An Electrifying 'ntroduction to Electricity

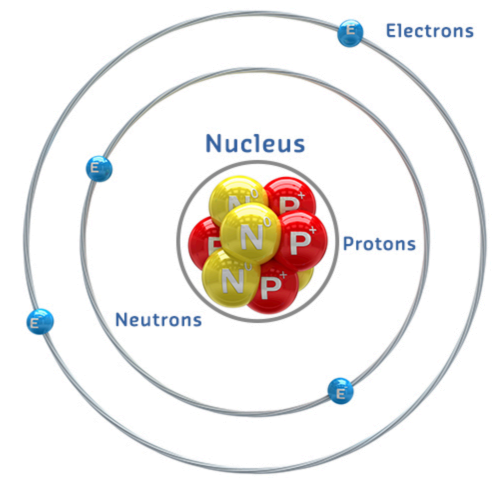
44-440/640-IoT

Objectives

- Students will be able to
  - define charge, electrostatic force, circuit, current, voltage (aka electromotive force), resistance and power
  - distinguish between current and static electricity
  - state Ohm's law

Charge!

- **Charge** is a property of matter, like mass:
  - you can measure how much mass an object has
  - you can measure how much charge it has
- Unlike mass, charge comes in 2 types: positive (+) and negative (-)
- **Electrons** are negatively charged; **protons** positively charged; **neutrons** have no charge (they are neutral)
- Both electrons and protons carry the same *amount* of charge, just of a different type.
- Since 1 electron represents the smallest unit of negative charge (1-), we can talk *equivalently* about the motion of charges and the motion of electrons.



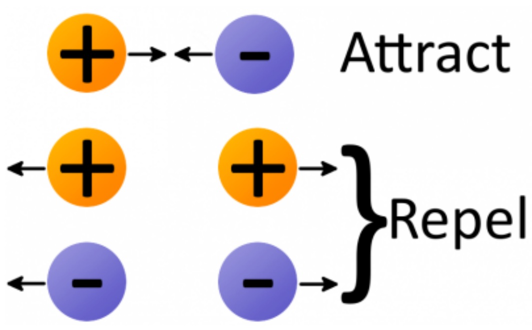
Particles in an Atom

Particle	Symbol	Charge	Relative Mass (amu)	Model
Proton	p^+	1+	1	
Neutron	n	0	1	
Electron	e^-	1–	$\frac{1}{1,836}$	

Most objects generally have the same # of protons and electrons, & hence are neutral.

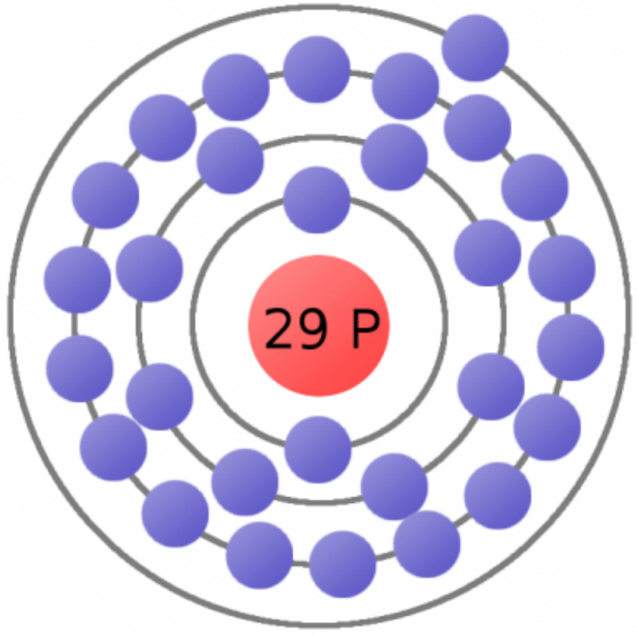
Electrostatic Force

- **Electrostatic force** is the force between charges
- Like charges repel; opposite charges attract
- Electrostatic force follows the inverse square law (like gravity): e.g., if you double the distance, the force is $1/2^2 = 1/4$ of what it was; triple the distance, the force is $1/3^2 = 1/9$ of what it was; etc.
- This was formulated by Charles-Augustin de Coulomb in 1784, as a consequence of which we use flashlight apps on cellphones rather than candles 😀

