CHAPTER 17: ELECTRIC CHARGE, FORCE, AND ENERGY

17.1: ELECTROSTATIC INTERACTIONS

17.2: EXPLANATIONS FOR ELECTROSTATIC INTERACTIONS

17.3: CONDUCTORS AND INSULATORS (DIELECTRICS)

17.4: COULOMB'S FORCE LAW

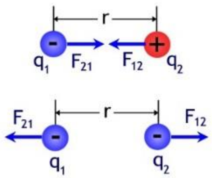
17.5: ELECTRIC POTENTIAL ENERGY

17.6: SKILLS FOR ANALYZING PROCESSES INVOLVING ELECTRIC CHARGES

17.7: CHARGE SEPARATIONS AND PHOTOCOPYING

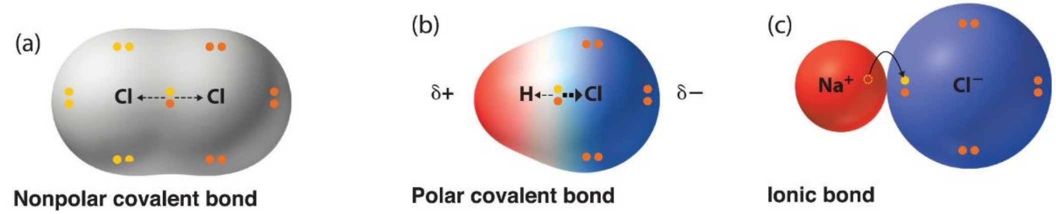
ELECTROMAGNETISM

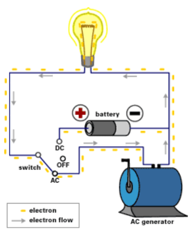
"Science of charge and of the forces and fields associated with it."



