Electricity
Electric charge and Coulomb law

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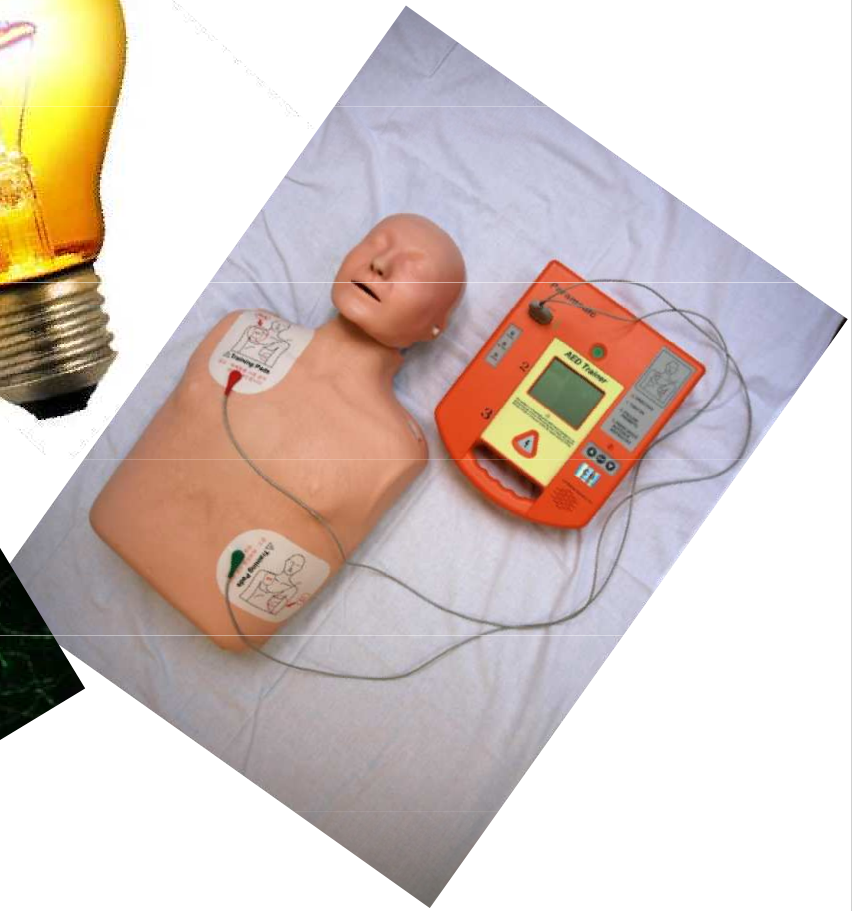
Theory of electricity

- The theory of electricity is the part of physics dealing with properties of electric charge, the interactions between electric charges, and the conduction of electric charge in various materials.



Electricity

- *Electricity* is the presence and motion of charged particles.
- *Electric current* is the flow of charged particles around an closed path – *an electric circuit.*

Electric Charge

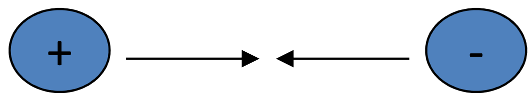
The *electric charge* ***Q*** can be imagined as "amount of electricity" in units called coulombs (C). All electric charges are multiples of the electric charge of an electron.

$$Q_e = e = 1.602\times10^{-19}\ C$$

There are two types of charge, which are labeled positive and negative.

Like charges repel

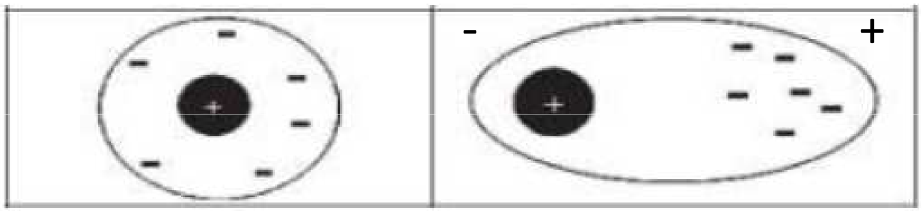
Unlike charges attract



To charge an object means to transfer electrons from one object to another. They are not created or destroyed, just moved!

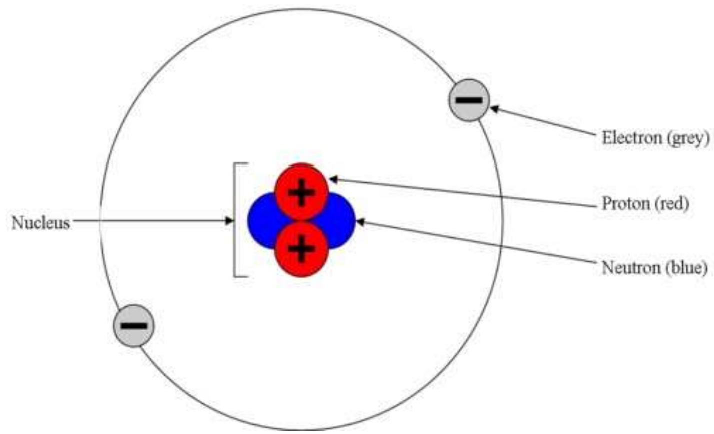
Electric charge

- Most electric charge is carried by the electrons and protons within an atom. Electrons carry negative charge, while protons carry positive charge.
- Protons and electrons create electric fields, which exert a force called the Coulomb force, which radiates outward in all directions.
- Because protons are generally confined to the nuclei imbedded inside atoms, they are not nearly as free to move as are electrons. Therefore, when we talk about electric charge, we nearly always mean a surplus or deficit of electrons.
- We are usually unaware of electric charge because most objects contain equal amounts of positive and negative charge that effectively neutralize each other.