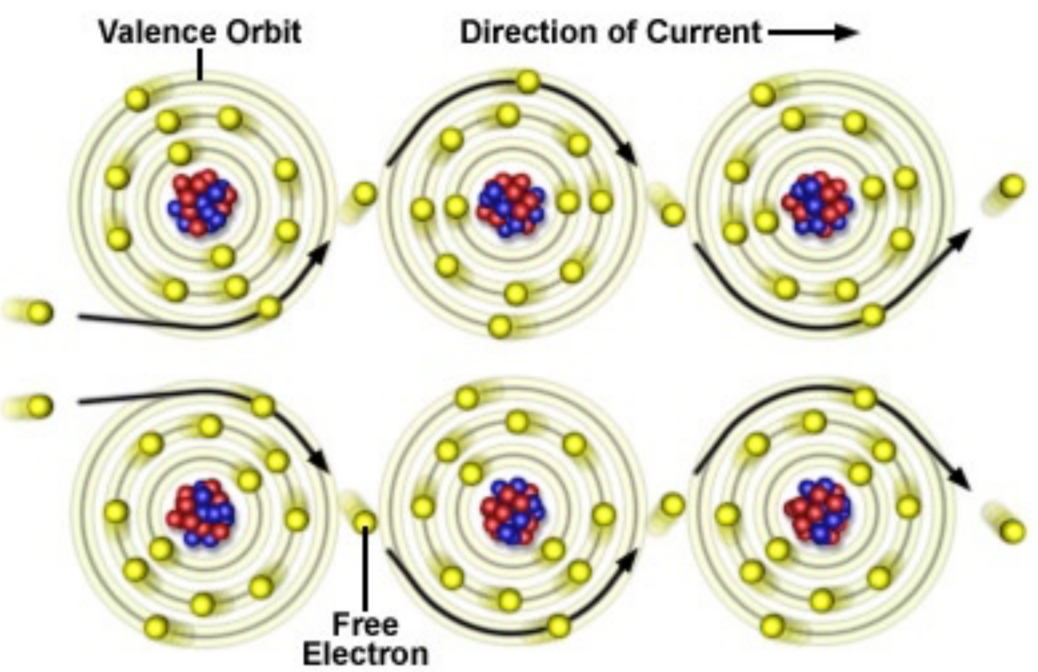


Electric Current

- In an atom, electrons exist in different orbits.
- Electrons in orbits closer to the nucleus are more tightly bonded to it, since electrostatic force follows an inverse square law
- A **valence** electron — in the outermost orbit, relatively far away from protons in the nucleus — can be dislodged via electrostatic force (from another electron), becoming a **free** electron.
- Free electrons, as they drift between the atoms, jostled by electrostatic forces, will eventually run into another atom, dislodging *its* valence electron — which in turn becomes free, then eventually gets attracted to another atom, etc. The result is an **electric current**.
- A **conductor** (a metal, usually) is comprised of atoms that have a very weak grasp of their valence electrons, so electrons can flow easily through them. An **insulator** (glass, plastic, rubber, air) is the opposite.



Copper: 29 protons, 29 electrons



Measuring Current

- Current is measured as a **rate**, the number of charges (electrons) passing a given point per second.

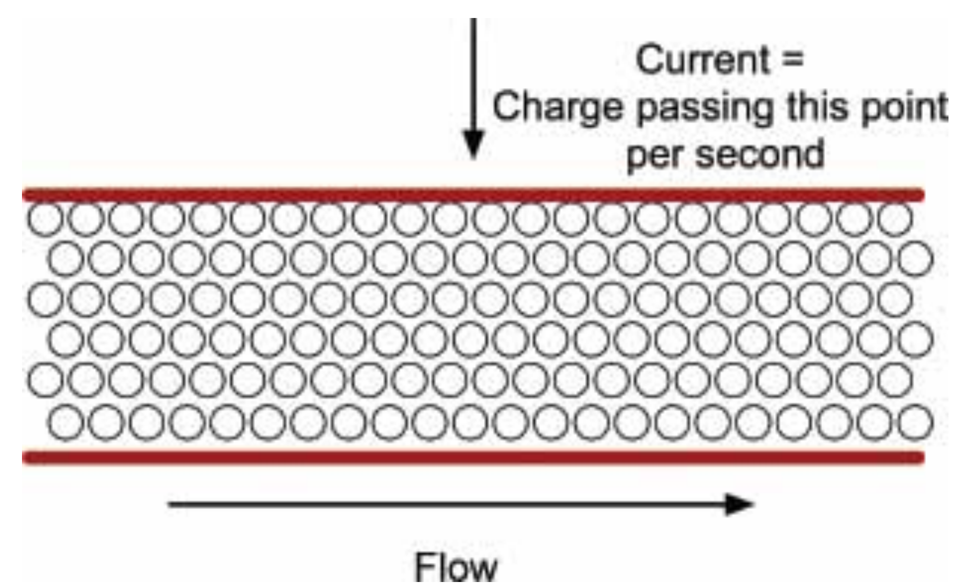
- Since there are so many of them — in a 100W bulb, 6×10^{18} charges pass by per second — engineers measure charges in coulombs:

  - **1 coulomb = 6.2×10^{18} electrons**

  - **1 coulomb / second = 1 Ampere (1A)**

- 1 A is a lot of current. We will be working in milliamps (mA) through this course

Think of electric **current** like water current in a river... except instead of H_2O molecules or rubber duckies, we are talking of charge.

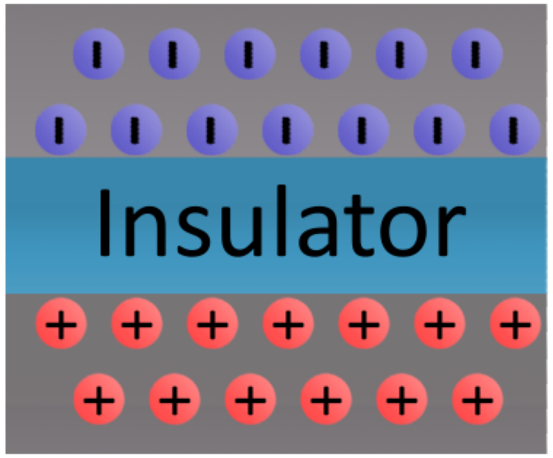


Static vs. Current Electricity

- **Static electricity** is the result of a build up of opposite charges separated by an insulator. If the charges build up sufficiently, they can leap through the insulator, causing a **static discharge**.

- Static electricity damages electronic components.

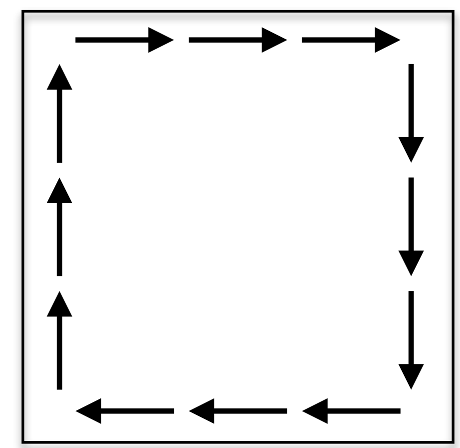
- **Current electricity** is a continual flow of electrons.



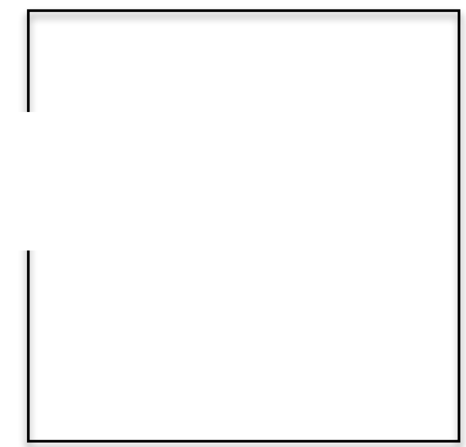
Circuits

- Charges can only flow through a **circuit**, a *closed* path of conductive material.

- If there is a break *anywhere* in the circuit — an **open circuit** — no charge flows *anywhere*.



A continuous flow



No flow *anywhere*

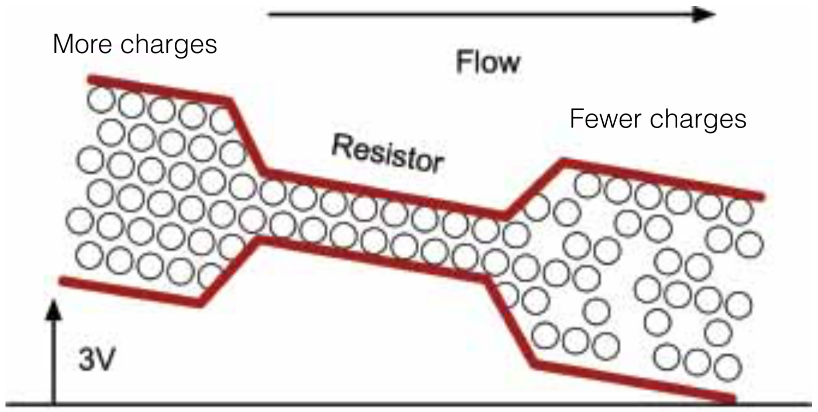
Voltage

- Free electrons, drifting from atom to atom, bumping valence electrons, represent a current. But what gets them moving in the first place? 🧐

