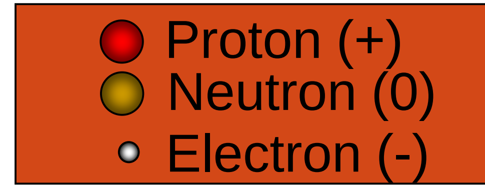
IDC102:Hands-on Electronics
Lecture - 1

Basic - 2

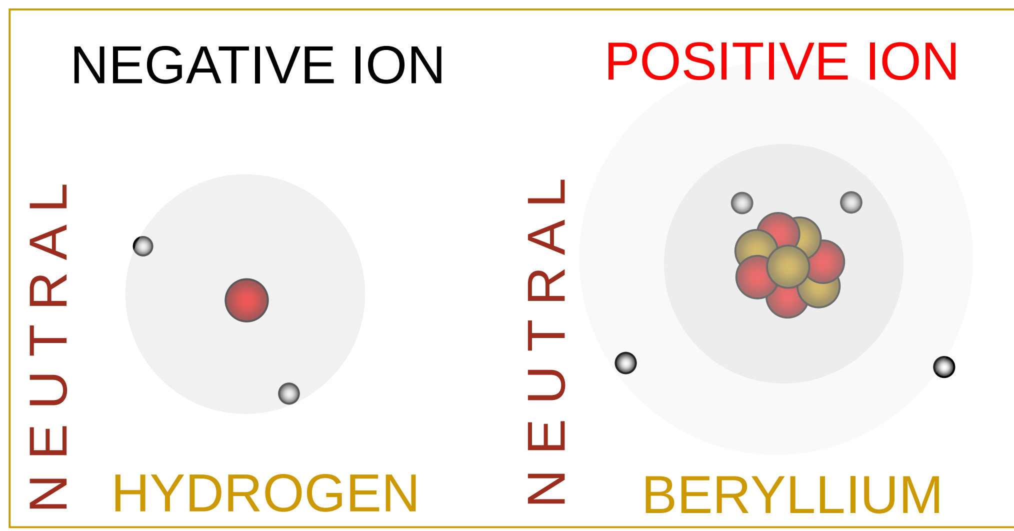
IISER

Satyajit Jena, 09/05/2022

Recap: Charge

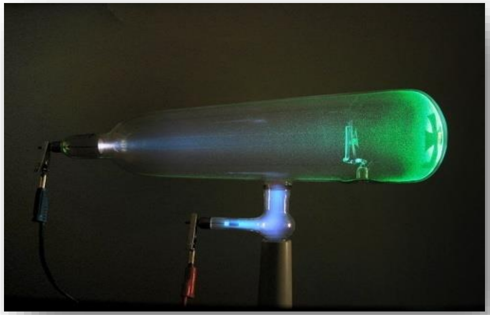


- In a simplified atomic model, electrons orbit about a central nucleus:
- As long as the number of electrons equals the number of protons, an atom is neutral.
- If an electron is **removed from** an atom, the atom has a net (+) charge and becomes a **positive ion**.
- If an electron is **added to** an atom, the atom has a net (-) charge and is called a **negative ion**.



Charge

Charge – the elementary charge *e*



- Although we like to consider the charge of an electron -1 and the charge of a proton +1, it turns out the actual charge of each is given in terms of the **elementary charge** *e*.

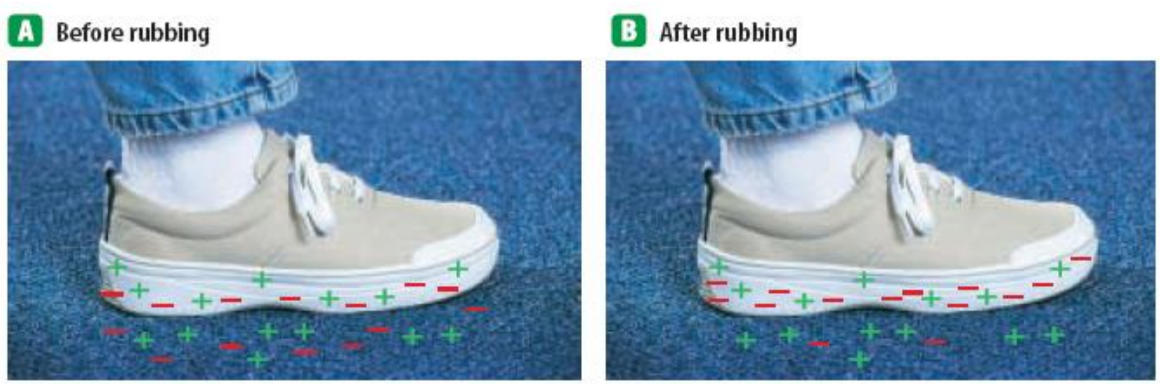
$1e = 1.60\times10^{-19}$ C	the elementary charge

- Sir William Crookes used his cathode ray tube to demonstrate the electrons were negatively charged.

- Physicists Robert Millikan and Harvey Fletcher performed the famous oil-drop experiment to determine the actual value of the charge of an electron in 1909.

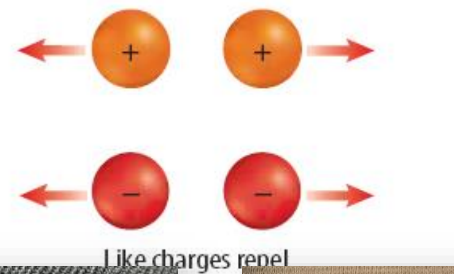
Electrons

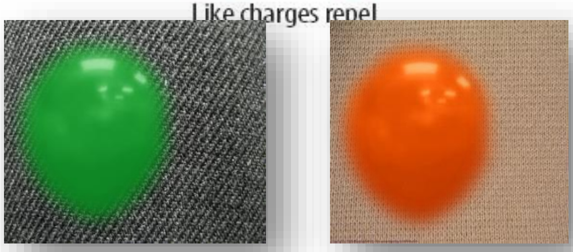
- Are located on the outer edges of atoms…they can be moved.
- A concentration of electrons in an atom creates a net negative charge. (More E than P makes Neg.); If electrons are stripped away, the atom becomes positively charged. (More P than E makes Pos.)
- A simple experiment can demonstrate not only the “creation” of charges, but a simple force rule.: Like the shoes rubbing against the carpet. Electrons are transferred from the carpet to the shoes.



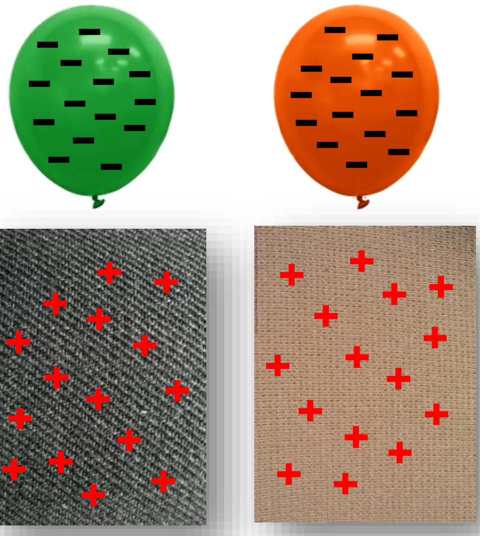
Static charge and Static Electricity

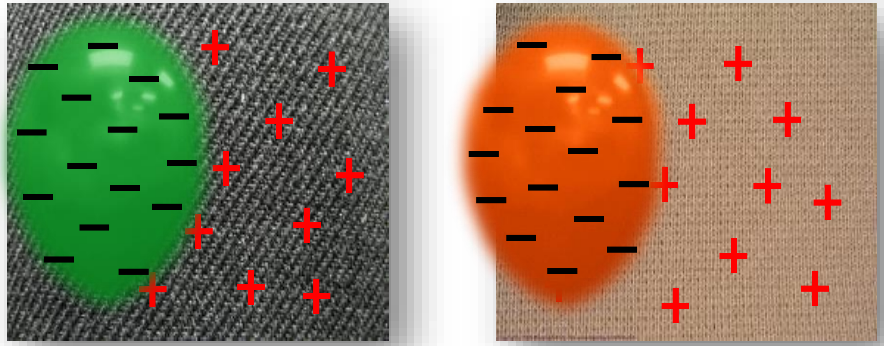
- The build up of an electric charge on the surface of an object.
- The charge builds up but does not flow.
- Static electricity is potential energy. It does not move. It is stored.



