Chapter 23

Electric Charge

Some observations:

- Electric charge appears to come in two "flavors." Call them

  - ~~vanilla and chocolate~~
  - ~~up and down~~
  - positive and negative

It doesn't matter which is which!

- Like charges repel each other while unlike charges attract each other.

demo

One kind of charge is applied to rubber by stroking it with hair (wool, fur, human hair)

negative on rubber

positive charge on fur

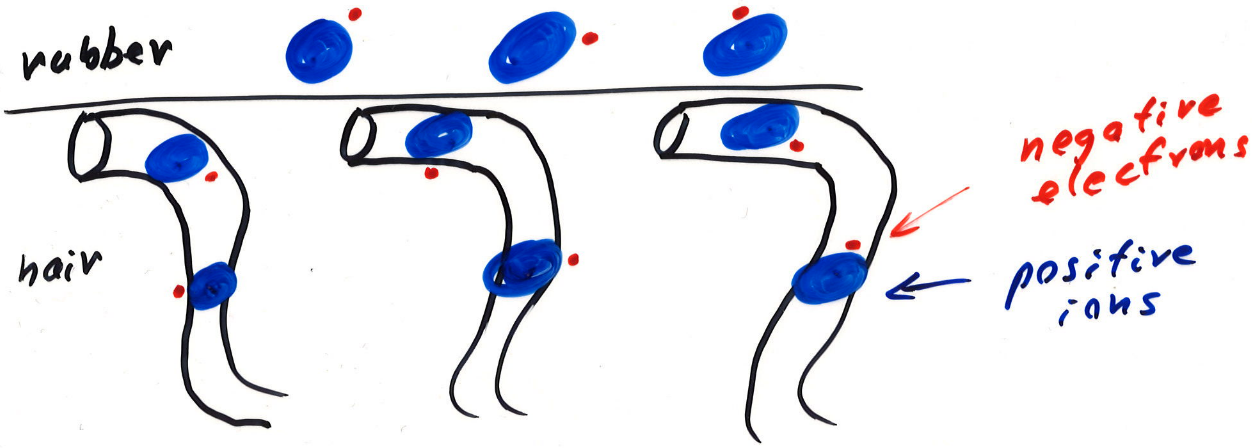
The other kind of charge is applied to glass by stroking it with silk.

Positive on glass

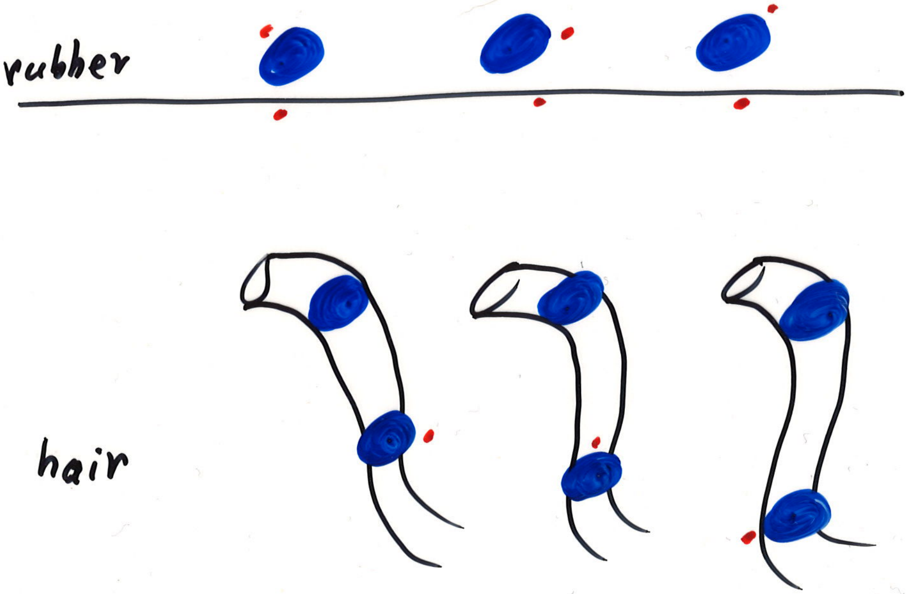
negative on silk

Charge is conserved.