ELECTRIC FORCES BETWEEN OBJECTS CARRYING AN ELECTRIC CHARGE

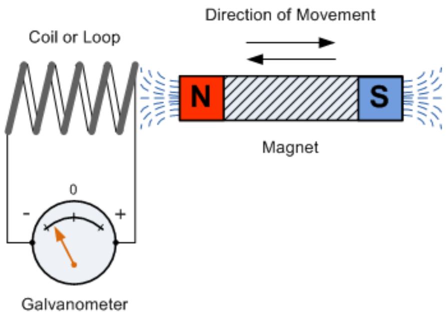
CHEMICAL BONDS BETWEEN ATOMS





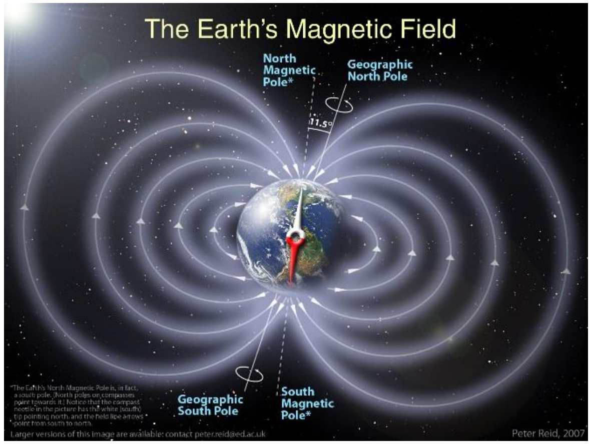
CURRENTS THAT POWER ELECTRONIC DEVICES

MAGNETIC FORCES ON MOVING CHARGES

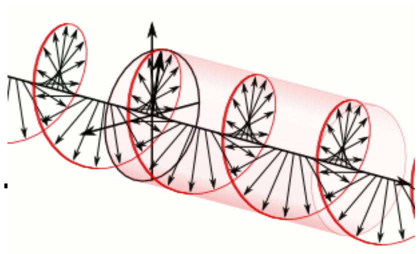


INDUCTION OF ELECTRICITY WITH MOVING MAGNETS

MAGNETIC FIELD OF EARTH



LIGHT



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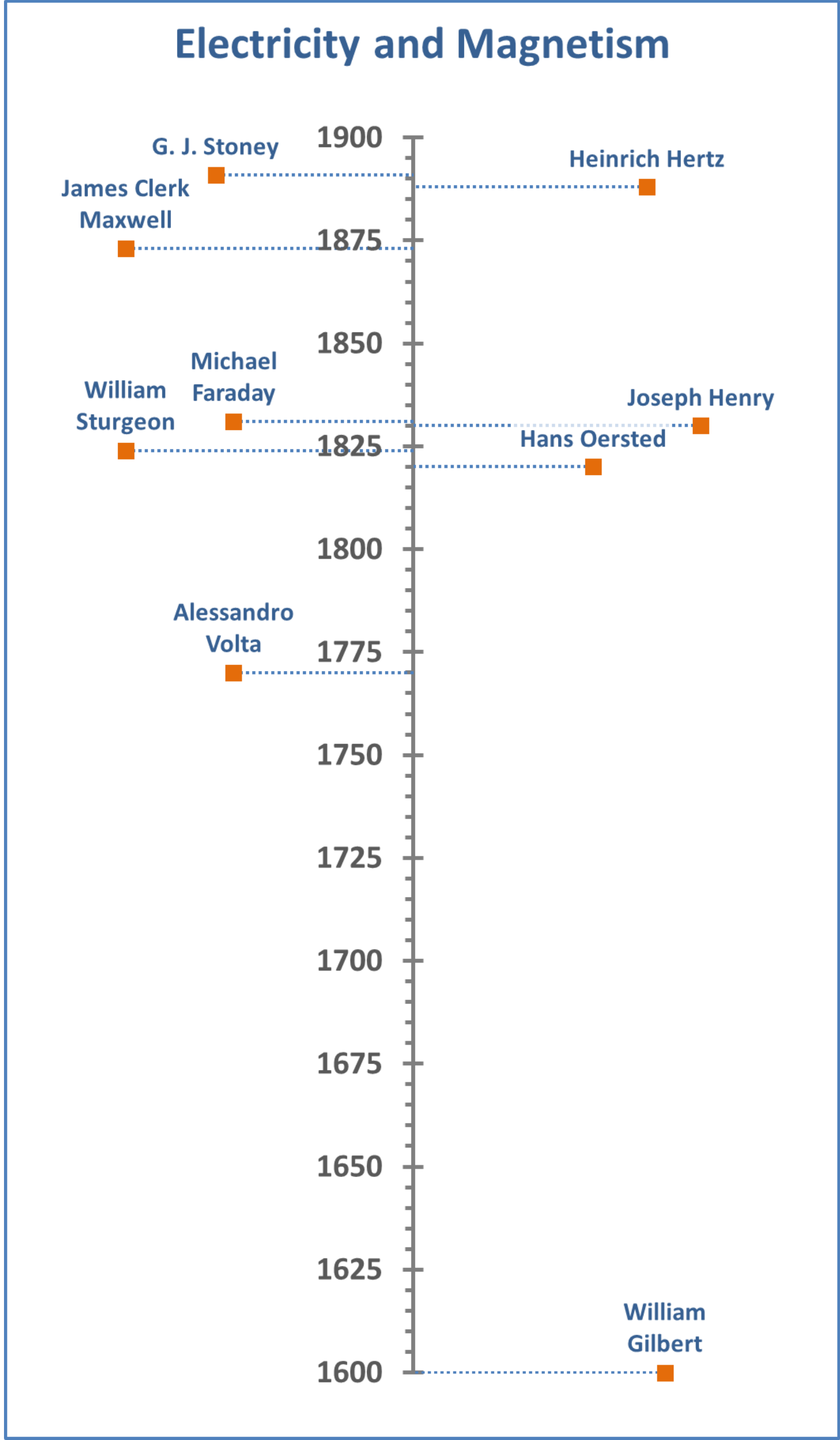
after: www.britannica.com

HISTORICAL OVERVIEW

- 2000 BC – magnetism recognized (*Chinese documents*)
- 700 BC – electric and magnetic phenomena observed by the Greeks
  - Piece of amber, when rubbed, attracted pieces of straw and feathers
- 1600: ***William Gilbert*** discovers that electrification is not limited to amber, but is a more general phenomena