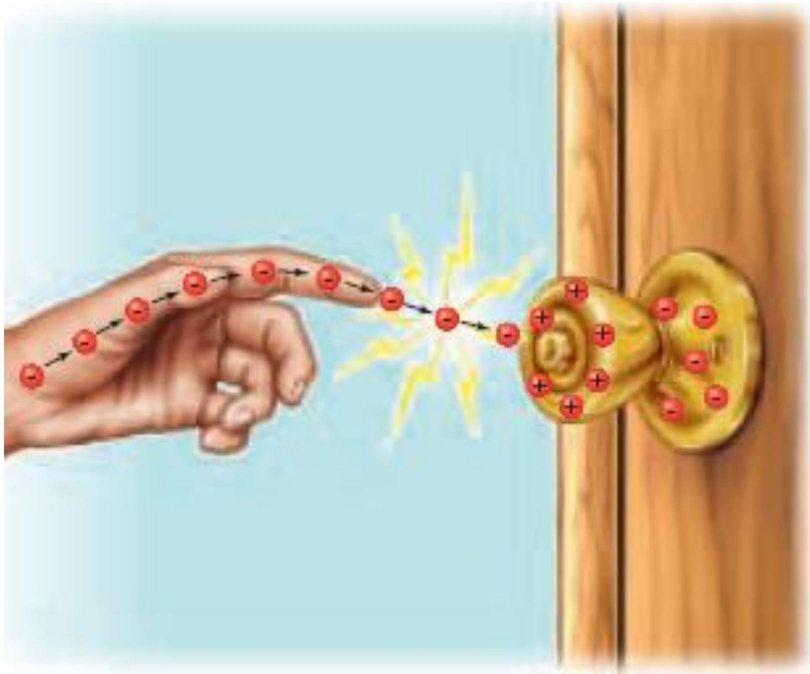


- As electrons collect on an object, it becomes negatively charged. As electrons leave an object it attains a positive charges. Charges interact with each other:





Sometimes you get shock touching a metallic contact



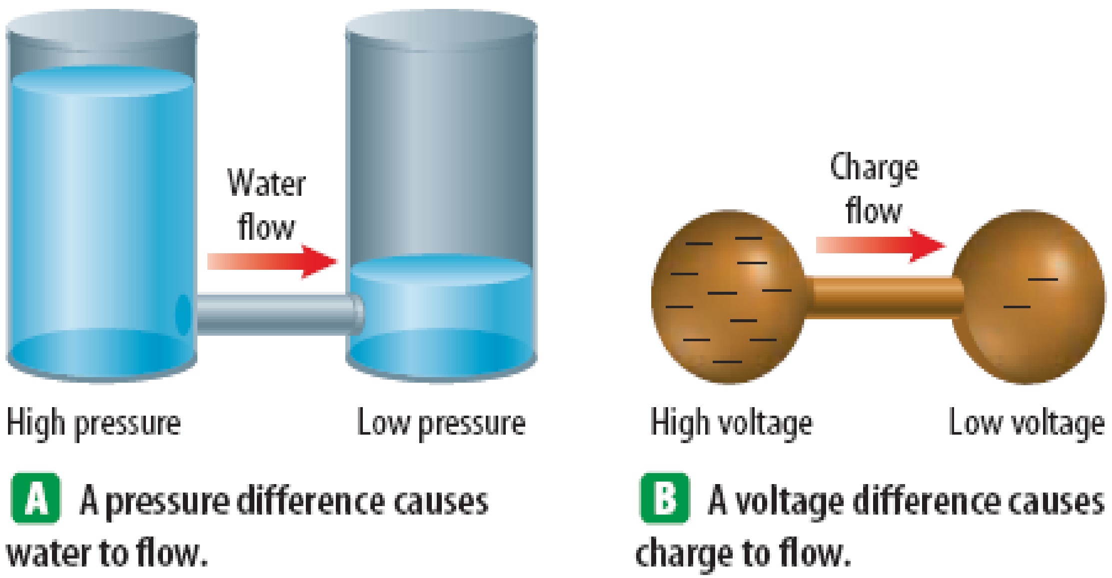
As you walk across a carpeted floor, your body builds up a static charge. When you reach for a metal doorknob, the charges flow between your hand and the doorknob and you feel a shock.

An electrical discharge is the passing of an electric current through the air from a negatively charged object to a positively charge object. This is what causes lightning!

Static vs. Current Electricity

Static electricity is stationary, whereas current electricity is flowing very rapidly through a conductor.

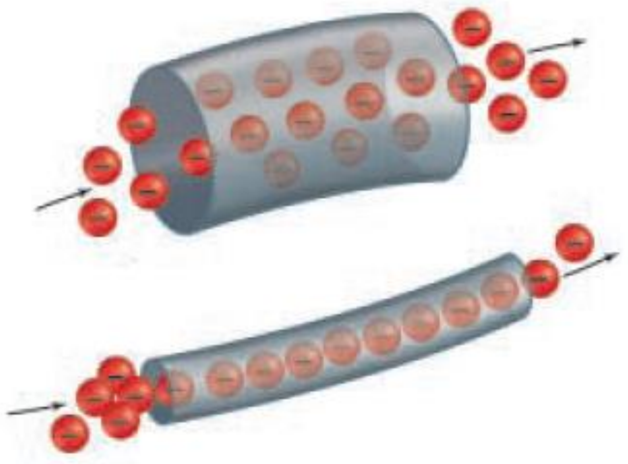
The flow of electricity in current electricity has electrical pressure or voltage. Electric charges flow from an area of high voltage to an area of low voltage.



Water pressure and voltage behave in similar ways.

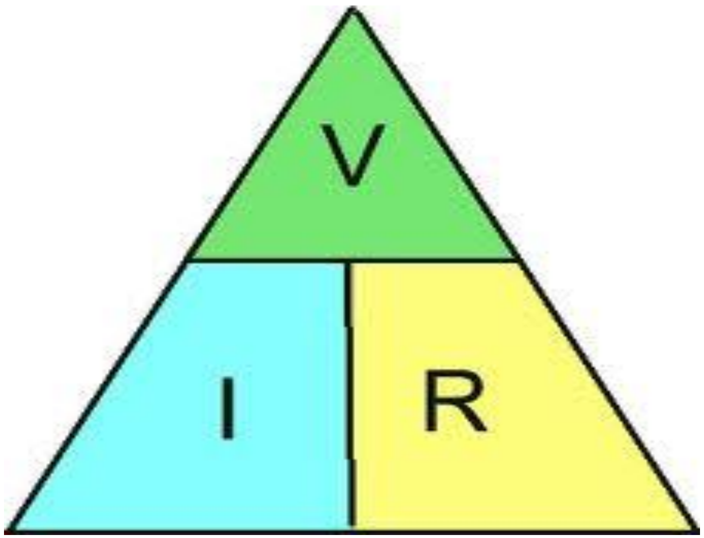
Difference b/t Volts and Amps

- Example – you could say that…
  - Amps measure how <u>much</u> water comes out of a hose.
  - Volts measure how <u>hard</u> or the pressure at which the water comes out of a hose.
  - Thus, the opposing force (which stops water) is just the pressure at which water comes out over how much of water is coming



Ohm's Law

- An electron travelling through the wires encounters resistance. **Resistance** is the hindrance to the flow of charge. For an electron it is a zigzag path that results from countless collisions with fixed atoms within the conducting material



- **Voltage = Current x Resistance**
  (Volts) (Amps) (Ohms)

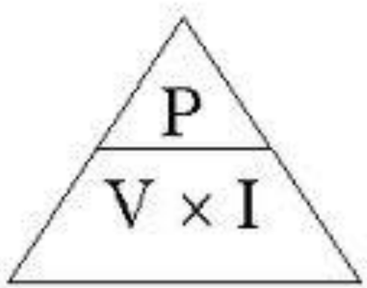
$$V = IR$$

I and V are directly proportional to one another when the resistance stays constant

Power

- Power is the rate of energy used (how quickly you use energy).
- Power = energy / time
- Power is measured in Watts (W)
- 1Watt = 1 joule of energy used every second.

- In electricity we use the equation:
- Power = Voltage x Current
  (Watt) (Volts) (Amps)
- Or use symbols
- P=VI



Electricity that moves…

- Current: The flow of electrons from one place to another.
- Measured in amperes (amps)
- Kinetic energy

- How can we control currents?:
  - We need to understand the flow of electricity
  - And a suitable circuit
  - Also, to understand what is the source of electricity or how the electricity is generated => to understand this we need to look little bit about history of magnetism
  - Let's go through the history

Magnetism and electricity

- Term comes from the ancient Greek city of Magnesia, at which many natural magnets were found. We now refer to these natural magnets as **lodestones** (also spelled loadstone; lode means to lead or to attract) which contain **magnetite**, a natural magnetic material Fe_3O_4.
- Pliny the Elder (23-79 AD Roman) wrote of a hill near the river Indus that was made entirely of a stone that attracted iron. And the material is known to many other civilization
- Use of magnets to aid in navigation can be traced back to at least the eleventh century.

