Electromagnetism:

One of the 4 fundamental forces in nature:

Gravity	Newton (1687) + Einstein (1915)
EM	Maxwell (1860)
Weak	Fermi (1930)
Strong	Feynman, Gross, Politzer, Wilczek(1970)

- Gravity always around but hard to think about.
- EM effects much more evident: lighting, magnets, sparks from clothing,...
- Known since at least 3000bc (Egyptians) via electric eels
- Electricity comes from the greek word Elecktron (Amber) “from the sun”

→ Electromagnetism, electron, electronics,...

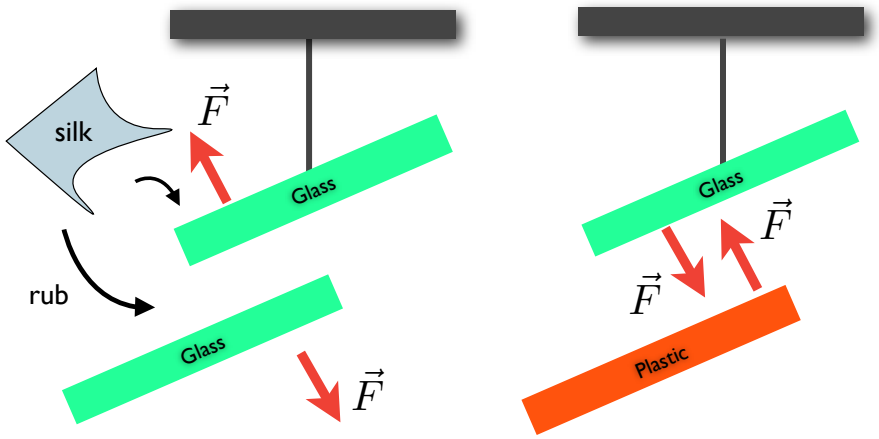
- Connection between electricity and magnetism not until 1820 from Oerstad.
- Now everything takes advantage of electromagnetism
  - Entire output of the world connected to EM

Electrostatics: Not going to worry about effects due to moving

Electric Charge

- Every object contains electric charge.
- Charge is a fundamental property of the material out of which everything is made, just like mass.
- Everyday objects have vast amounts of charge
- The properties of charges first determined experimentally

Simple experiment:



Rods of **any** material will always repel or attract

- Situation can be described by two different types of charge that are related by a minus sign:

Attractive forces → -

Repulsive forces → +

Note: Add charges to previous figures

Charges with same sign repel; opposite charges attract

- Choice of +/- for charges is arbitrary. Determined by Benjamin Franklin ($100 guy)

Positive (+) charges

Negative (-) charges

Charges usually come in equal amounts (no net charge)

- Objects with no net charge are called neutral

- Have seen that objects can have net charge; determined types of charge

- How are charges distributed over objects?

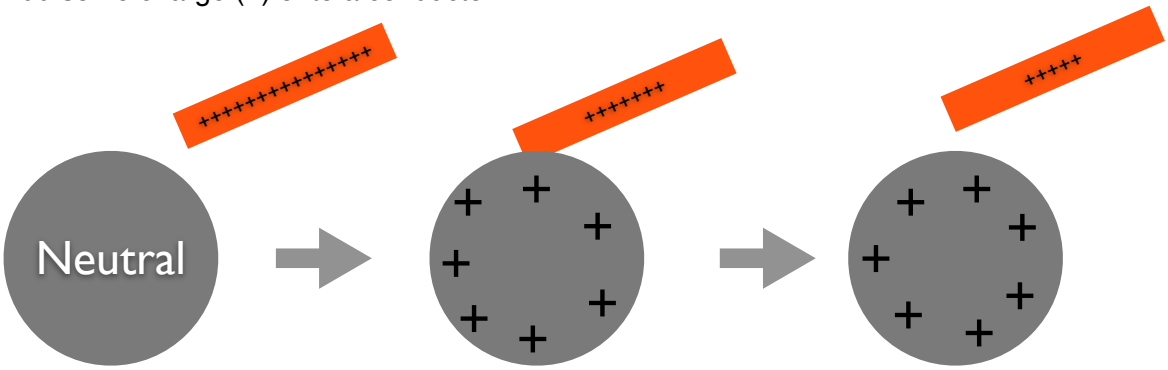
Conductors & Insulators

- Materials can be divided into 4 categories depending on how easily charges move:

Conductors: Charges move easily. i.e. metals, saltwater, people,...
Insulators: Charges cannot move. i.e. rubber, glass, plastics, pure H2O
Semiconductors: In between conductors and insulators. i.e. silicon, germanium
Superconductors: Charges move perfectly. i.e mercury@2k, aluminum@1.2k