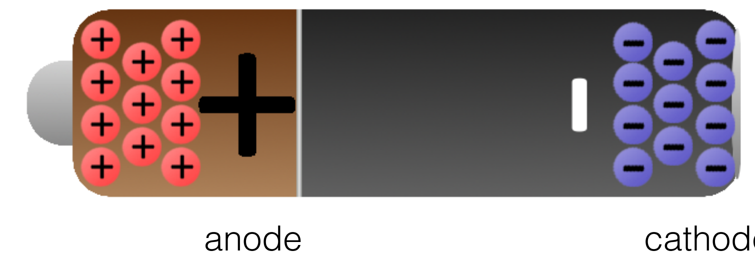
- In a river, water flows because one end is higher than the other. Gravity provides a force that induces water to flow: the greater the difference in height, the greater the flow.

- The equivalent in electronics, **voltage** (aka **electromotive force**, aka **potential difference**), propels charges in a particular direction.

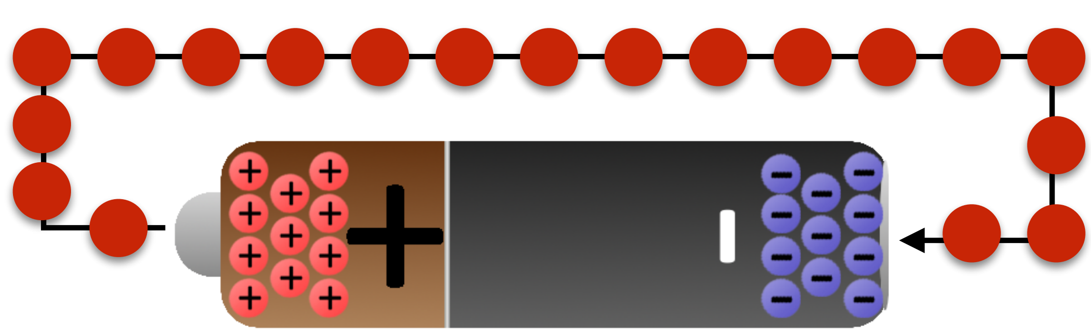
- Voltage is the **difference in charge between two points**. It exists whenever there is a **surplus of electrons** in one region, and a deficit in another: the greater the difference in charge, the greater the current will be when the two regions are connected



Voltage Sources: Batteries



- A battery has two terminals:
    - **cathode** - the negative terminal, with an excess of electrons and
    - **anode** - the positive terminal, with a deficit of electrons
- If we connect the two terminals using a conductive material to form a circuit between the two, electrons will flow. But if we did so, the electrons would flow too quickly and the resulting heat might destroy the battery, wire, or both 🙀🔥. We need something to impede the flow -- resistance!