- William Gilbert coined the term electric, from the Greek elektron, to identify the force that certain substances exert when rubbed against each other.
- The science of electricity has its roots in observation, known in 600 BC that a piece of amber rubbed with animal fur would attract straw, feathers
- Flying a Kite Experiment during a thunderstorm by Benjamin Franklin 1752

Basically, we knew the phenomenon existed and we learned useful applications for it. We just did not understand it. => Not until 1819

Magnetism and electricity

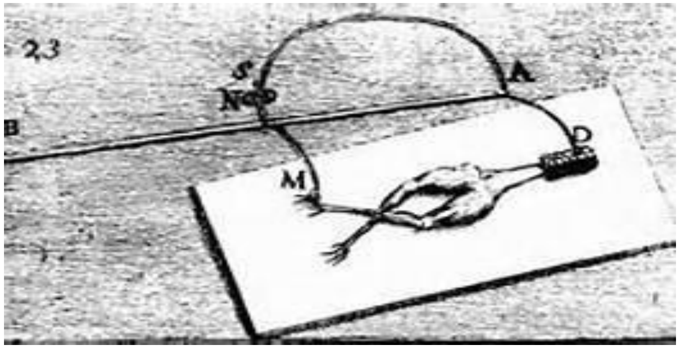
Let's wait a moment before checking what we understood.

- The Leyden Jar: The Leyden jar stored electricity and therefore could be studied at length => Progress quickened after the Leyden jar was invented in 1745

- 1752: By tying a key onto a kite string during a storm, Ben Franklin , proved that static electricity and lightning were the same.

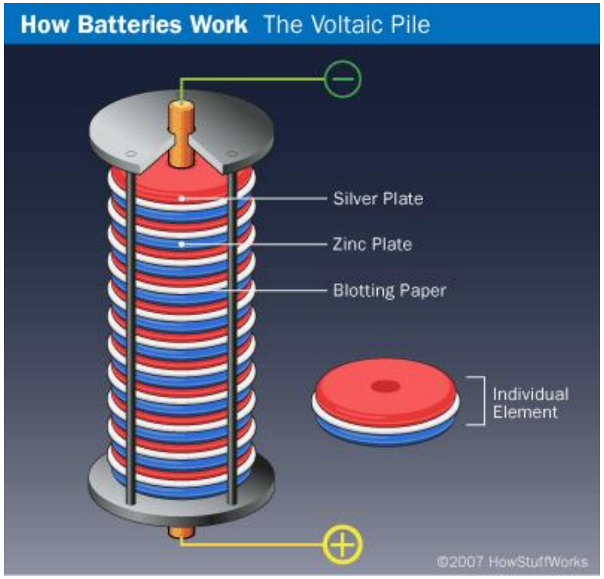
- A new interest in current began with the invention of the battery. Luigi Galvani had noticed (1786) that a discharge of static electricity made a frog's leg jerk.

- Galvani thought the leg supplied electricity, but Alessandro Volta thought otherwise. He showed that the metal plate and the Leyden jar were different metals and produced a current. He built the voltaic pile, an early type of battery, as proof.

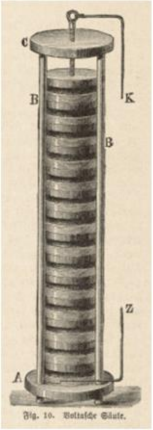


Magnetism and electricity

- **<u>voltaic pile</u>** a.k.a. the electric battery
  The first device to produce a steady electric current
- alternating layers of **silver** plates and **zinc** plates
- **blotting paper** (like a super absorbent paper towel) soaked in salt water between each layer
- [this acts like an **electrolyte**]
- a voltage can be measured at the terminal ends
- similar idea to a typical car battery



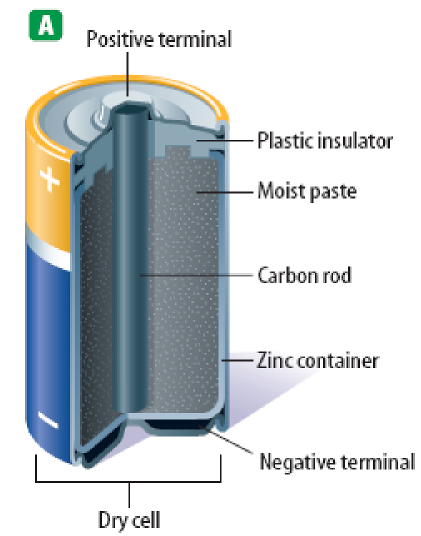
- Volta, not Franklin, discovered that certain chemical reactions could produce electricity.
- Volta also created the first transmission of electricity by linking positively-charged and negatively-charged connectors and driving an electrical charge, or voltage, through them.

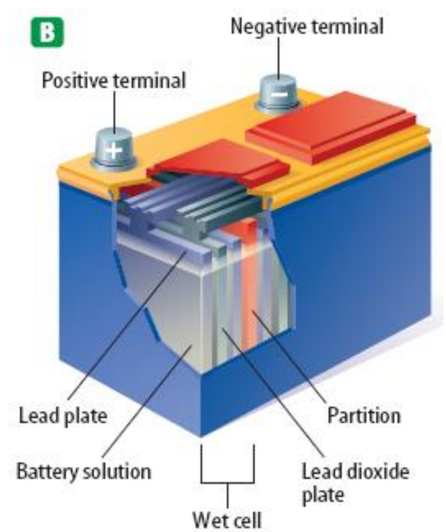


Batteries

- **Batteries** are composed of a chemical substance which can generate voltage which can be used in a circuit.
- Two kinds of batteries: dry cell and wet cell batteries.
- The zinc container of the dry cell contains a moist chemical paste surrounding a carbon rod suspended in the middle. (Alkaline and Lithium)

- A **Wet Cell** contains two connected plates made of different metals or metal compounds in a conducting solution. Most car batteries have a series of six cells, each containing lead and lead oxide in a sulfuric acid solution.

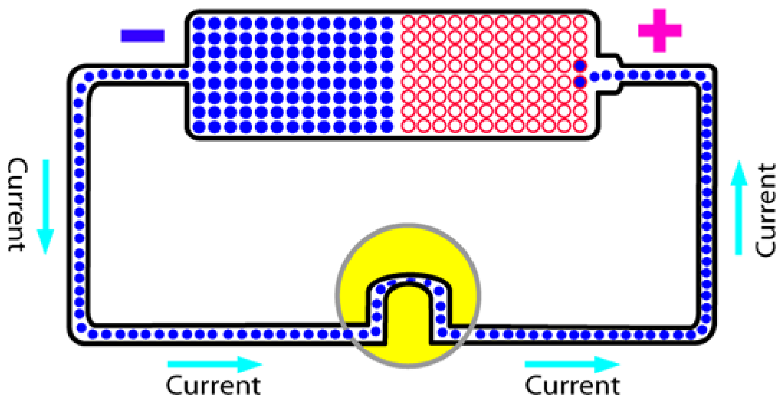




IDC102 - Basics: Electric Circuit

- The path of electric charges (current) is called electric circuit
- An electric circuit allows electrons to flow from a negative pole (excess electrons) to a positive pole (deficient in electrons)

  - It provides the path for the electrons to move
  - It controls the movement of electrons