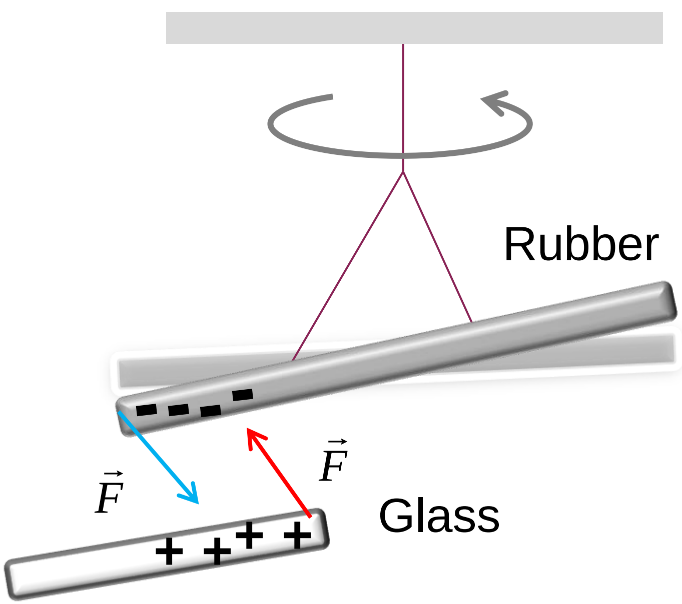
17.1 ELECTROSTATIC INTERACTIONS

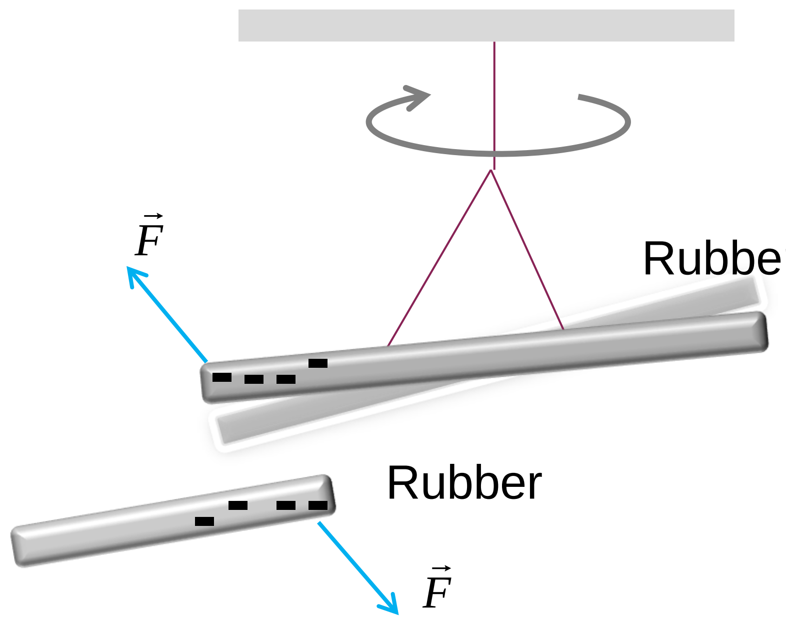
Goal:
To develop a model for understanding electric phenomena in terms of
charges and ***forces***.

Electric charge is an **intrinsic** property of particles: protons (+) and electrons (–).

It determines the strength of the **electric force** between two objects.

It **cannot** be created or destroyed (conservation!), but it **can** be transferred from one object to another.





Charge is Quantized

Any positive or negative charge q that can be detected can be written as

$$q = \pm Ne$$

Where e, the **elementary charge,** has the approximate value

$$e = 1.602 \times 10^{-19}\ \mathrm{C}$$

And $N \in \mathbb{N}$ *

Particle	Symbol	Charge
Electron	e	$-e$
Proton	p	$+e$
Neutron	n	0

up $+\frac{2}{3}e$	charm $+\frac{2}{3}e$	top $+\frac{2}{3}e$
down $-\frac{1}{3}e$	strange $-\frac{1}{3}e$	bottom $-\frac{1}{3}\mathrm{e}$

Quarks do have partial charge, but will not worry about this now.

*$\mathbb{N}$ is fancy math symbol indicating integers

EXAMPLE 17A

CHEAT SHEET:

$1\,mC = 1\times10^{-3}C$ milli-
$1\,\mu C = 1\times10^{-6}C$ micro-
$1\,nC = 1\times10^{-9}C$ nano-
$1\,pC = 1\times10^{-12}C$ pico-

How many **electrons** have to be transferred in order to charge a metallic sphere to $q = +6.0\ \mu\text{C}$?