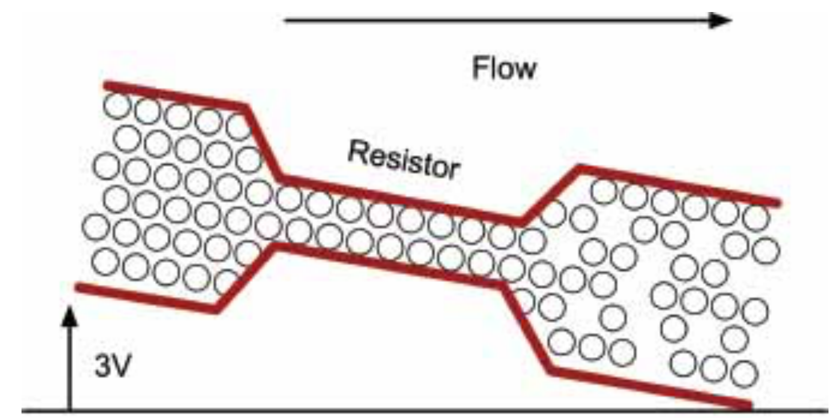


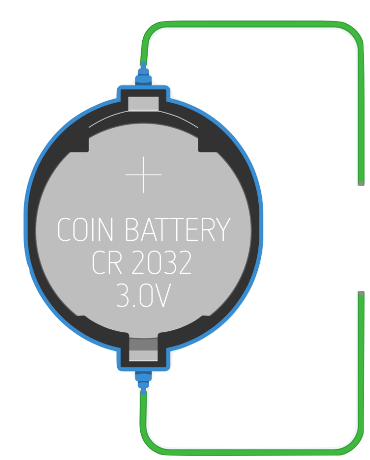
Voltage is Relative

- Voltage is *relative* — it depends on the *difference* in charge between two points — it doesn't matter if the voltage drop is from, say, 7V to 0V, or 10V to 3V, the rate of flow will be the same

- Again returning to the river analogy, it doesn't matter if the drop is from 500 to 100 feet, or 7000 feet to 6600 feet, it is the same difference (400 feet), so you would have the same current

- Note that you can have voltage without a current — for example, in an open circuit. What would the equivalent be in our river analogy?



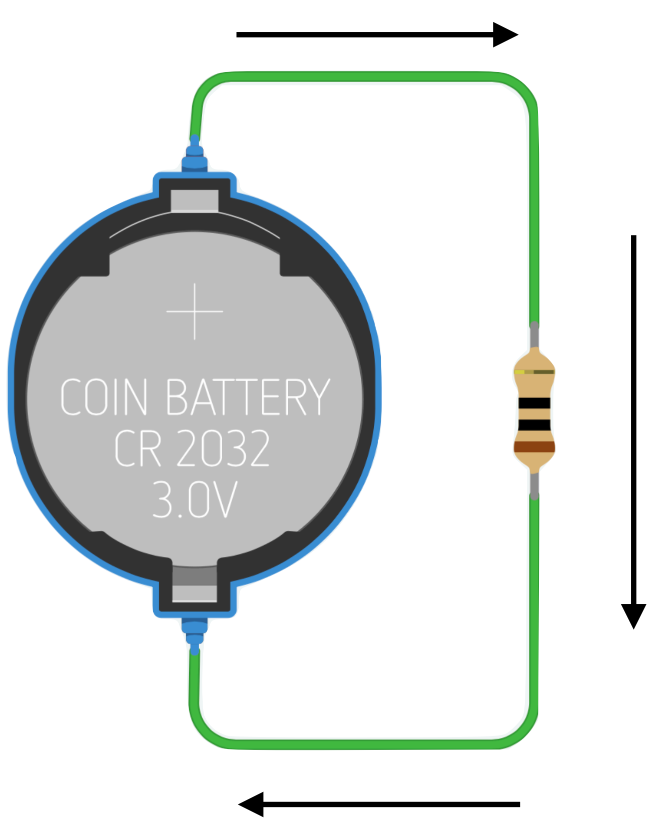


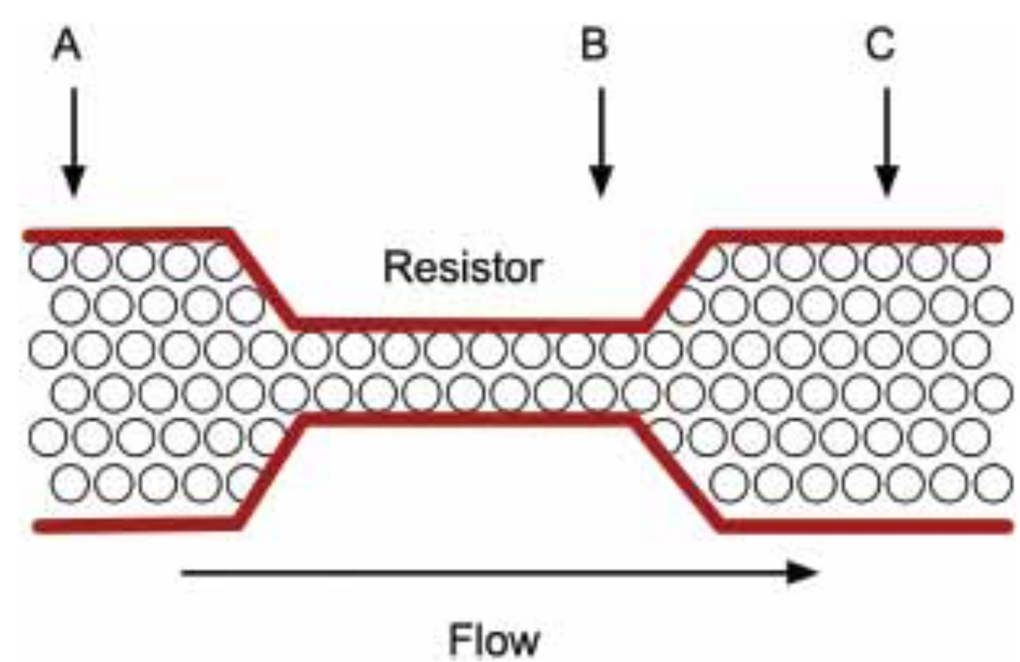
The battery has a voltage, but there is no current