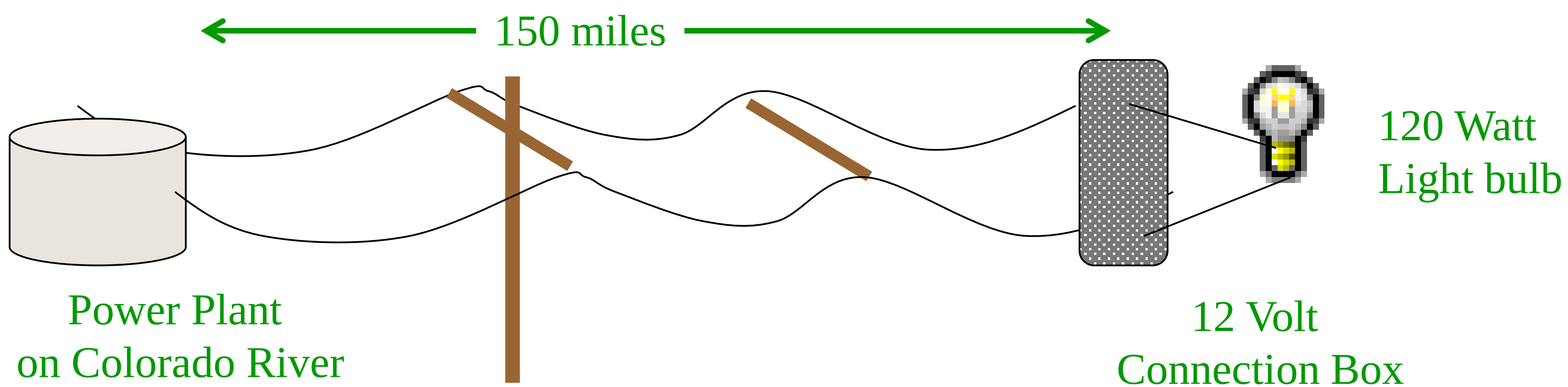


The interesting point is the path of electric circuit is always closed loop for electron to flow

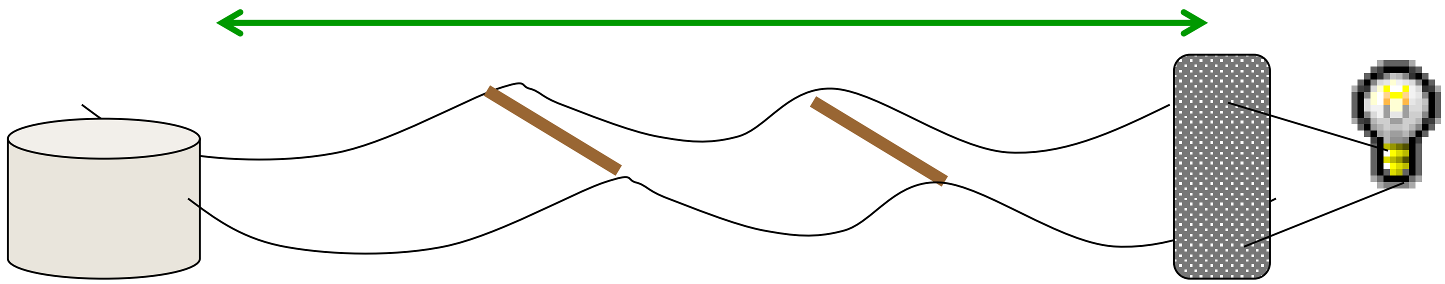
Powering Home

- To powering our home, we need to connect to power source
- Which means we will have a transmission line
- If power lines are long, then resistance are not negligible

Power Dissipated in an Electricity Distribution System: Example



Power Dissipated in an Electricity Distribution System



- Estimate resistance of power lines: say 0.001 Ohms per meter, times 200 km = 0.001 Ω/m $\times$ 2×10^5 m = 20 Ohms
- We can figure out the current required by a single bulb using $P = VI$ so $I = P/V$ = 120 Watts/12 Volts = 10 Amps (!)
- Power in transmission line is $P = I^2R = 10^2 \times 20 = 2{,}000$ Watts!!
- "Efficiency" is ε = 120 Watts/4120 Watts = 0.3%!!!
- What could we change in order to do better?

The Tradeoff

- The thing that kills us most is the high current through the (fixed resistance) transmission lines
- Need less current
  - it's that square in I^2R that has the most dramatic effect
- But our appliance needs a certain amount of power
  - $P = VI$ so less current demands higher voltage
- Solution is high voltage transmission
  - Repeating the above calculation with 12,000 Volts delivered to the house draws only

$$I = 120\,\text{Watts}/12\text{ kV} = 0.01\text{ Amps for one bulb, giving}$$

$$P = I^2R = (0.01)^2 20 = 20\times10^{-4}\,\text{Watts, so}$$

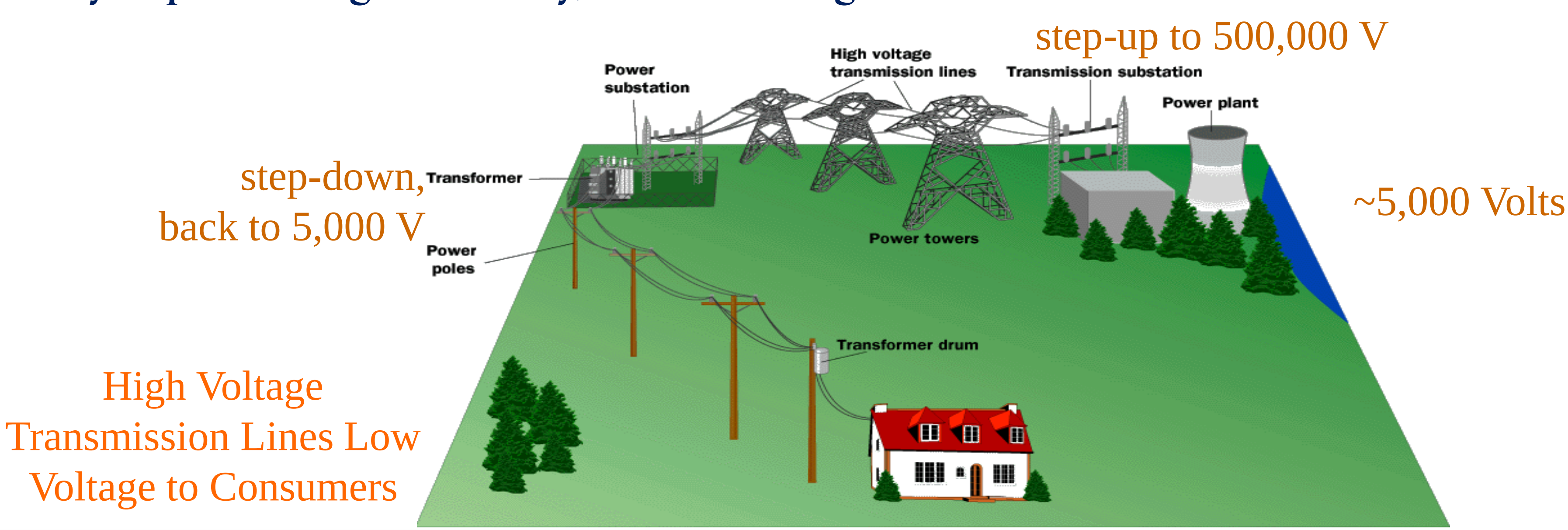
$$P = 0.002\,\text{Watts of power dissipated in transmission line}$$

Efficiency in this case is $\varepsilon = 120\,\text{Watts}/120.004 = 99.996\%$

DANGER!

- But having high voltage in each household is a recipe for disaster
  - sparks every time you plug something in
  - risk of fire
  - not cat-friendly
- Need a way to step-up/step-down voltage at will

A way to provide high efficiency, safe low voltage:



We just did not understand it => Not until 1819

- Not until 1819 was a connection between electrical and magnetic phenomena shown. Danish scientist Hans Christian Oersted observed that a compass needle in the vicinity of a wire carrying electrical current was deflected!

  => Oersted discovered that a compass needle responded to the a current in a loop of wire

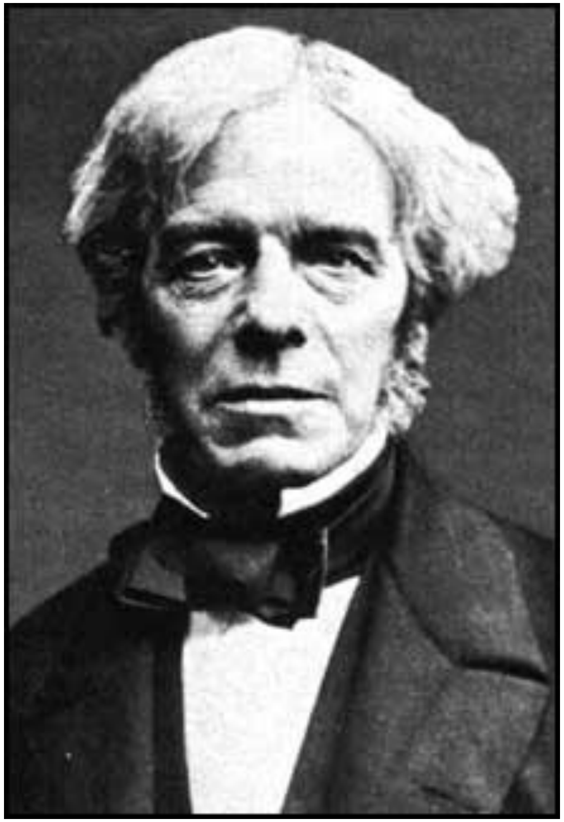
- Ampere deduced the law describing how a magnetic field is produced by the current in a wire
- *magnetic field lines are always closed loops* – no isolated magnetic poles; magnets always have a north and south pole
- permanent magnets: the currents are *atomic currents* – due to electrons spinning in atoms - these currents are always there
- electromagnets: currents in wires produce magnetic fields

We just did not understand it => Not until 1819

- Faraday wondered if the magnetic field due to the current in one coil could regulate the current in an adjacent coil.

