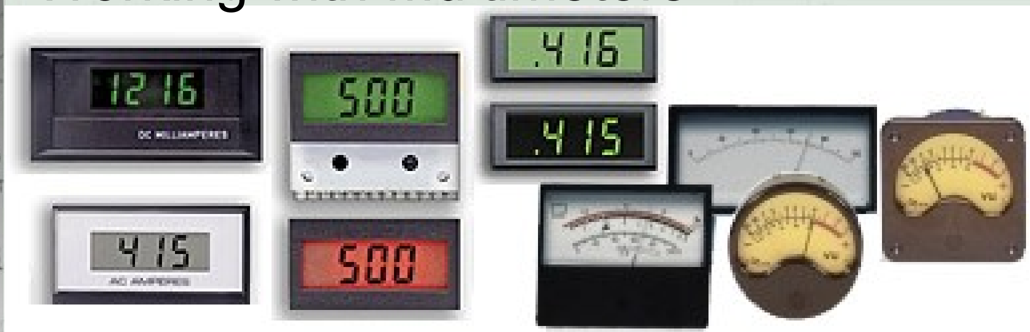
Prefixes:

These prefixes are universally used to scale units in science and engineering:

Prefix	*Abbreviation*	*Multiplier*
tera	T	10^{12} (= 1,000,000,000,000)
giga	G	10^{9} (= 1,000,000,000)
mega	M	10^{6} (= 1,000,000)
kilo	k	10^{3} (= 1,000)
(none)	*(none)*	10^{0} (= 1)
centi	c	10^{-2} (= 0.01)
milli	m	10^{-3} (= 0.001)
micro	µ	10^{-6} (= 0.000 001)
nano	n	10^{-9} (= 0.000 000 001)
pico	p	10^{-12} (= 0.000 000 000 001)
femto	f	10^{-15} (= 0.000000000000001)

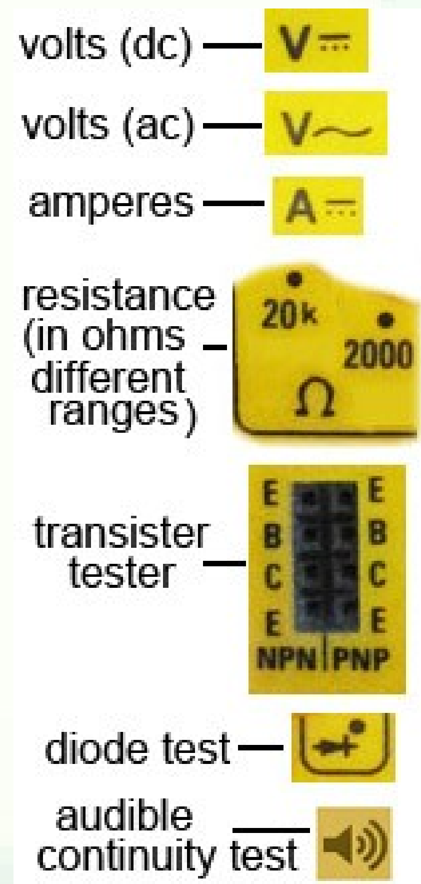
When abbreviating a unit with a prefix, the symbol for the unit follows the prefix without space. Be careful about upper-case and lower-case letters (especially m and M.) 1mW is a milliwatt, or one-thousandth of a watt, but 1MW is a megawatt (one million watts.) The unit name is only capitalized when it is abbreviated. For example, in describing cycles-per-second we use hertz and kilohertz, but Hz and kHz.

Working with Multimeters



As you can imagine there are many different meters for measuring things. (“Ohmmeters” for measuring resistance, “Voltmeters” for measuring voltage, etc.) They come in analog and digital flavors.

Probably the most useful tool we will be using to understand what's going on in our circuits is the digital multimeter (DMM). You should all get one if you are serious about working with electronics.
As its name implies, it is a collection of multiple types of meters in one handheld device. Especially useful in our first circuits are the voltmeter (with the dashed line indicating dc current) and the ohmmeter (in different ranges by the “omega” symbol.)



Meter “ranges”

Multimeters are available that are “auto-ranging”, but we will be using the more economical manually-ranged meters. This means you will be manually selecting both the *type of meter* and the *range* within which you will be measuring.
Start by selecting the range you think is closest to the value you will be measuring. In this example, I'm measuring something I think is around 6 volts, so I start in the range of 0 – 20 volts. I'm measuring dc current, so I select the range in the area next to the “V” with a dashed line. (The “V” with the wavy line is volts of ac current.)

Meter “ranges”

If I move dial to the 0 – 200 volt range, notice what happens:
The meter is displaying the same value, but it moves over one decimal place to make room for a sign (+ or -) and larger, three digit number. - And notice I'm losing some resolution (the hundredths place) in the process. Selecting the range closest to the value you are measuring will give you the most precise measurement (most decimal places.)

Meter “ranges”

If I move dial to the 0 – 1000 volt range, notice what happens:
The meter is displaying the same value, but it moves over one decimal place to make room for a sign (+ or -) and larger, four digit number.
-And notice I'm losing some resolution (the tenths place) in the process.

Meter “ranges”

The range below 0 – 20 volts has a small letter “m” indicating that it is a range measuring millivolts (thousandths of a volt.)
Note: 0 – 2000 thousandths of a volt is the same as measuring 0 – 2 volts.

Since the voltage we are measuring is 5.71 volts, the meter displays a numeral 1 at the left of the display. This is what the display looks like when it is measuring a value that is “out of range.” If you see it, just move the dial to a larger range. (Or check that you are not trying to measure the wrong units, like volts instead of ohms.)
Lastly, be sure to turn the meter off when you are finished to save battery life.

Let's put these tools to work!