Ω = Omega, the last letter in the Greek alphabet

Resistance

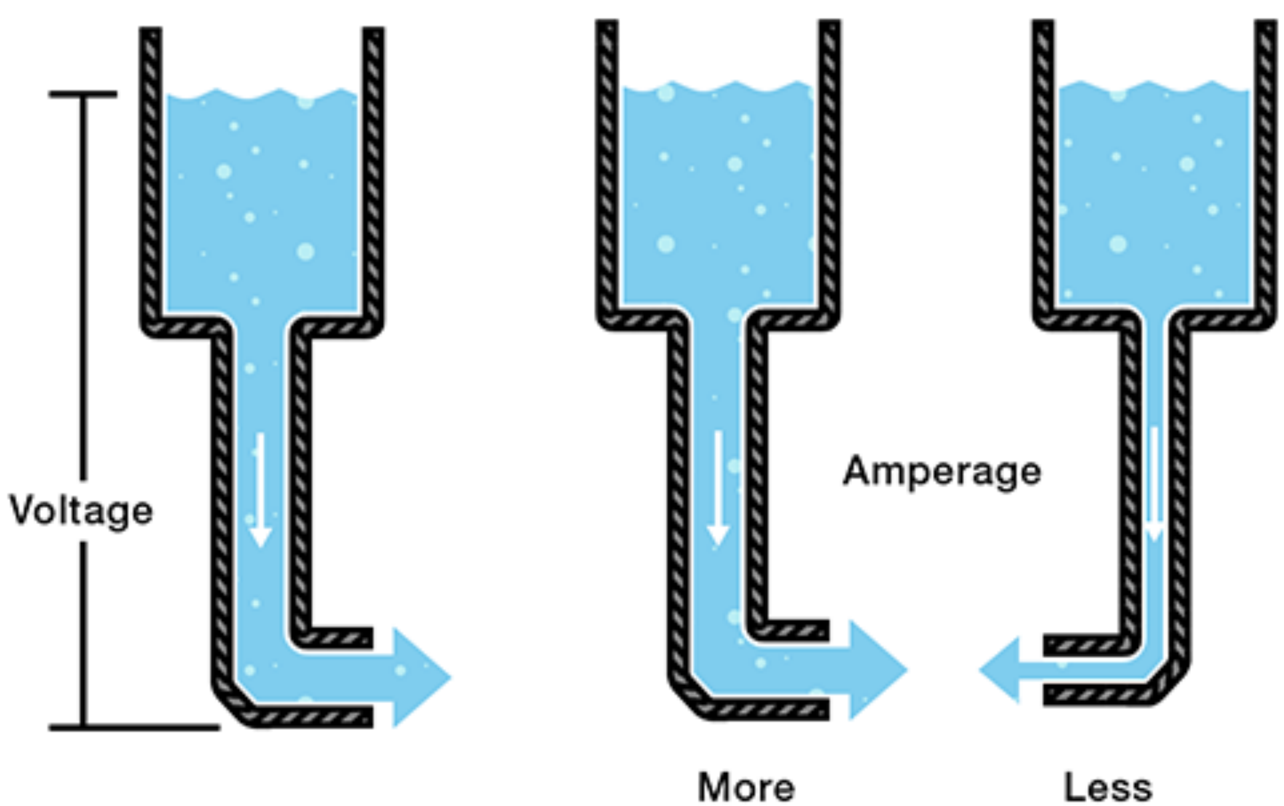
- **Resistance** is **a material's tendency to resist the flow of charge** (current). Even though the restriction is just in one location, current flow will be the same at A, B and C.
- The electronic component with the stripes is a **resistor** that has a specific amount of resistance. We discuss it in detail later.
- Resistance is measured in **ohms** (Ω). The more the resistance, the less flow