Dielectric Polarization in Nonpolar Molecules. The electric field causes the shifting of charges

Helium Atom



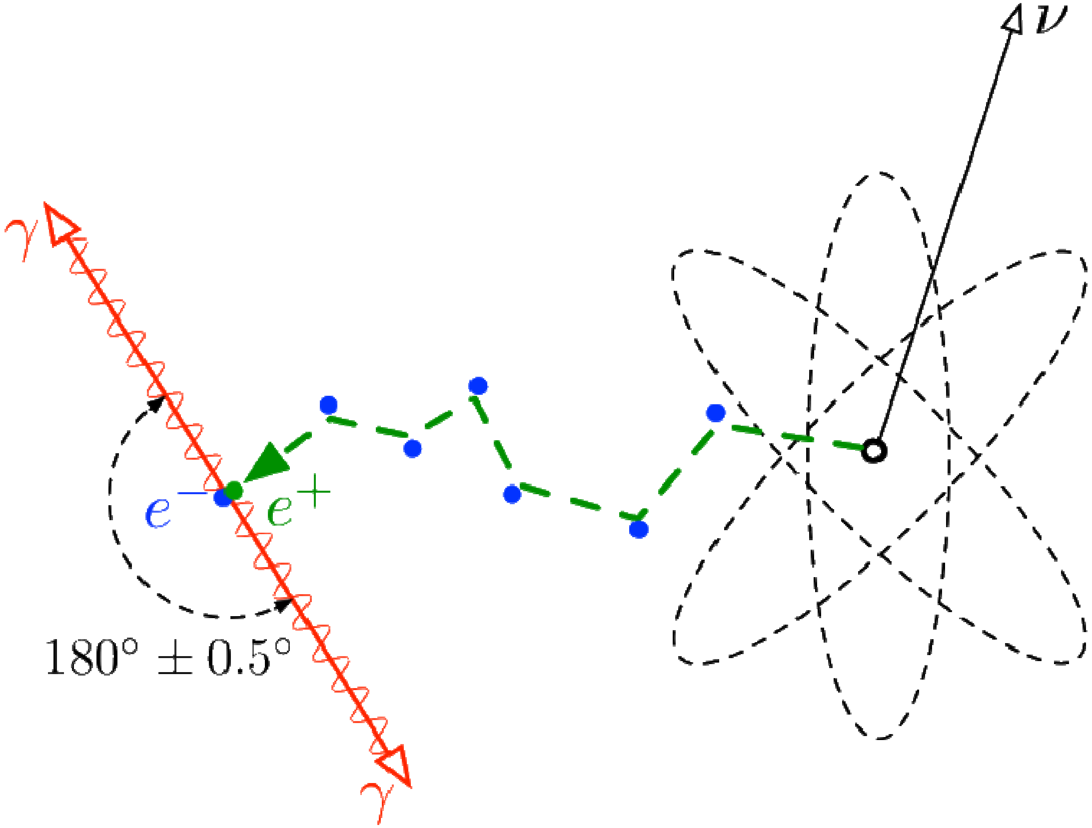
Electric charge

- It is a scalar physical quantity
- E.ch. characterized by the electrical properties of bodies
- The presence of e.ch. is important for the formation of an electric or magnetic field
- It is bound to elementary particles
- Electric charge can be „create“ by add or remove an proton or (namely) electron
- The „Law of conservation of charge“ must be valid!
- The process of „be positive/negative charged“ …

Law of conservation of charge

- *The algebraic sum of all the electric charges in any closed system is constant.*
- The only way to change the net charge of a system is to bring in charge from elsewhere, or remove charge from the system.
- *Charge can be created and destroyed, but only in positive-negative pairs.*

Electron-positron annihilation



e^+ positron

e^- electron

ν neutrino

γ quantum/photon (511 keV)

Charges can only be in multiples of e-

$Q_e = e = 1.602 \times 10^{-19}$ Coulombs

Multiples of Charges Chart

charge of an electron - Coulombs

1*e*	1.6×10^{-19}
2*e*	3.2×10^{-19}
3*e*	4.8×10^{-19}
4*e*	6.4×10^{-19}
5*e*	8.0×10^{-19}

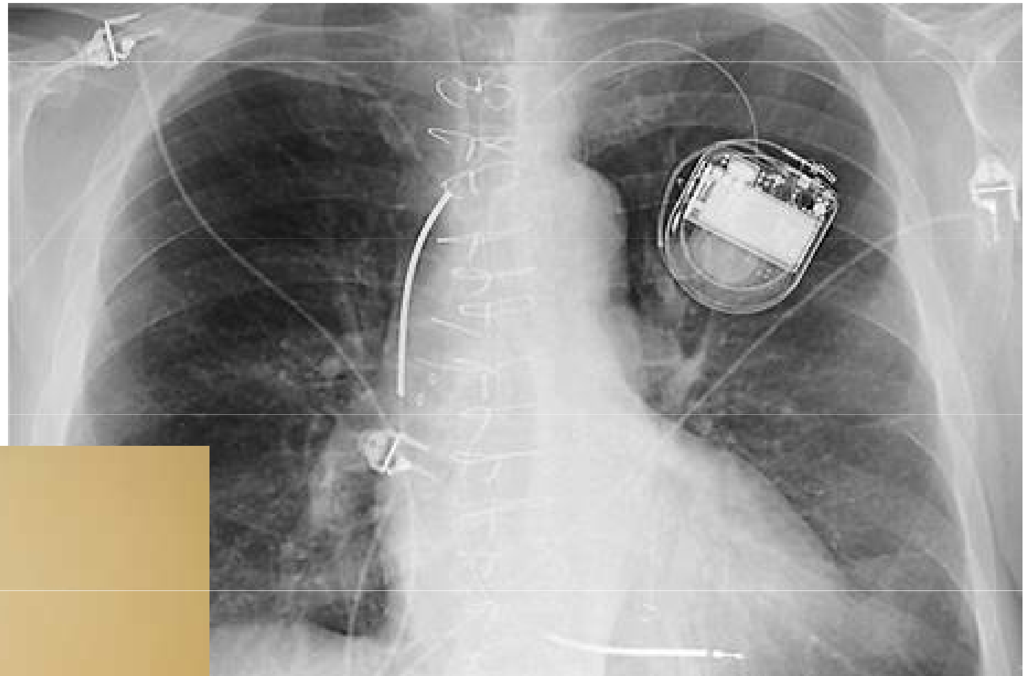
Electric charge is when …

Getting Shocked

Hair sticking out

Electrostatic forces

Electric charge is when …



cardiostimulator

defibrillator

How to make a electric charge?