$6.0\times10^{-6}C$

$\frac{q}{e} = N$

1.6×10^{-19}

result
$\sim 3.7\times10^{13}$

$Ne = q$

$e = +1.6\times10^{-19}C$

we have a net positive charge $+6.0\mu C$
∴ we are removing electrons

Learning catalytics

typo

$N = 2.75\times10^{+10}$

$e = -1.6\times10^{-19}$

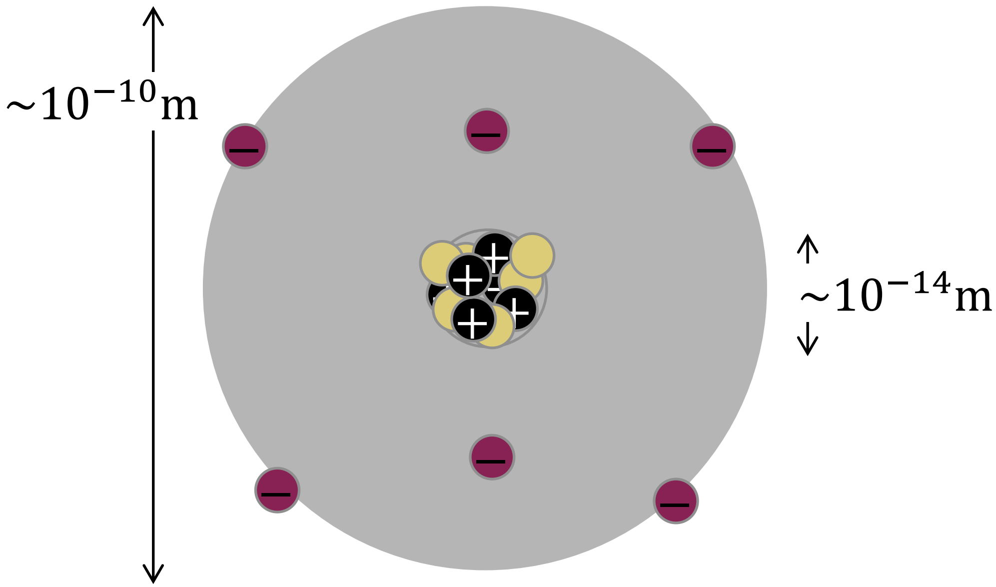
You determine the value & have to decide on the sign based on the context.

In LC we are REMOVING electrons ∴ charge is positive (missing -e)

Atoms

Atoms consist of a small (10^{-14} m) and dense *nucleus* surrounded by *electrons (-)* orbiting around it.

Nucleus is composed of *protons (+)* and *neutrons (0).*



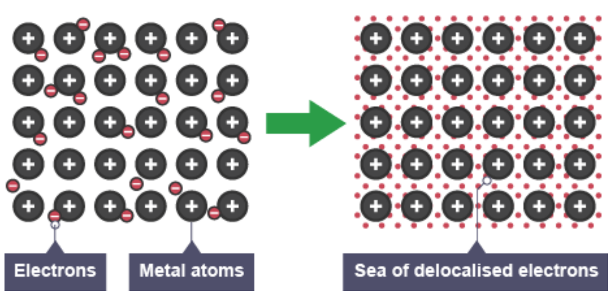
Particle	Mass [kg]	Size [m]	Charge
Proton	$1.67 \cdot 10^{-27}$	$0.87 \cdot 10^{-15}$	$+e$
Electron	$9.11 \cdot 10^{-31}$	$??$	$-e$

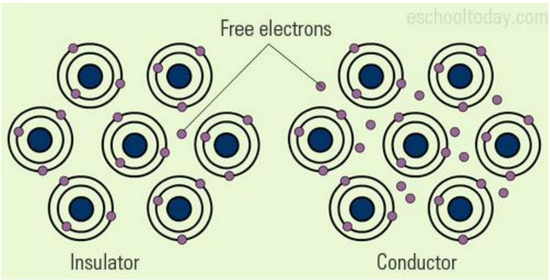
Electrons and protons are particles of matter, whose motion is governed by Newton's Laws.

https://javalab.org/en/conductor_and_insulator_en/

17.3 Conductors and Insulators

Conductors	Semiconductors	Insulators
Charges can move freely Large number of charged particles In equilibrium, excess charge resides on the surface	Charges can move freely but there are less of them than in conductors.	Charges cannot move freely In equilibrium, excess charge is uniformly distributed throughout the volume
	Superconductors	
	Materials that are *perfect* conductors that allow charge to move without any hindrance	