- He was correct, with one important qualification: the magnetic field must be *changing* in some way to produce a current

- the phenomenon that a changing magnetic field can produce a current is called electromagnetic induction



Michael Faraday (1791-1867)

We just did not understand it => Not until 1819

1831

- Electricity became viable for use in technology.
- English scientist **Michael Faraday** created the ***electric dynamo*** - a crude precursor of modern power generators.
- This invention opened the door to the new era of electricity. A few decades later, in ***1879***, Thomas Alva ***Edison*** "*invented*" the light bulb.

- Laws of electricity
  - Oersted showed that magnetic effects could be produced by moving electrical charges; Faraday and Henry showed that electric currents could be produced by moving magnets

- Laws of electricity
  - electric charges produce *electric* fields (Coulomb)
  - electric fields begin and end on charges
- Laws of magnetism
  - currents produce *magnetic* fields (Ampere)
  - magnetic field lines are closed loops
  - a changing magnetic field can produce a current (*induced currents*) (Faraday)
  - A changing electric field can produce a magnetic field (Maxwell)

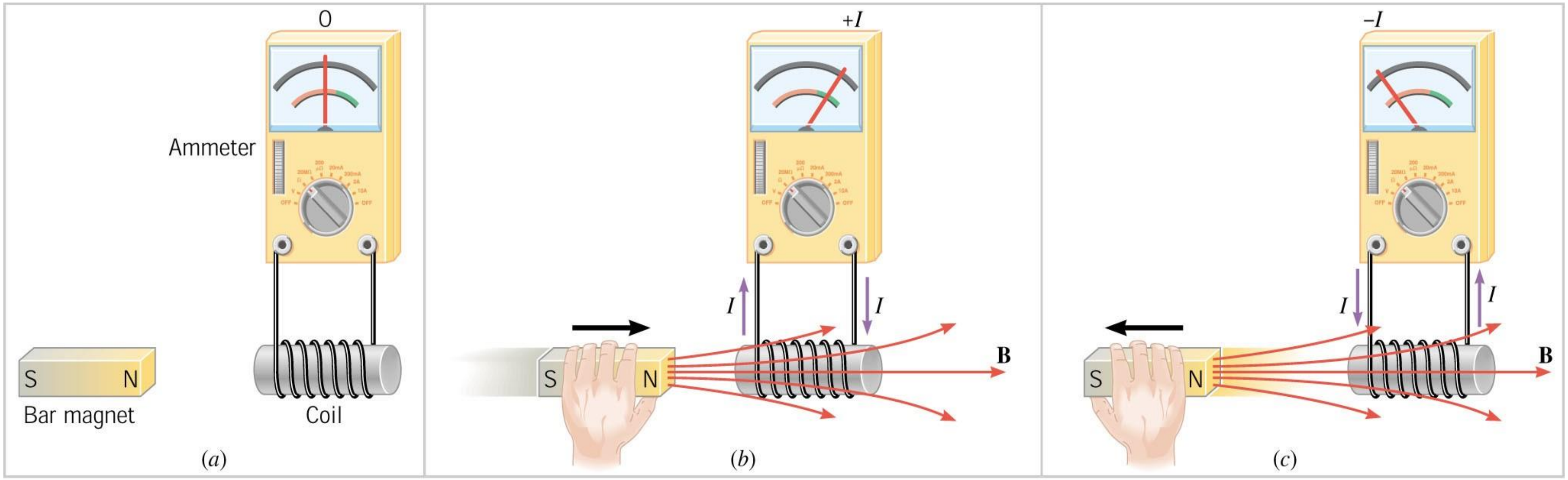
Lesson and path to application

- All magnetic phenomena result from forces between electric charges in motion.

- In 1831, Michael Faraday discovered that a momentary current existed in a circuit when the current in a nearby circuit was started or stopped

- Shortly thereafter, he discovered that motion of a magnet toward or away from a circuit could produce the same effect.

Induced currents



a) No current is induced if the magnet is stationary.
b) When the magnet is pushed toward the coil or pulled away from it, an induced current appears in the coil.
c) The induced current only appears when the magnet is being moved

Electromagnetic Induction

- Electromagnetic induction is when a current is made to flow in a wire.
- This happens when a wire cuts the field lines of a magnetic field and the magnetic field gives the electrons a push. (Voltage). Or the magnetic field changes direction.
- The voltage gives the energy to the electrons to move. This gives the electrons a push, they move, this is an induced current

Induction with Coil and Magnet

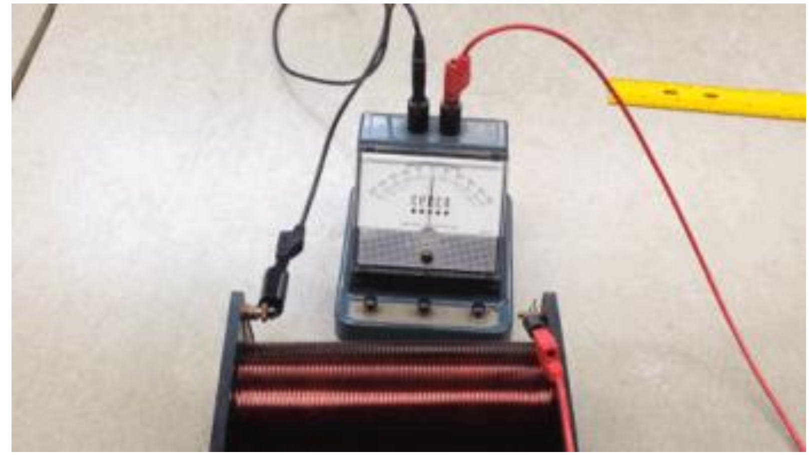
A **changing magnetic field induces** a **current** in a conducting wire

The **magnitude** of this induced electric current depends on **how fast** the magnetic field is **changing**.

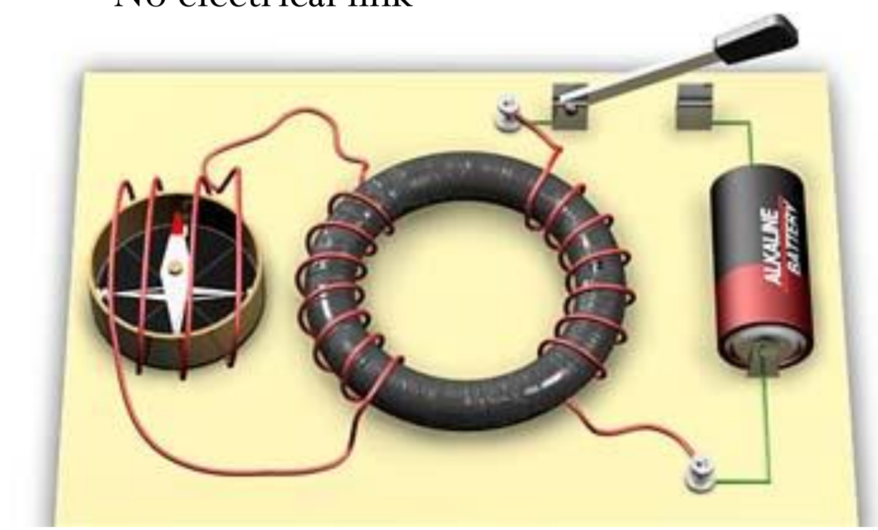
Move the **magnet faster** and you get a **larger current**.

Keep the magnet **stationary** and the magnetic field doesn't change at all and you have **zero current**.