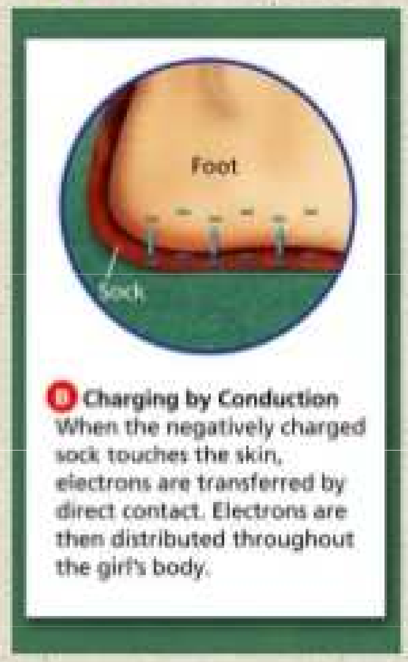
The electric charge can be obtained by:

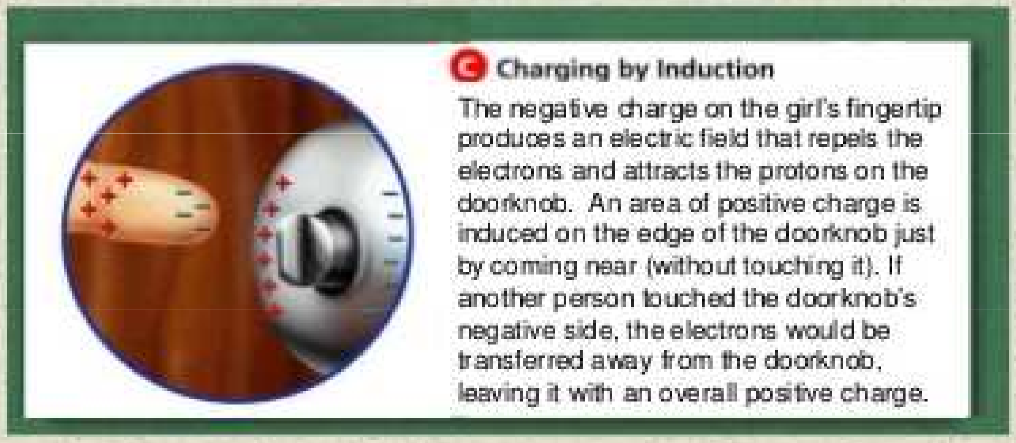
- Direct contact
- Electrostatic induction
- Electromagnetic induction
- Friction
- Pyroelectric effect (heat)
- Piezoelectric effect (force)
- Fotoelectric effect (photon)
- Ionization

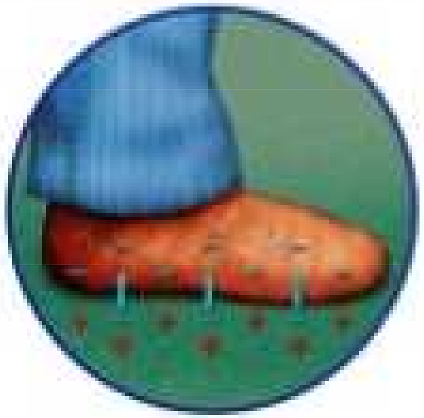
Haw to transfer charge?

Transferring Charge

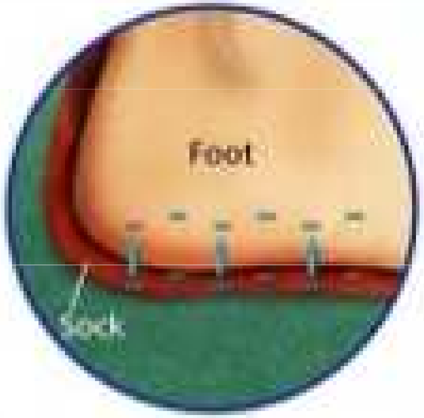
- Three methods by which an object can become charged:
  - Friction
  - Conduction
  - Induction



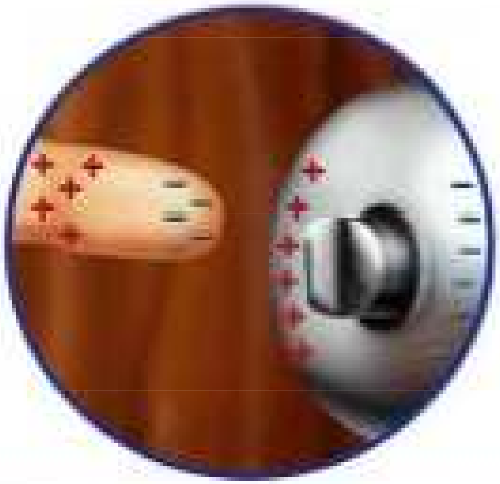




A Charging by Friction
Electrons are rubbed from the carpet to the girl's sock. The charges are distributed evenly over the sock.



B Charging by Conduction
When the negatively charged sock touches the skin, electrons are transferred by direct contact. Electrons are then distributed throughout the girl's body.



C Charging by Induction
The negative charge on the girl's fingertip produces an electric field that repels the electrons and attracts the protons on the doorknob. An area of positive charge is induced on the edge of the doorknob just by coming near (without touching it). If another person touched the doorknob's negative side, the electrons would be transferred away from the doorknob, leaving it with an overall positive charge.

Charging by Conduction

- Charging by conduction involves the **contact** of a **charged object to a neutral object.**

- When charging by conduction **both object have the same type of charge** when separated.

- To charge by conduction successfully, your charged and neutral object must be **conductors**!

Charging by Induction

- **charging by induction** method is to charge an object **without actually touching** the object to any other charged object.

Charging by induction using negatively charged object

Diagram i. Diagram ii. Diagram iii. Diagram iv.