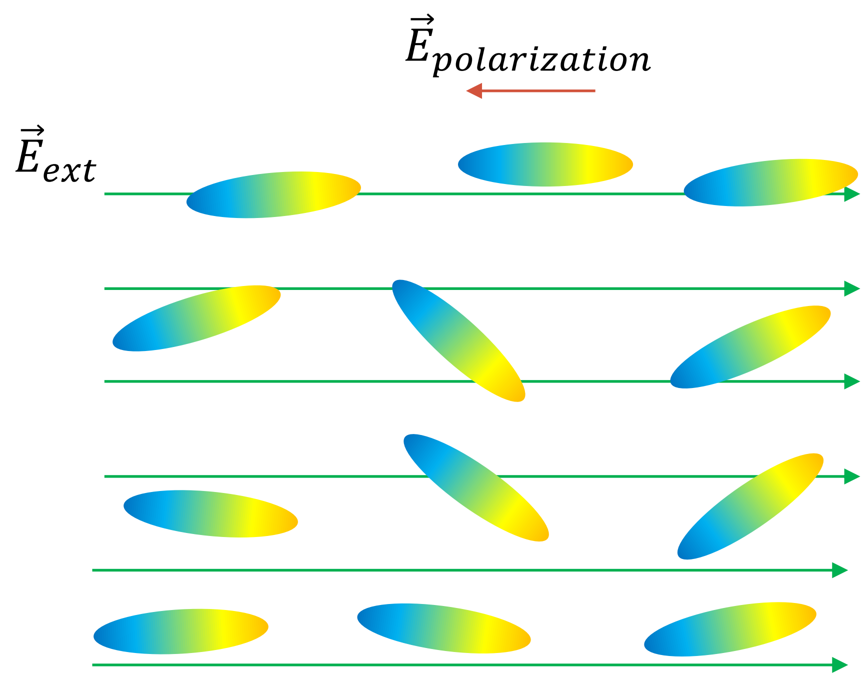
http://eschooltoday.com/science/electricity/images/conductor-insulator-difference.jpg

http://www.bbc.co.uk/schools/gcsebitesize/science/triple_ocr_gateway/electricity_for_gadgets/resisting/revision/3/

ATOMIC VIEW OF DIELECTRICS

POLAR DIELECTRICS: electric dipoles tend to line up with an external electric field. Because the molecules are jostling each other due to thermal motion, to complete the alignment increase of the field strength or decrease in temperature may be required.
The alignment produces (smaller) electric field in the direction opposing the external field.

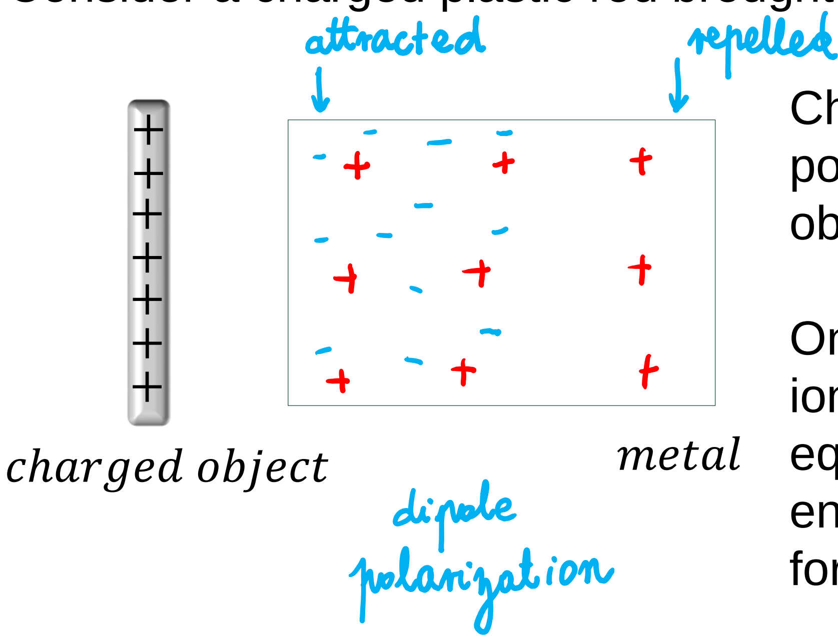
NONPOLAR DIELECTRICS: molecules acquire dipole moments due to external field – usually by stretching the molecules and creating separation of positive and negative charges.