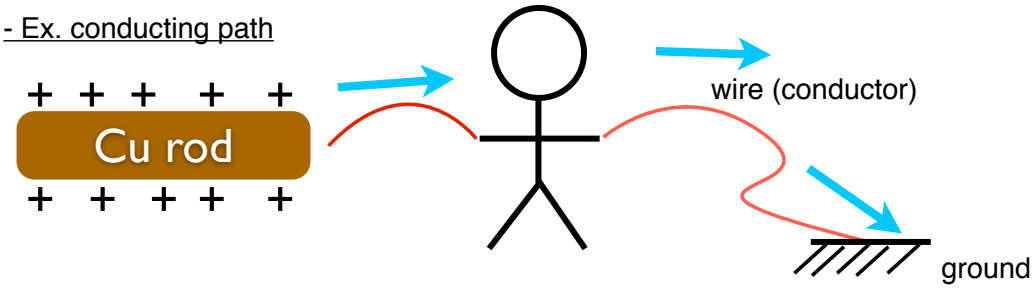
Conductors

- Charges move freely + like charges repel.
- Add some charge (+) onto a conductor



Charge spreads out over conductor to reach equilibrium

- Ex. conducting path

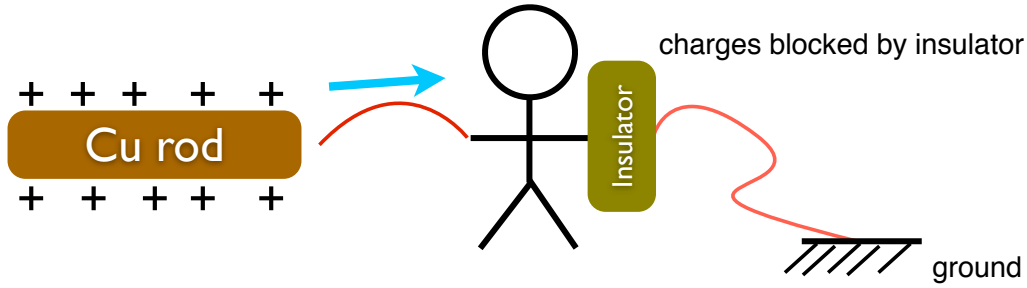


- Charge moves through conductors due to repelling force to ground

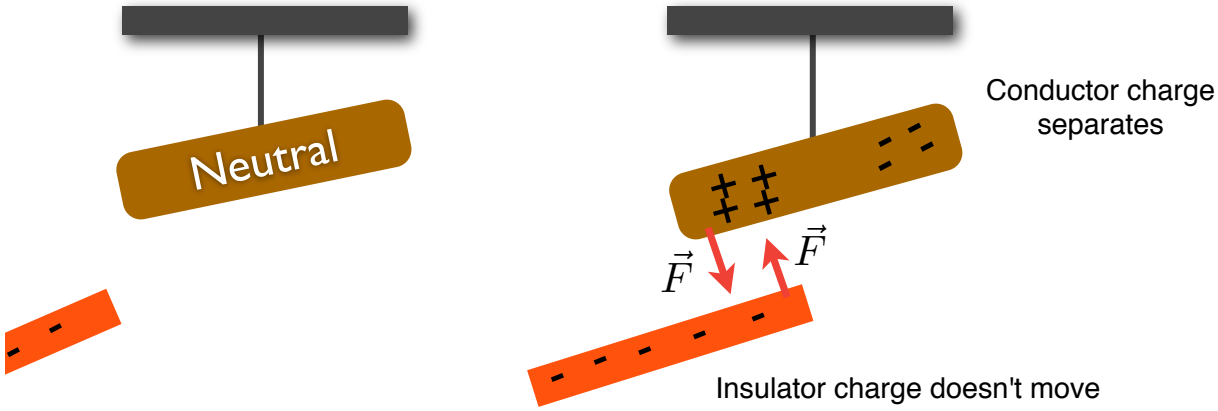
- Earth is a huge conductor... can always dump charge there.

- Any conducting path connected to the Earth is called **grounded**

- Ex. conducting path + insulator



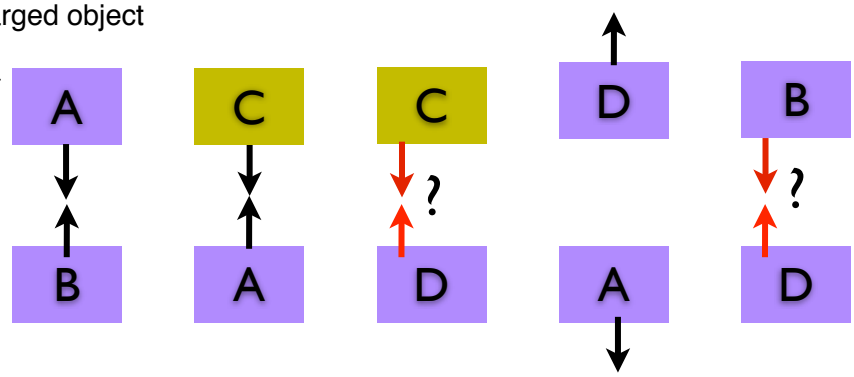
- Since charges move freely, can **induce** a charge on a conductor:



- Copper rod is neutral but had induced charge; positive and negative charges separated due to force from nearby charged object

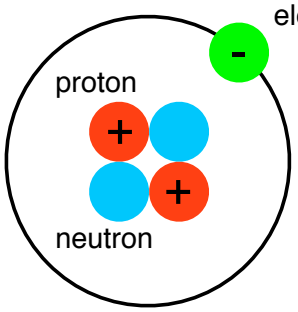
Conceptual Question:

A,B,D charged plastic
C is neutral metal



Where do charges come from?

- Recall that charge is a fundamental property of matter.



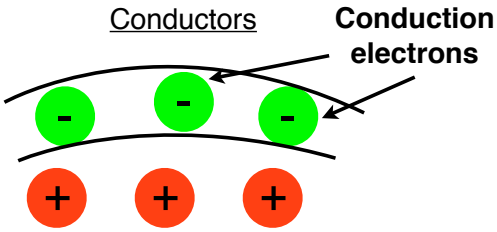
1st guess:

+ charges = protons

- charges = electrons

Not True! Only electrons are free to move in most materials

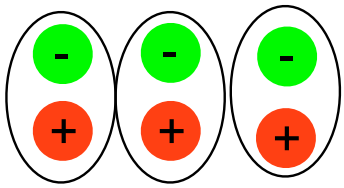
Conductors



fixed in place

Electrons do not belong to single atom, spread out over surface

Insulators



- Electrons tightly bound to nucleus, cannot move.

- None or few conduction electrons

Only way to get positive charge is to remove electrons such that:

# of protons > # of electrons

Positive charge implies deficit of electrons

- Electrons are fundamental particles; they can not be subdivided (Thompson 1897)

Charge comes only in discrete units

charge → $q = n \cdot e \quad n = \pm 1, 2, 3 \ldots$

"elementary charge" $e = 1.602 \times 10^{19}\mathrm{C}$ Coulombs

- Elementary charge e is a fundamental constant; cannot be derived from theory.

- Discreteness proven by Millikan in 1910.

Electrons: - e

Protons: + e

Electrons have a single, negative unit of charge (initial convention was chosen incorrectly)

What is a Coulomb?

- The coulomb is the SI unit of charge

- Derived from the SI unit for electric current (moving charges) I

$$I = \frac{dq}{dt}$$

Rate at which charges passes though a single point or region.

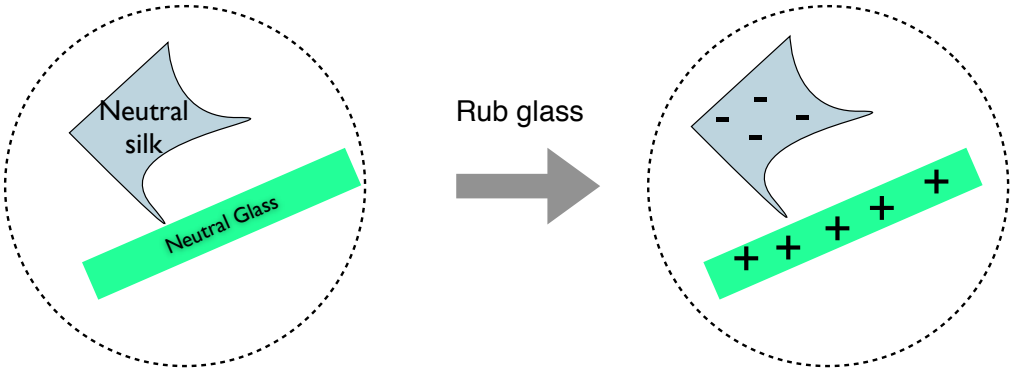
- Current has units of Amps (A) → $1\text{C} = 1\text{A} \times 1\text{sec}$

$$e = 1.602 \times 10^{-19}\text{C} \rightarrow 1\text{C} \approx 6.25 \times 10^{18}\text{e}$$

7.5×10^{18} Grains of sand on the entire Earth! U. of Hawaii est.

Charge is a conserved quantity.

- Let's return to the silk + glass example.



No **net** charge

No **net** charge

- Charge is **not** created, just moved around

- True for any physical process.

Conservation of charge: The **net** charge of <u>any</u> closed system cannot change.

- Will show this later
- 4th conservation law encountered: Energy, Momentum, Angular Momentum, Charge
- Key word here is "net": Can create +/- charges in pairs; net charge is still zero.