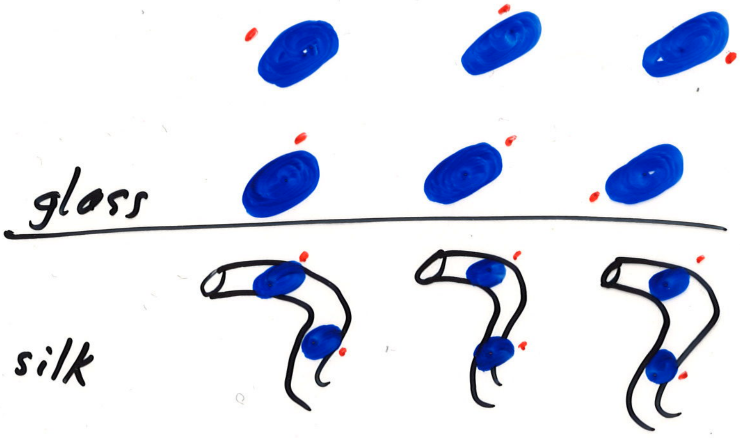
What's really going on here? Microscopically:



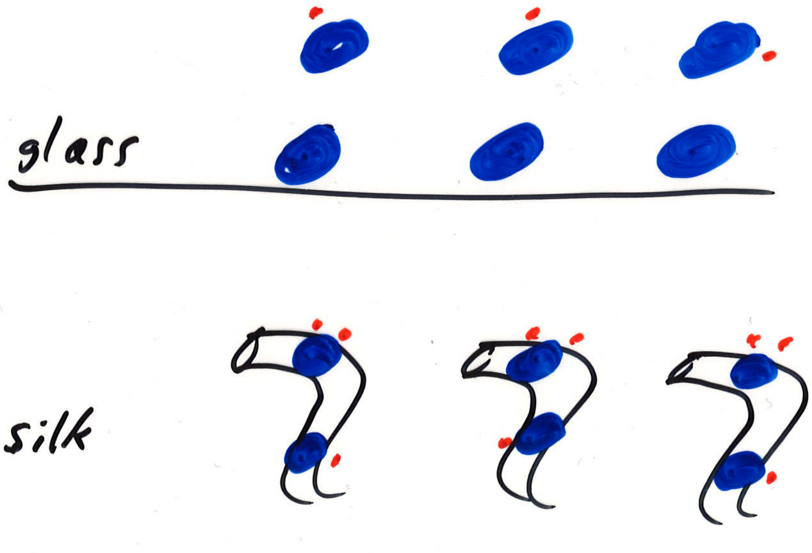
Electrons from the hair remain on the surface of the rubber. By convention, electrons are said to have negative charge.