POLARIZATION AND ELECTRIC DIPOLE

Recall the charged balloon in the simulation being attracted to the neutral wall.

Consider a charged plastic rod brought close to a metallic object without touching it.



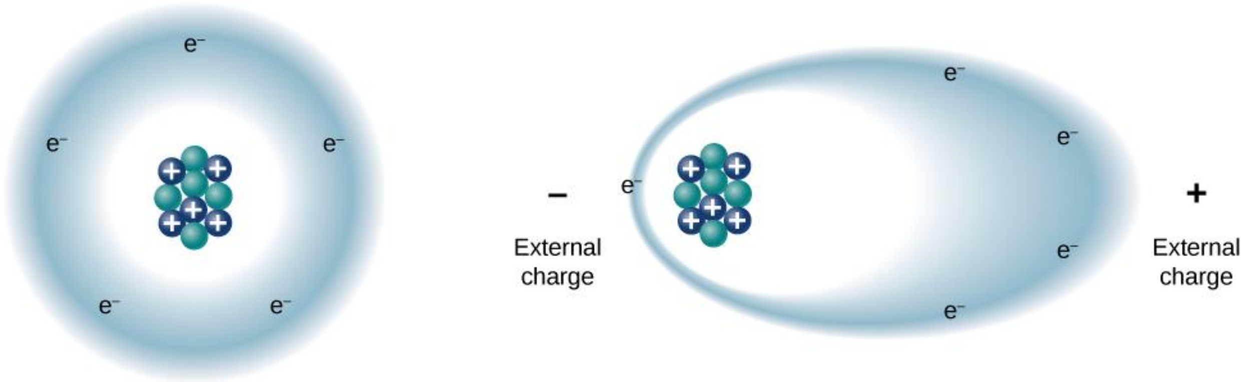
Charge polarization is a slight separation of positive and negative charges in a neutral object.

Once electrons move, the stationary positive ions exert a force (restoring force). The equilibrium position for the electrons is just far enough to the right that the external and internal forces balance (equilibrium!).

Polarization Force exists between the polarized metal and the charged rod.

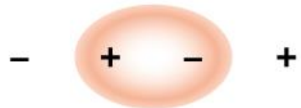
ELECTRIC DIPOLE

A neutral (and usually symmetrical atom) is polarized by an external charge.
In the figure the distortion is highly exaggerated.



Unpolarized

Polarized



Large-scale view of polarized atom

The atom is attracted to the external charge.
The attractive force between the negative cloud is larger than the repulsive force between the nucleus and positive charge.

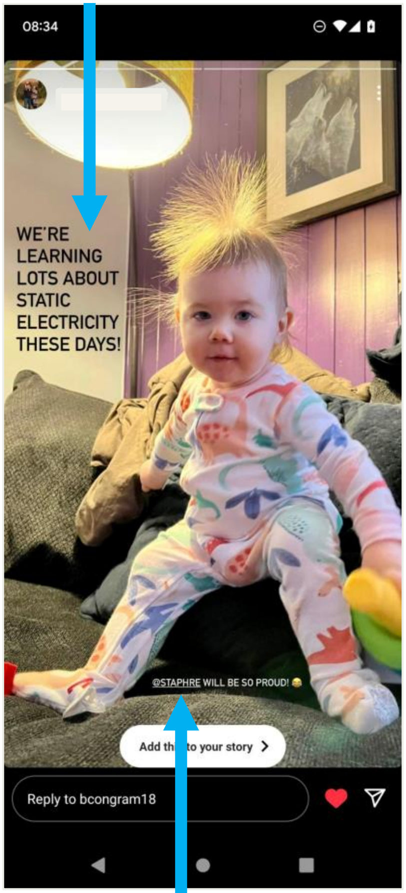
Two opposite charges with a slight separation between them form **an electric dipole.**

Electrical Interactions - Charging

Charging by rubbing:

Photos: One year-old Harper demonstrating the effects of acquiring charge from rubbing her feet (and other body parts) on the couch

Harper's mom was my student



I was her lab TA in E&M course.