Just like the faraday ring, it only conducted as the **current increased** OR **decreased**. So when you close or open the switch. When running it produces a **steady electromagnet** which **does not induce** a PD in the secondary coil



No electrical link



Secondary coil

Primary coil

Understanding EM Induction

Figure -> Use **LH rule** (as it is moving charges in the field causing motion)

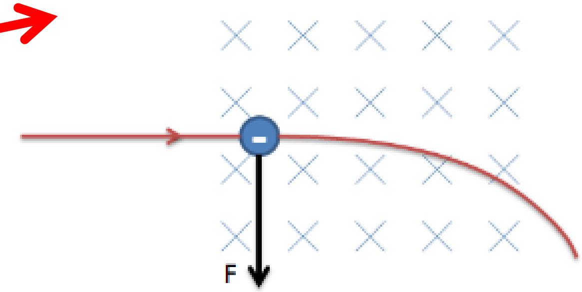
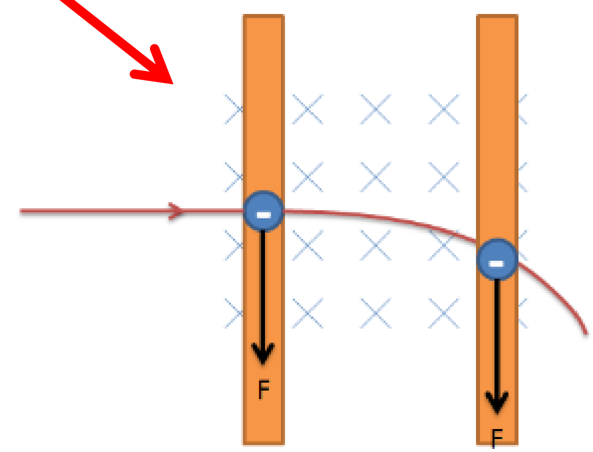
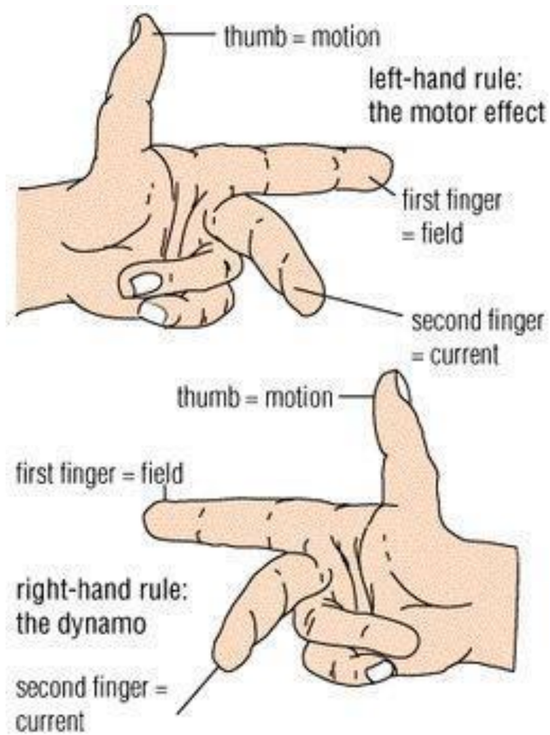


Figure -> Use **RH rule** (as it is you moving an object to create a flow of charges and an induced EMF)



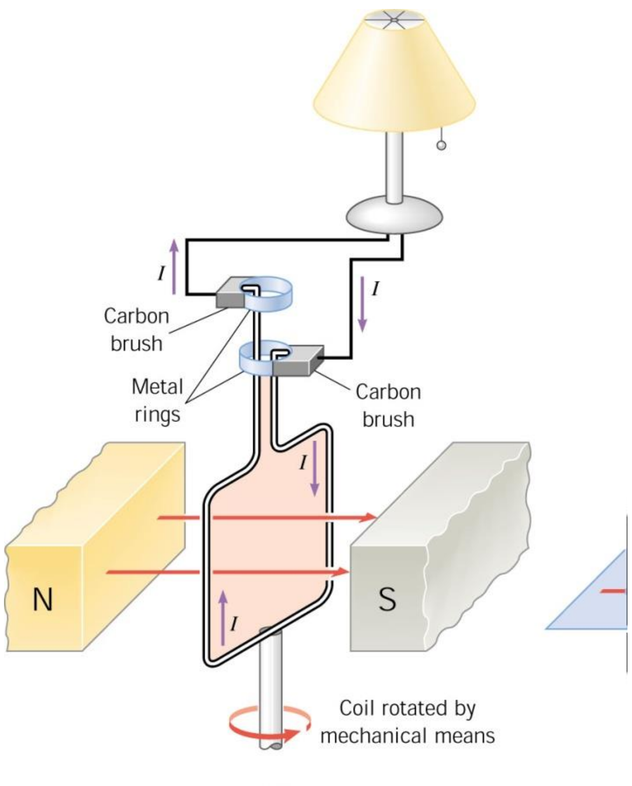
Common misconceptions:
Don’t confuse Fleming’s left-hand rule (Topic 7.1) with the right-hand rule (Topic 8.1).

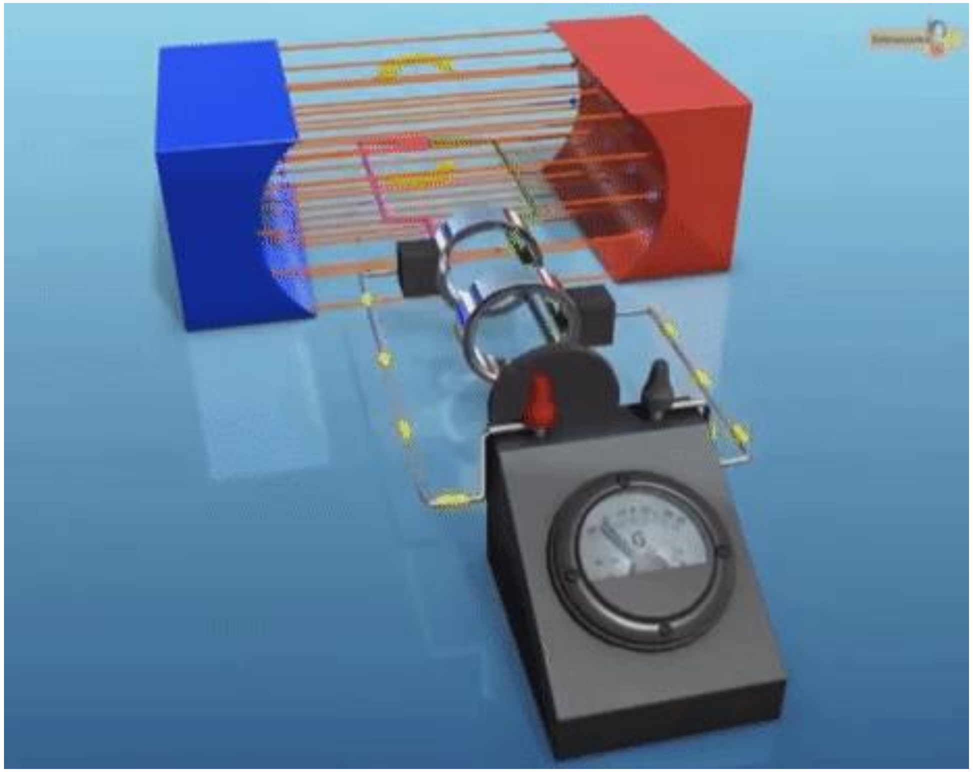
Remembering the phrase ‘**motors drive on the left**’ may help to distinguish the motor rule from the dynamo rule.



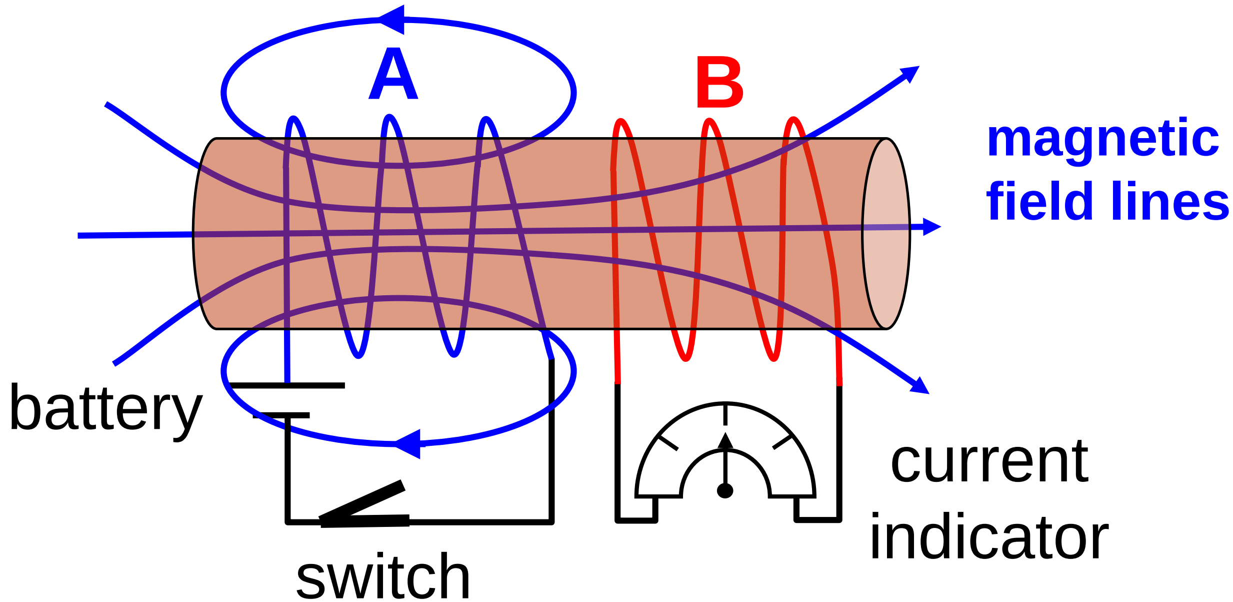
Electric generators

When a coil is rotated in a magnetic field, an induced current appears in it. This is how electricity is generated. Some external source of energy is needed to rotate the turbine which turns the coil.