A Water Analogy

- Consider a tank of water representing a battery, and a hose out of it representing a wire
- Add water to increase charge, and thence voltage and thence current; change the hose width to affect resistance and thence current

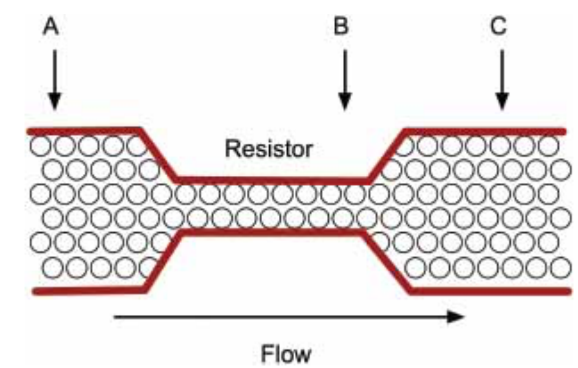


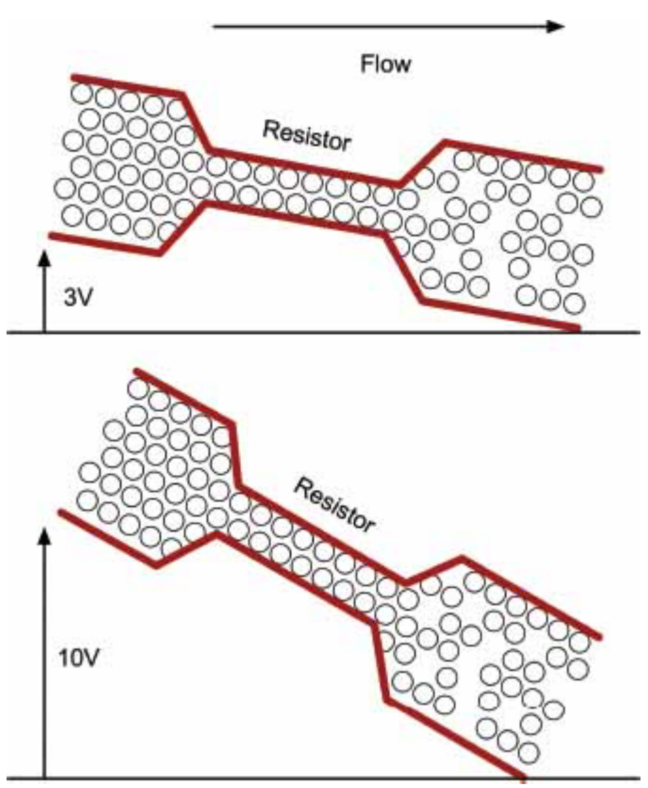
Water	Electricity
Amount of Water	Charge
Pressure at End of Hose	Voltage
Water Flow	Current
Hose Width	Resistance

ICE: Questions to Ponder

- What do you think happens to current flow if you increase resistance? Decrease resistance? What does that tell you about the relationship between current and resistance?

- What do you think happens to current if you increase voltage? Decrease voltage? What does that tell you about the relationship between current and voltage?





Ohm's Law

Some texts use E (for **E**lectromotive force), instead of V.

- Ohm's law, discovered by Georg* Ohm**, states that current between two points is directly proportional to voltage across those two points, and inversely proportional to resistance, i.e.,

$$I = V / R$$

$$V = IR$$

where

  - I = Current, measured in amperes (A)
  - V = Voltage, measured in volts (V)
  - R = Resistance, measured in ohms (Ω)

- So, for example, if you have a circuit with just one resistor and a battery source, as the illustrations of a single constriction in the circuit have implied, the current through that resistor would be given by the voltage drop across the resistor divided by the resistance. If we have more than 1 resistor it gets a little complicated: we explore that later on.

* why the missing 'e' in his first name? The historical record is silent on the subject.