The rubbing between the clothes and the couch (and probably carpets, floors and everywhere else in the house) made for the charge build-up on Harper's body.

Human body is a conductor, so the charges spread across it, creating quite a spectacular result.

This is exactly the reason why your clothes are charged after coming out of a dryer.

Physics. Ruins Everything.

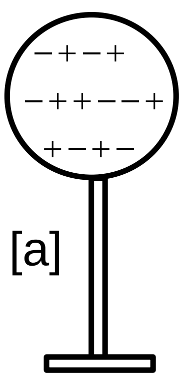
ELECTRICAL INTERACTIONS - CHARGING

CHARGING BY INDUCTION:

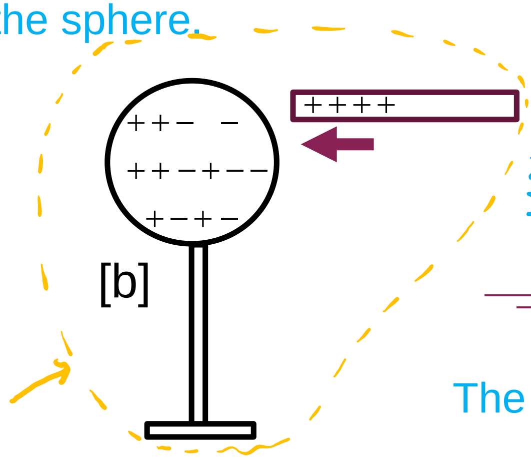
Charging an object by induction **requires no contact** with the object inducing the charge.

Consider a metallic sphere insulated from the ground.

Metallic sphere, insulated from the ground.
Net charge is zero.



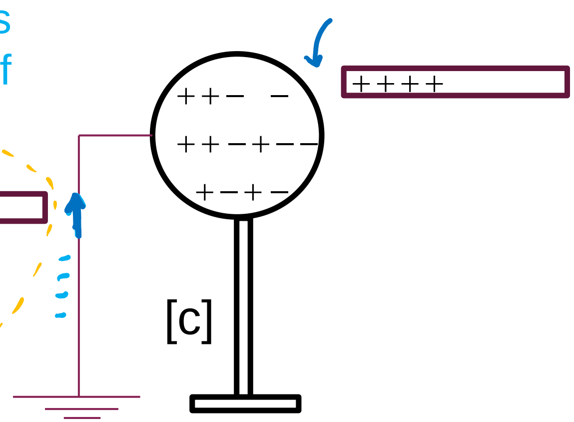
Positively charged rod is brought into proximity of the sphere.



SYSTEM

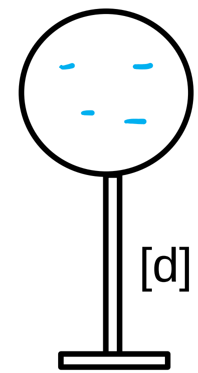
Sphere polarizes, the system (rod + sphere) has a net **positive charge.**

no contact



The sphere is grounded.

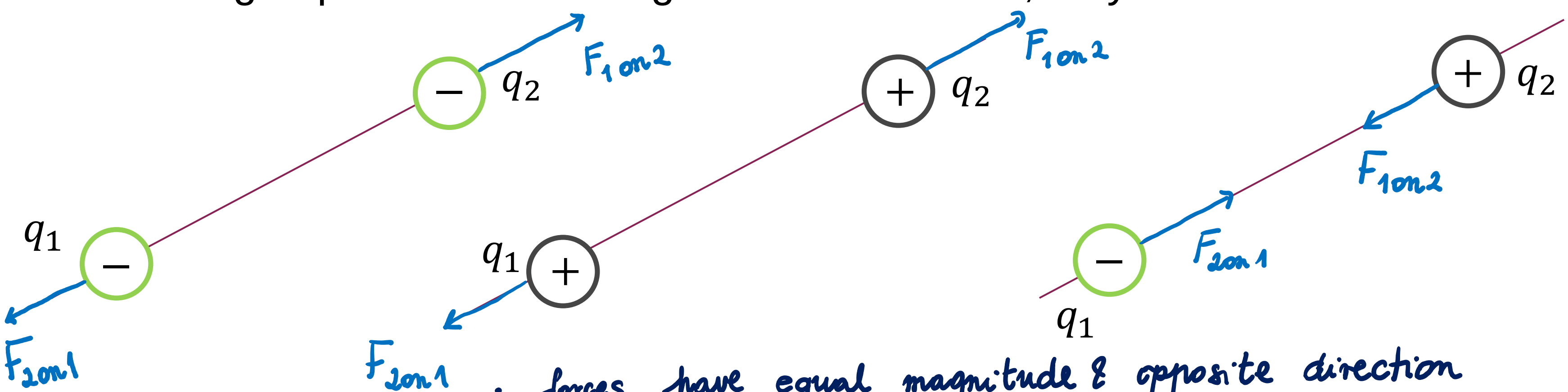
The system (sphere and rod) now have excess charge that has to be neutralized.