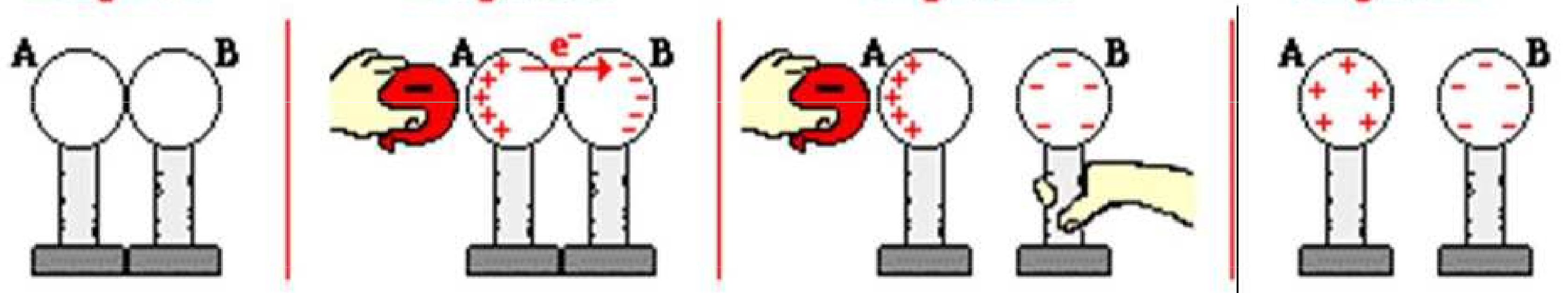


Diagram i.: Two metal spheres are mounted on insulating stands.

Diagram ii.: The presence of a – charge induces e⁻ to move from sphere A to B. The two-sphere system is polarized.

Diagram iii.: Sphere B is separated from sphere A using the insulating stand. The two spheres have opposite charges.

Diagram iv.: The excess charge distributes itself uniformly over the surface of the spheres.

Objects that tend to give up electrons and become positive:

- Glass
- Nylon
- Fur
- Hair
- Wool

Objects that tend to attract electrons and become negative:

- Rubber
- Polyester
- Styrofoam
- Saran Wrap
- PVC

When rubbed together, *materials* have a different *strength* of *attraction* for the *electrons*

Most Positive (+)

Easily lose electrons

+++

Human Skin
Fur
Glass
Human Hair
Wool
Silk
Paper

+

Cotton

Rubber
Copper
Silver
Polyester
Plastic

-

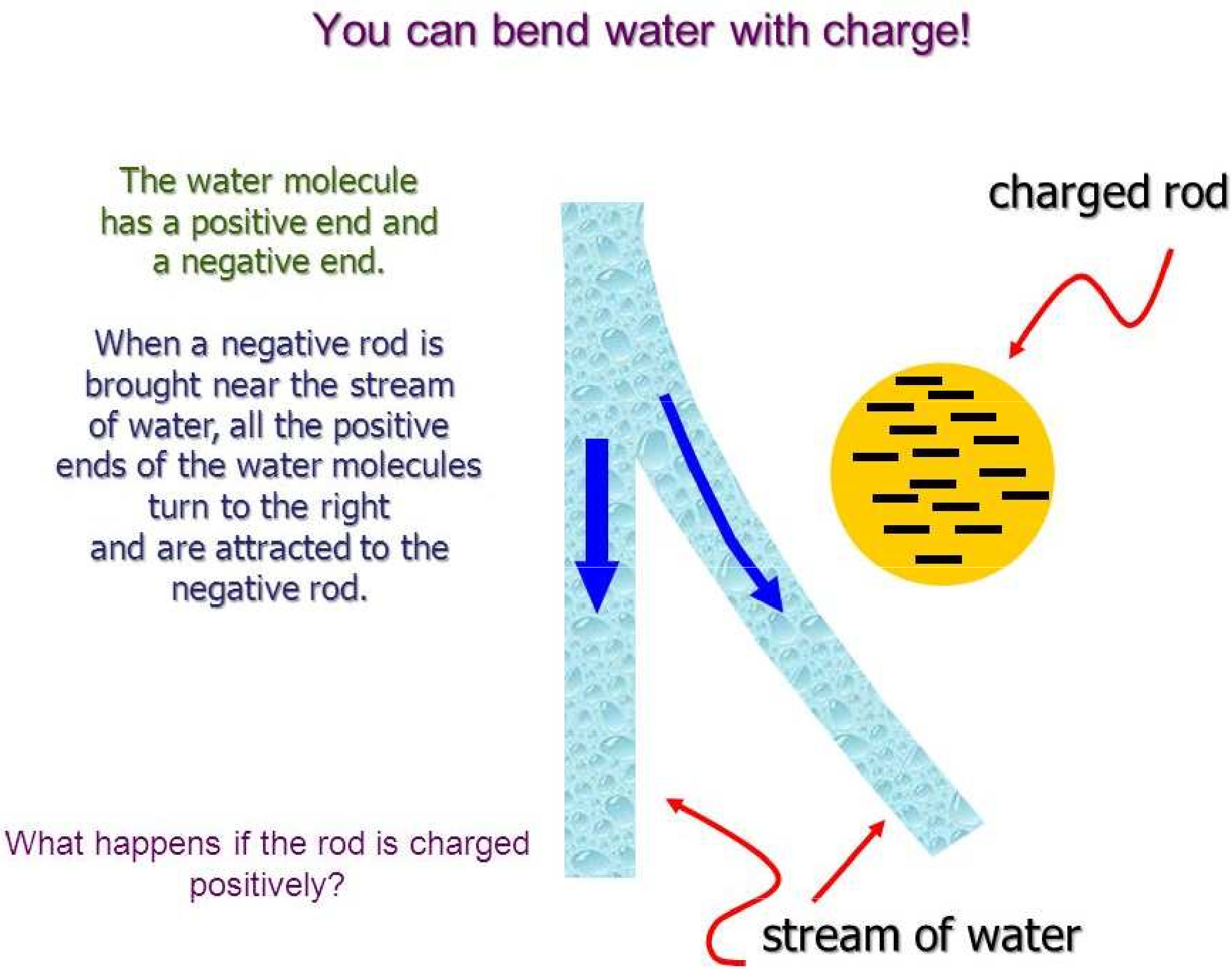
Easily gain electrons

- - -

Most Negative (-)