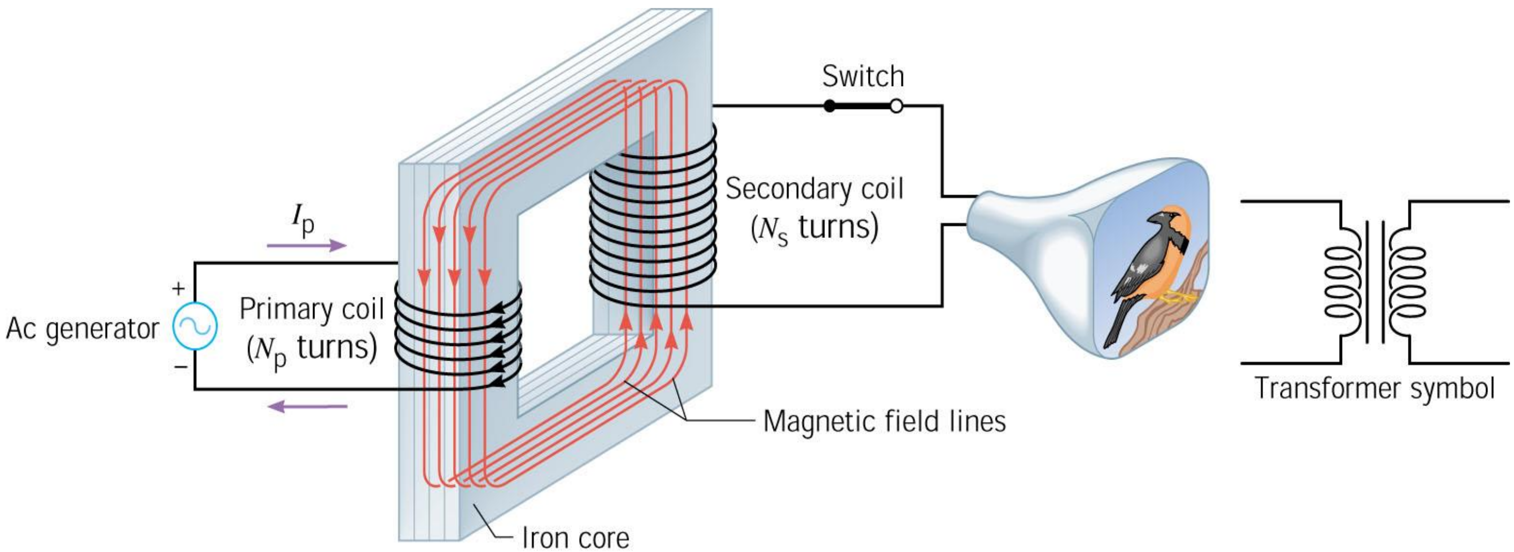
Induced currents



- When a current is turned on or off in coil A, a magnetic field is produced which also passes through coil B.
- A current then **briefly** appears in coil B
- The current in coil B is called an **induced current.**
- The current in B is only present when the current in A is turned on or off, that is, when the current in A is *changing*

Transformer

Transformers use primary (input) and secondary (output) coils around a soft iron core to either *step up* (increase) or *step down* (decrease) the voltage



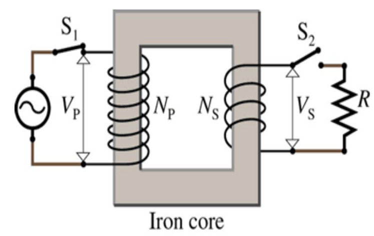
The voltage on the secondary depends on the number of turns on the primary and secondary.

Step-up → the secondary has more turns than the primary
Step-down → the secondary has less turns than the primary

Transformer

- Transformers are used to change the voltage (or emf – electromotive force).
- The voltage created is *directly proportional* to the number of coils.

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

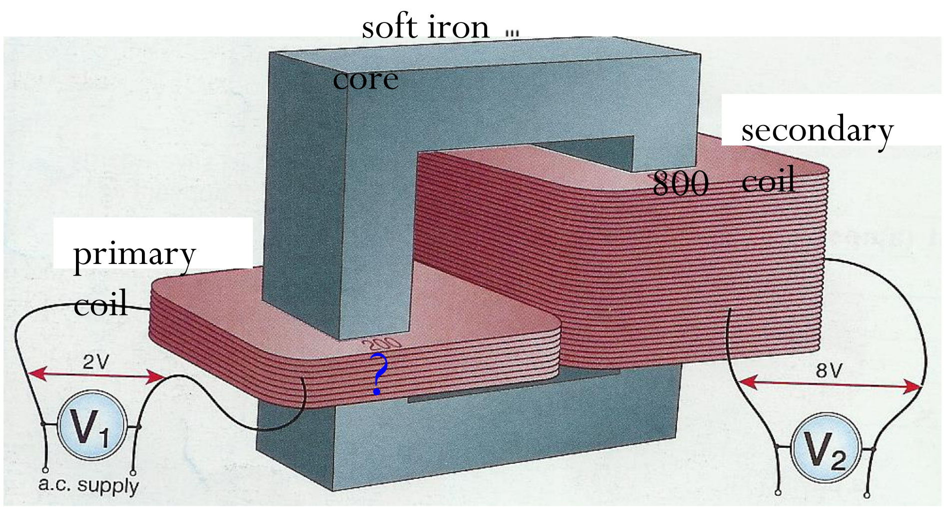


(a)