** if you are planning to sing a punny song about "'ohm, ohm on the range", you are too late!

Ohm's Law Examples

- A 100Ω resistor has 2mA of current flowing through it. Find the voltage drop across the resistor
  - $V = IR = 0.002 * 100 = 0.2V$.
- A resistor is in a circuit with a 6V battery, and the current needs to be 50 mA. What is the resistance?
  - $R = V/I = 6/(50x10^{-3}) = 120\Omega$
- If you doubled the size of the resistor, what would the current be?
  - Since V=IR=6, if R is doubled, I must be halved, i.e., 25 mA

Metric Units

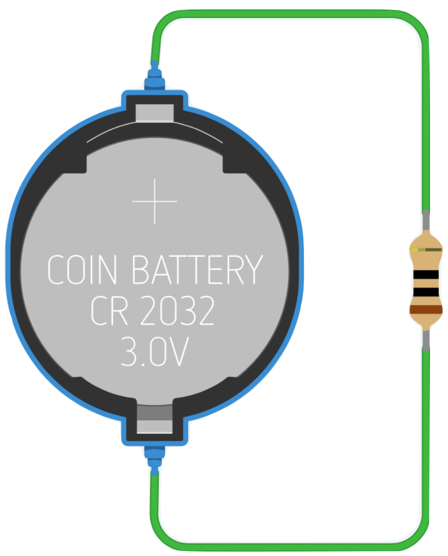
Letter	Unit	Value	English	Value
p	pico	10^{-12}	Trillionth	1/1,000,000,000,000
n	nano	10^{-9}	Billionth	1/1,000,000,000
μ	micro	10^{-6}	Millionth	1/1,000,000
m	milli	10^{-3}	Thousandth	1/1,000
k	kilo	10^{3}	Thousands	1,000
M	mega	10^{6}	Millions	1,000,000

These show up in all sorts of places, so it's worth while to know them

Power

- As charges move through a device, those charges do work, as that energy is converted into **mechanical work**, **heat**, or **light**. Like current, power is a *rate*, the amount of energy transformed per second. It is given by the formula

$$P = IV$$



- where
    - P = Power, measured in Watts (W)
    - I = Current, measured in amperes (A)
    - V = Voltage, measured in volts (V)
- In the case of a resistor, what do you think that energy will be transformed to?
- When designing a circuit, it is important to make sure we don't exceed the maximum power rating of a component, otherwise it could melt 😐

Techy Aside: Units

- 1 coulomb (C) = 6.24 $\times 10^{18}$ electrons
- 1 ampere (A) = 1 coulomb per second
- 1 joule (J) = the amount of work done when a force of 1 Newton is applied through 1 metre
- 1 volt (V) = 1 joule / coulomb
- 1 watt (W) = 1 joule / second
- The units work:
    - P = IV = coulombs/s * joules/coulomb = joules/s

Exercises

1. Define the following terms: charge, electrostatic force, valence electron, current, static electricity, current electricity, circuit, open circuit.

2. Define current, resistance, and voltage.

3. State Ohm's Law, and explain what it means.

4. What units are V, I and R expressed in?

5. How many Amps are in 350 mA? 15 mA? How many mA's are in 0.015 A? 15A?

6. Calculate the voltage drop across a 330Ω resistor when the current is 330 mA

7. Calculate the current flow through a 1KΩ resistor when the voltage is 0.25V

8. A circuit has a 3.3V battery and a current flow of 100 mA. What is the resistance in the circuit?

9. What is the charge of an electron? Proton? Neutron?

Exercises

10. **Programming assignment.** Write a C++ program to repeatedly

    1. prompt the user for a quantity to calculate -- V, I, R -- or Quit.

    2. prompt for the variables required to for the chosen quantity, then calculate and print it

    3. repeat steps 1-2 until Q is chosen.

```
Choose quantity to calculate:
V) oltage
I) Current
R) esistance
Q)uit

Choice: V

Enter I and R: 100 5
V = 500.0 volts

Choose quantity to calculate:
V) oltage
I) Current
R) esistance
Q)uit

Choice: Q
Thanks for dropping by!
```

Resources

- Bayle, Julien. *C Programming for Arduino*. Packt Publishing, 2013.
- https://learn.sparkfun.com/tutorials/what-is-electricity
- http://www.colorado.edu/physics/phys1120/phys1120_fa09/LectureNotes/Voltage.pdf
- Monk, Simon. *Hacking Electronics:An Illustrated DIY Guide for Makers and Hobbyists*. McGraw-Hill, 2013.
- https://www.ampbooks.com/mobile/tutorials/lesson-002/
- https://www.eeweb.com/toolbox/4-band-resistor-calculator/
- http://www.mi.mun.ca/users/cchaulk/eltk1100/ivse/ivse.htm#
- http://www.nutsvolts.com/magazine/article/which-way-does-current-really-flow
- https://en.wikipedia.org/wiki/Hydraulic_analogy