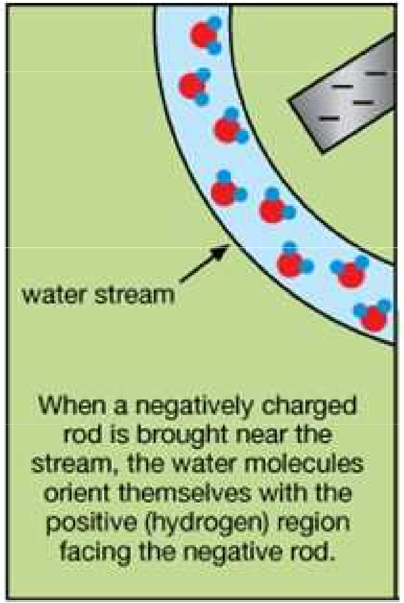
Why is static electricity more apparent in winter?

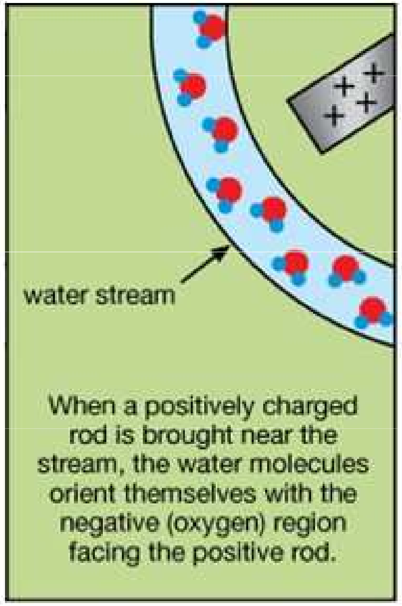
You notice static electricity much more in winter (with clothes in a dryer, or taking a sweater off, or getting a shock when you touch something after walking on carpet) than in summer because the air is much drier in winter than summer. **Dry air is a relatively good electrical insulator**, so if something is charged the charge tends to stay. In more humid conditions, such as you find on a typical summer day, water molecules, which are polarized, can quickly remove charge from a charged object.



What will happen when a charged rod or balloon is brought up close to a stream of water?

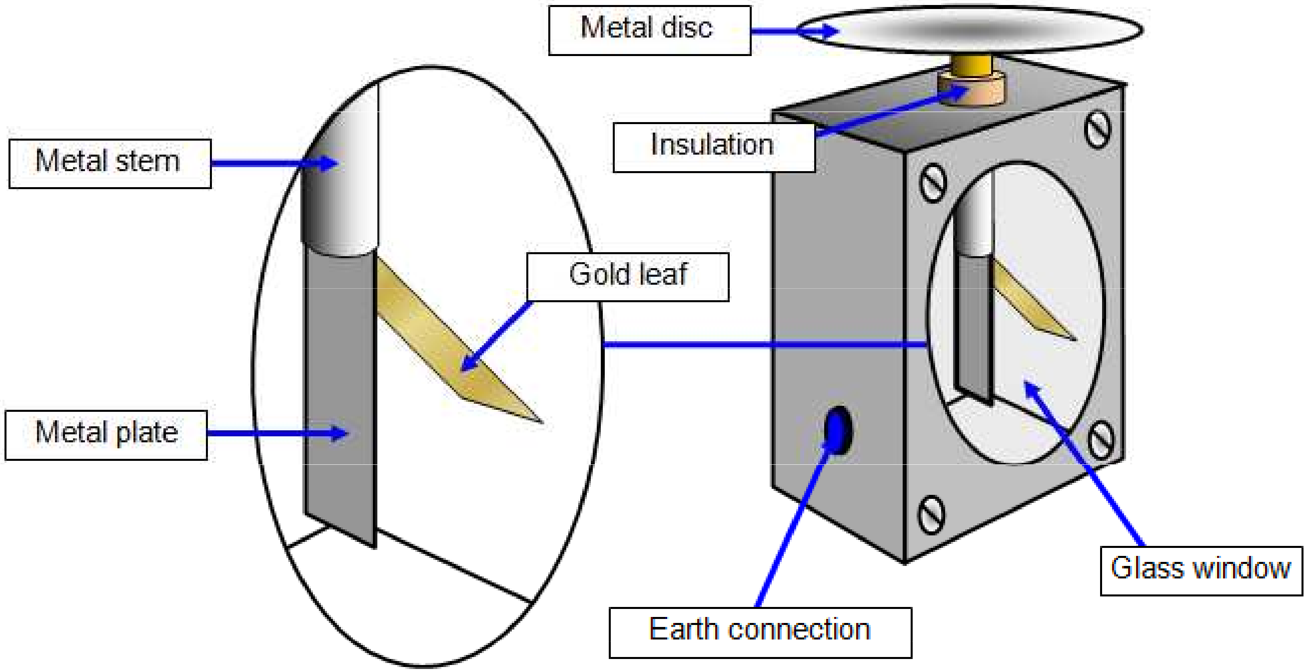
The water will be attracted toward the rod

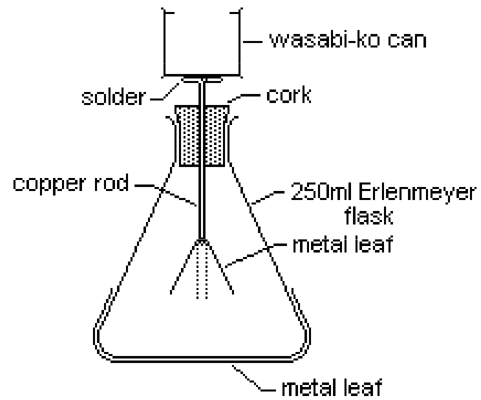




How to measure charge?