p = primary

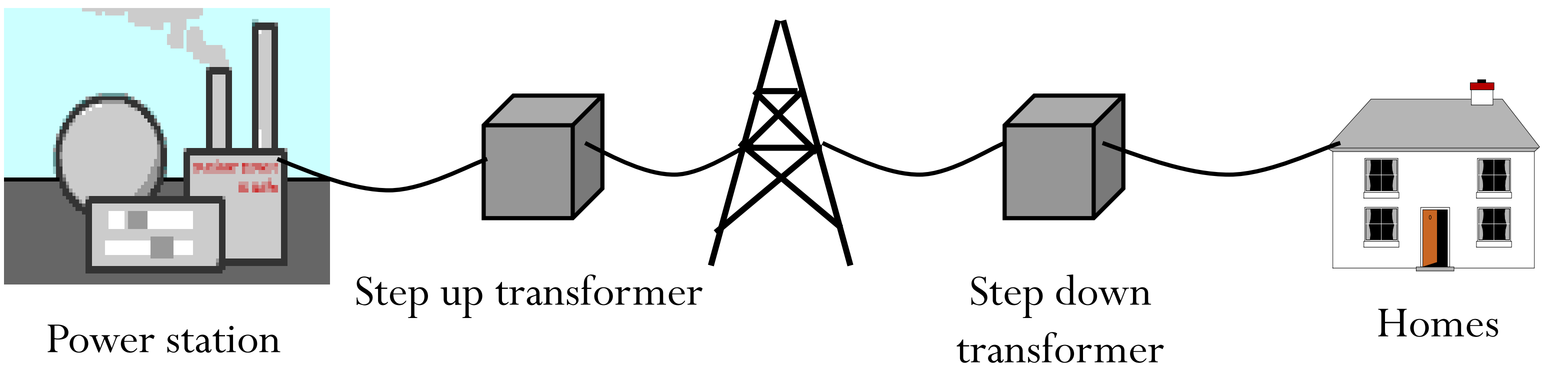
s = secondary

n = number of coils



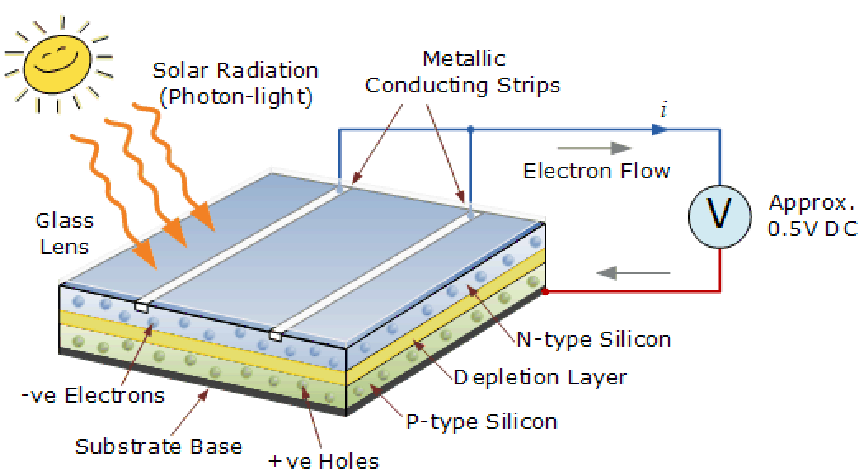
The Power Transmission Line

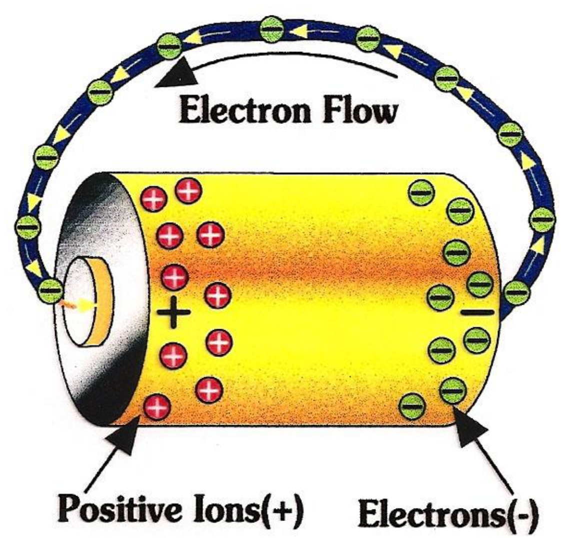
Electricity reaches our homes from power stations through the National Grid:



DC electricity (Direct Current)

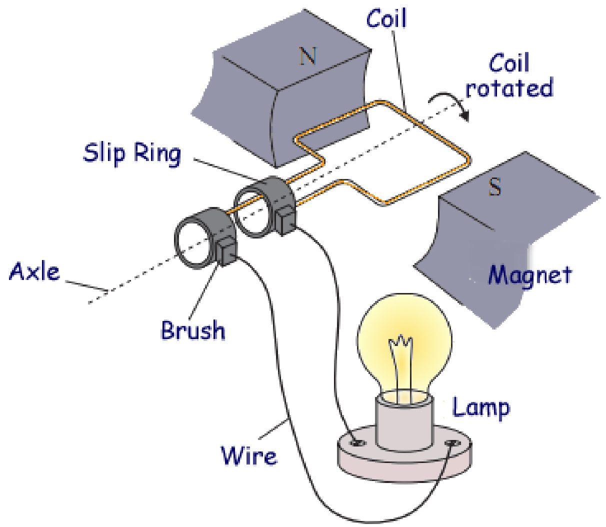
- The electrical energy we get from batteries and solar cells is transferred from where it is stored or produced to where it is required by a flow of charge in **<u>one direction</u>**
- We say that current is a flow of negative charge (electrons) that flows from negative to positive.



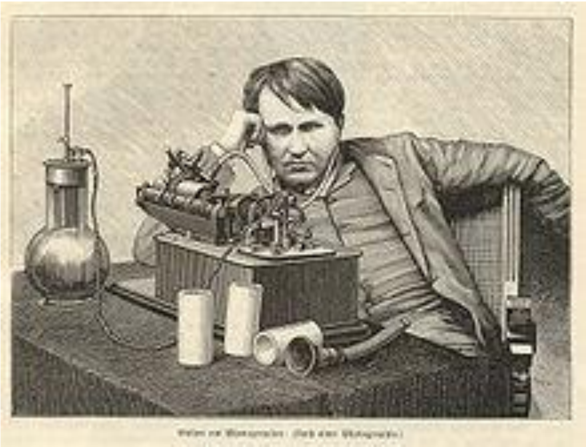


AC electricity (Alternating Current)

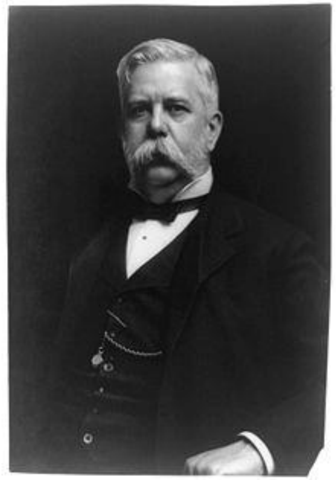
- AC electricity is produced by a “generator”. This is a spinning magnet inside a stationary coil of wire.
- The electricity flows one way then the other. The frequency of this alternating current depends on the frequency of rotation of the generator.
- In the UK our electricity is produced using generators that spin 50 times a second (50Hz)
- This alternating current is pushed one way and than pulled back the other way. This means that the flow of charge is always changing!



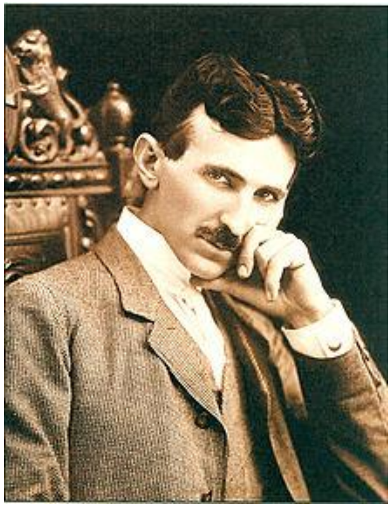
The DC vs. AC Current Wars



Thomas Edison pushed for the development of a DC power network.



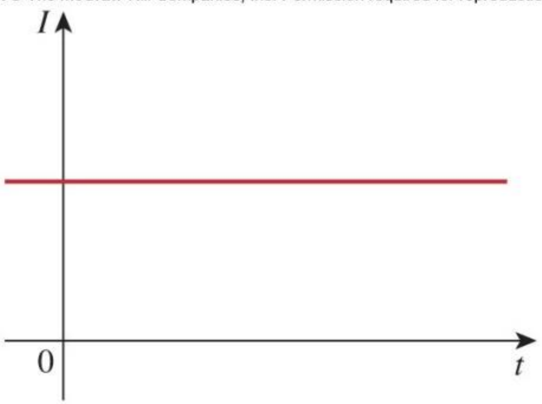
George Westinghouse backed Tesla's development of an AC power network.



Nikola Tesla was instrumental in developing AC networks.

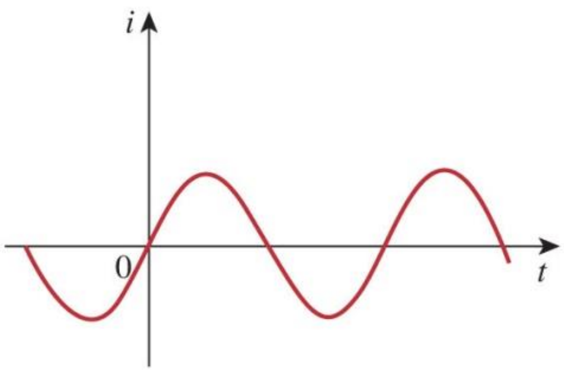
Edison was a brute-force experimenter, but was no mathematician. <u>AC cannot be properly understood or exploited without a substantial understanding of mathematics and mathematical physics</u>, which Tesla possessed.

- **DC vs AC**
- **Direct Current (DC)** is a current that remains constant with time is called
- A common source of DC is a battery.



(a)

- A current that varies sinusoidally with time is called **Alternating Current (AC)**
- Mains power is an example of AC



(b)

AC vs DC

- Direct currents work by electrons moving one way from negative to positive. Whilst doing this they transfer energy or power
- Alternating currents work by moving electrons backwards and forwards. Whilst doing this they also transfer energy or power (but in a different way)
- If we think about it a direct current is a steady current with I the same all the time.
- If we think about an alternating current it changes all the time so we cannot do the same simple calculations.
- However, if we could convert the AC current to a DC current we could.….