When the rod is removed from the system, the sphere is now left charged negatively.

17.4 Coulomb's Force

If two charged particles are brought near each other, they exert a force on the other.



- forces have equal magnitude & opposite direction (ACTION - REACTION)
- forces ALWAYS act along the line connecting charges

If the particles have **opposite** signs of charge, they attract each other..

If the particles have **the same** sign of charge, they repeal each other.

The force of repulsion or attraction due too the charge properties of objects is called an **electrostatic force.**

The equation giving the force for charged *particles* is called **Coulomb's Law**

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Charge values

Unit vector along the line connecting the charges, pointing from the agent to the object

$$\vec{F} = k_e \frac{q_1 q_2}{r^2} \hat{r}$$

Distance between the charges

Coulomb's constant $k_e = 8.99 \times 10^9 \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$

$$k_e = 8.99 \times 10^9 \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}} = \frac{1}{4\pi\varepsilon_0}$$

where $\varepsilon_0 = 8.85 \times 10^{-12} \frac{\mathrm{C^2}}{\mathrm{N \cdot m^2}}$

17.4 Coulomb's Force

As we can figure out the direction of the force from the sign of the charges and their interactions with each other, we will determine the magnitude of the electric force using equation:

Absolute values of the charges

$$|\vec{F}_e| = k_e \frac{|q_1||q_2|}{r^2}$$

Distance between the charges

Coulomb's constant $k_e = 8.99 \times 10^9 \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$

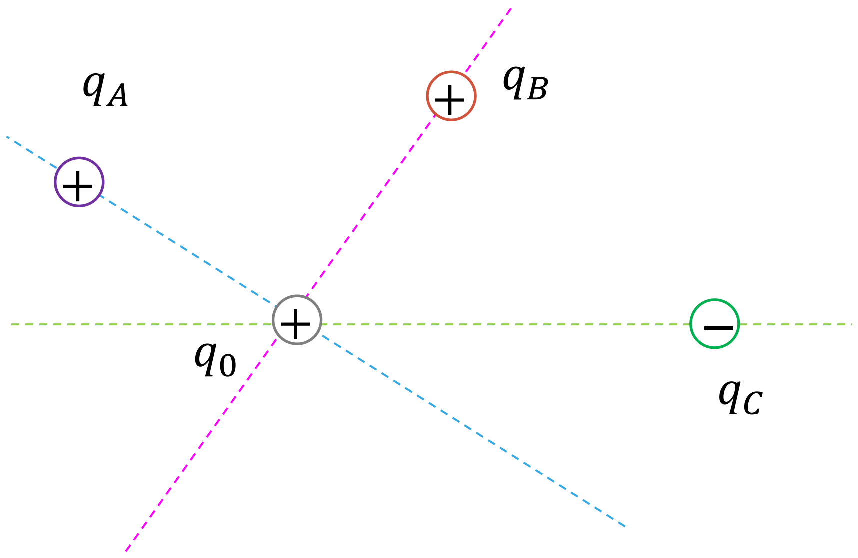
$$k_e = 8.99 \times 10^9 \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}} = \frac{1}{4\pi\varepsilon_0}$$

where $\varepsilon_0 = 8.85 \times 10^{-12} \frac{\mathrm{C^2}}{\mathrm{N \cdot m^2}}$

It is a force, therefore it is a vector and we will always treat it as such. We will just use different methods (understanding of the system and empirical equation) to determine direction and magnitude, respectively.

From Newton's Third Law: $\vec{F}_{1on2} = -\vec{F}_{2on1}$

Direction of the Force



Summary:

- there is a force between two charged objects:

$$F_{e12} = \frac{k_e |q_1| |q_2|}{r^2}$$