- Electroscope





Metal-Leaf Electroscope

History

- **„Electron“** came from the Greek word for amber, ἤλεκτρον (ēlektron).

- **Thales of Miletus** (624 – c. 546 BC) - Greek philosopher, mathematician and astronomer. Make an experiments with lodestone and amber - found attractive forces when rubbing it together.

- **Benjamin Franklin** (1706 – 1790) - American statesman and inventor, started studying electricity in 1742. The book *Experiments and Observations on Electricity. Theory of electrical fluid* - Franklin expressed the opinion that every non electric body contains a certain amount of electric fluid (positive or negative). Part of the electric fluid can be transferred from one body to another during the friction.

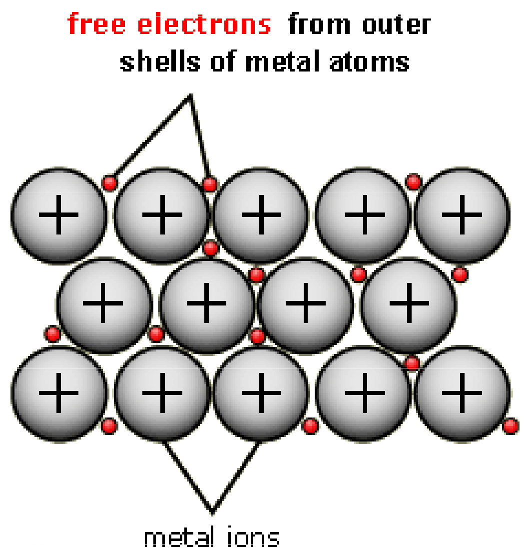
- **Charles-Augustin Coulomb** (1736-1806) - French physicist. The units of electric charge named after him : Coulomb. He developed the law descibed the force action between charges : Coulomb law

LZ 129 Hindenburg (Luftschiff Zeppelin)

Large German commercial passenger-carrying rigid airshift – destroyed 1937

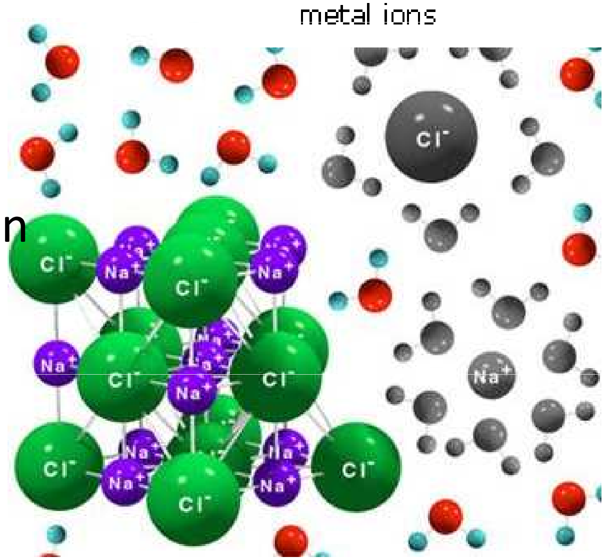
Fire caused the spark that resulted from the accumulation of static charge… maybee

Basic types of electric charge carriers and conducting media: conductors



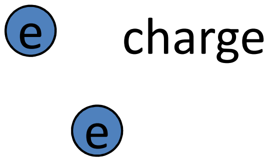
- **1st class conductors** are metals in which electrons (which behaviour resembles gas) enable electrical phenomena.

- **2nd class conductors** are electrolytes consisting of solutions of dissociated ionic compounds (e.g. NaCl). In this case, the anions and cations are the carriers of electric charge.

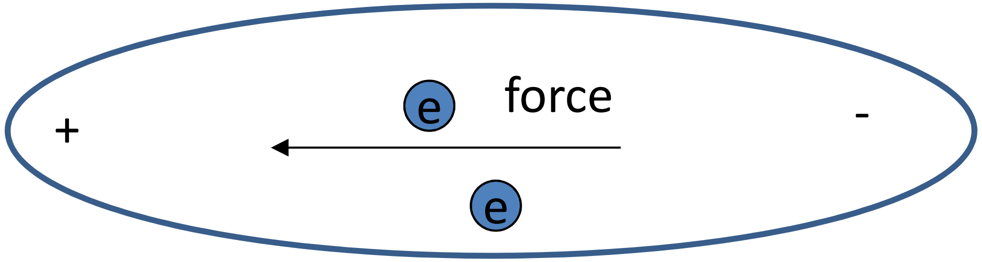


Example – effect of electric field

Conductors – electron flow

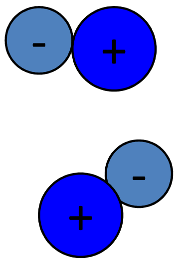


motion of charge

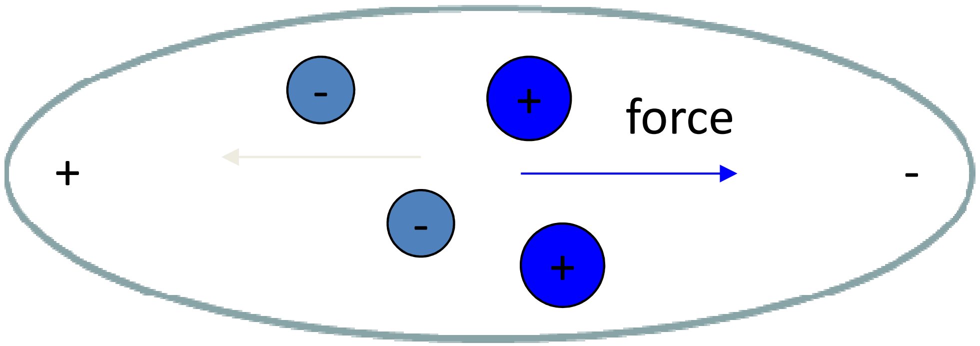


Electrolyte

mass



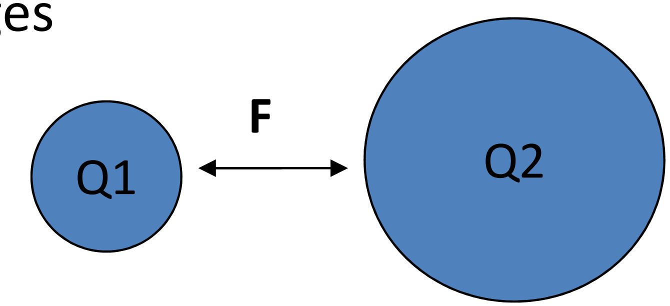
dissociation -→ ionts



Coulomb's law:

- This law describes the force existing between electric charges at rest.

$$F = \frac{1}{4\pi\varepsilon}\frac{Q_1Q_2}{r^2} \text{ [N]},$$

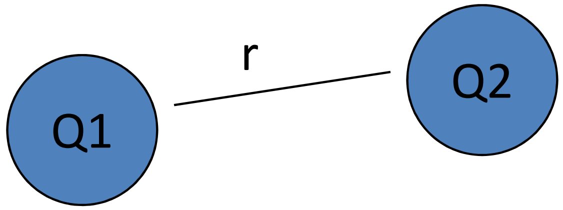


where ***F*** is the electrostatic force, *Q*1, and *Q*2 are the interacting charges, *r* is the distance between the charges (centres of charged spheres), and ε is the **electric permittivity** of the medium between charges.

$$\varepsilon = \varepsilon_0\varepsilon_r \qquad \frac{1}{4\pi\varepsilon} = k = 8.987 \times 10^9 \text{ N m}^2 \text{ C}^{-9}$$

where ε_0 is the permittivity of vacuum (8.85×10^{-12} $C^2m^{-2}N^{-1}$), a very important physical constant. ε_r is the relative permittivity (vacuum =1)

An example



Q1 = -20 nC
Q2= +80 nC
r= 10 cm
vacuum F= ???

$$F = \frac{1}{4\pi\varepsilon}\frac{Q_1 Q_2}{r^2}$$

insert values

conversion of units

$k = 8.987x10^{9}\ N\ m^{2}\ C^{-9}$

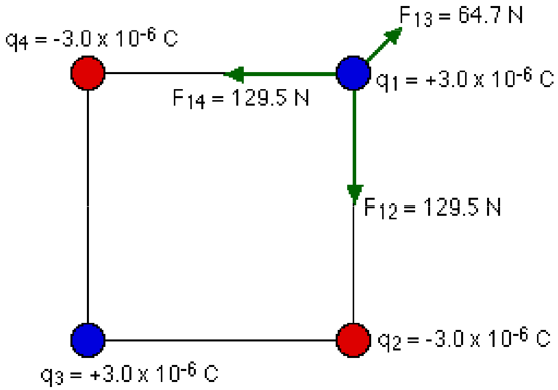
$$F = k \cdot \frac{20x10^{-9} \cdot 80x10^{-9}}{0.1^2}$$

calculation

$F = 1.4\ x\ 10^{-3}\ N$

The value of force is $1.4\ x\ 10^{-3}$ N.

An example



Four charges are arranged in a square with sides of length 2.5 cm. The two charges in the top right and bottom left corners are +3.0 x 10-6 C. The charges in the other two corners are -3.0 x 10-6 C. What is the net force exerted on the charge in the top right corner by the other three charges?

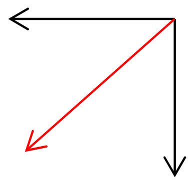
To solve any problem like this, the simplest thing to do is to draw a good diagram showing the forces acting on the charge. You should also let your diagram handle your signs for you. Force is a vector, and any time you have a minus sign associated with a vector all it does is tell you about the direction of the vector. If you have the arrows giving you the direction on your diagram, you can just drop any signs that come out of the equation for Coulomb's law.

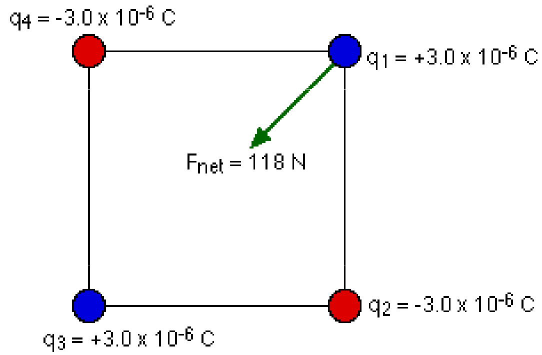
Consider the forces exerted on the charge in the top right by the other three:

from charge 2 : $F_{12} = k\, q_1\, q_2 / r^2 = (8.99 \times 10^9)(+3.0 \times 10^{-6})(-3.0 \times 10^{-6}) / (0.025)^2$
$= -129.5$ N $= +129.5$ N in the direction shown on the diagram

from charge 3 : (note that $r = 0.03536$ m)
$F_{13} = k\, q_1\, q_3 / r^2 = (8.99 \times 10^9)(+3.0 \times 10^{-6})(+3.0 \times 10^{-6}) / (0.03536)^2$
$= +64.7$ N $= +64.7$ N in the direction shown on the diagram

from charge 4 : $F_{14} = F_{12} = +129.5$ N in the direction shown on the diagram

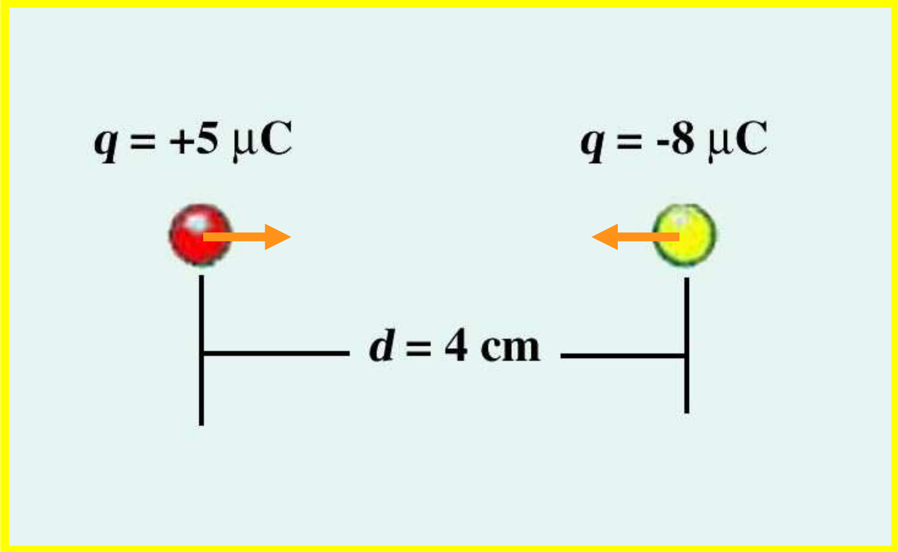




You have to be very careful to add these forces as vectors to get the net force. In this problem we can take advantage of the symmetry, and combine the forces from charges 2 and 4 into a force along the diagonal (opposite to the force from charge 3) of magnitude 183.1 N. When this is combined with the 64.7 N force in the opposite direction, the result is a net force of 118 N pointing along the diagonal of the square.

The symmetry here makes things a little easier. If it wasn't so symmetric, all you'd have to do is split the vectors up in to x and y components, add them to find the x and y components of the net force, and then calculate the magnitude and direction of the net force from the components.

EXAMPLE 1 - Find the force between these two charges

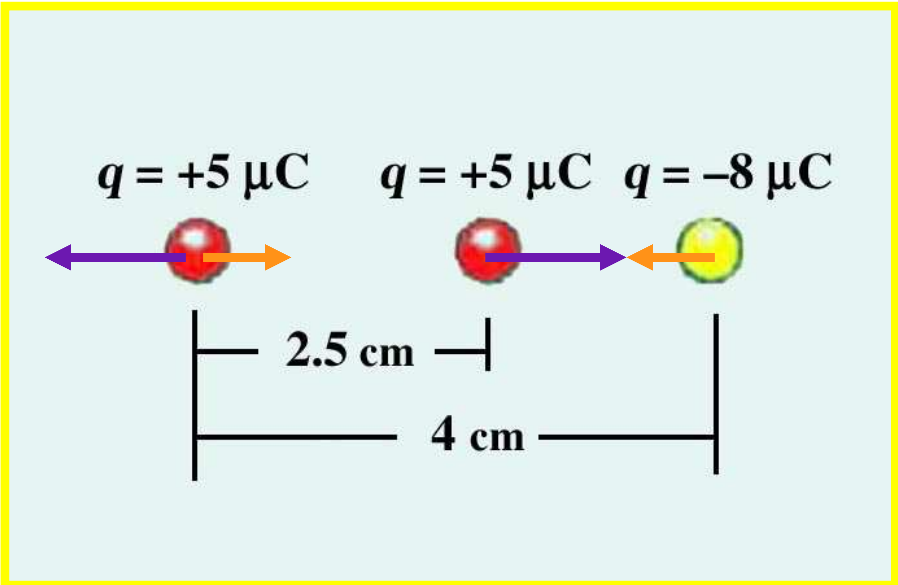


$$F_e = \frac{(9.0\times10^9)(5\times10^{-6}\ \text{C})(-8\times10^{-6}\ \text{C})}{(0.04\ \text{m})^2}$$

$$F_e = -225\ \text{N}$$

The negative signs means force of attraction, but does not indicate left or right direction

EXAMPLE 2 - Find the net force on the left charge



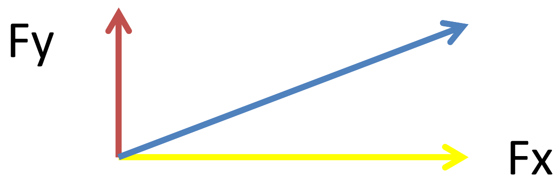
$$F_e = \frac{(9.0\times10^9)(5\times10^{-6}\ \text{C})(5\times10^{-6}\ \text{C})}{(0.025\ \text{m})^2}$$

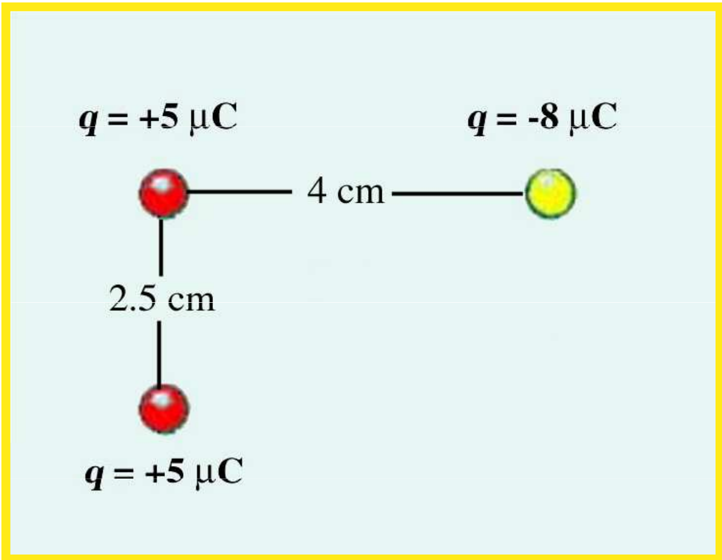
$$F_e = 360\ \text{N} \qquad \text{(force of repulsion)}$$

$$F_{net} = F_{left} - F_{right}$$

$$F_{net} = 360\ \text{N} - 225\ \text{N} = 135\ \text{N, to the left}$$

EXAMPLE 3 - Find the net force on the upper left charge





$$F_{e,x} = 225\ \text{N, right} \qquad F_{e,y} = 360\ \text{N, up}$$

$$\Sigma F_e = \sqrt{F_{e,x}^{\ 2} + F_{e,y}^{\ 2}} = \sqrt{225^2 + 360^2} = 425\ \text{N}$$

$$\theta = \tan^{-1}\left(\frac{F_{e,y}}{F_{e,x}}\right) = \tan^{-1}\left(\frac{360}{225}\right) = 58.0\text{Þ}$$