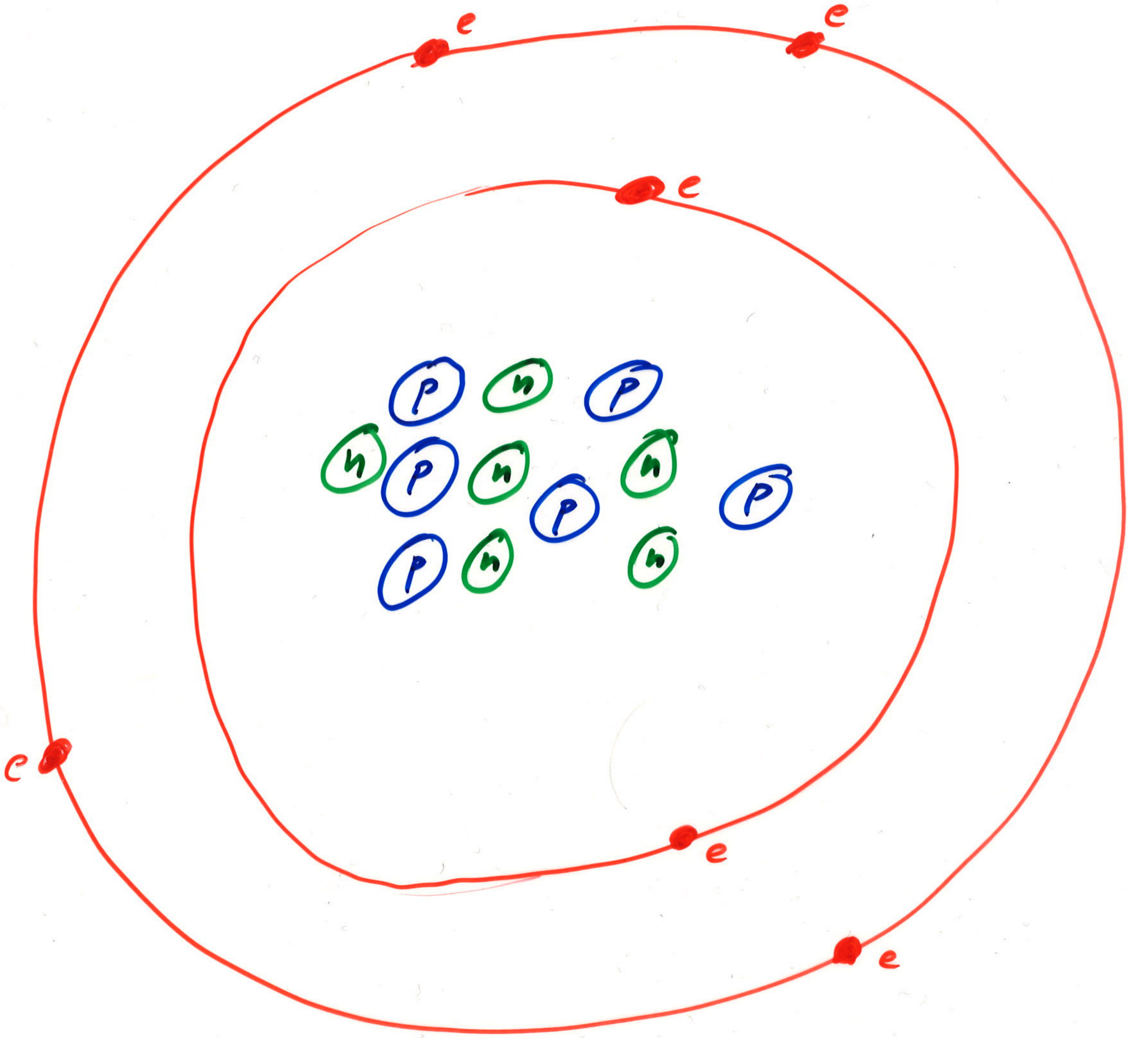
Again, microscopically:



Silk removes electrons from the surface of the glass, leaving the glass positively charged.



The Atom (e.g. Carbon)



Not to scale!

ⓟ proton - positively charged

ⓝ neutron - zero charge (neutral)

e● electron - negatively charged

The atom is electrically neutral.

All of the forces that you studied in Mechanics (1303) except gravity were electrical in origin.

- contact forces
  - normal force
  - friction
  - viscous drag
- string tension
- Hooke's law spring force

More Observations

Newton's Law of Universal Gravitation

Gravity

magnitude: $F_G = \dfrac{G\, m_1 m_2}{(r_{12})^2}$

direction: along the line joining the masses

always attractive

Coulomb's Law

Electric Force

magnitude: $F_E = \dfrac{k\, |q_1|\, |q_2|}{(r_{12})^2}$

direction: along the line joining the charges

attractive if $\begin{cases} q_1 \text{ positive}, & q_2 \text{ negative} \\ q_1 \text{ negative}, & q_2 \text{ positive} \end{cases}$

repulsive if $\begin{cases} q_1 \text{ positive}, & q_2 \text{ positive} \\ q_1 \text{ negative}, & q_2 \text{ negative} \end{cases}$

G is the gravitational constant.

$$G = 6.67 \times 10^{-11} \ \frac{N \cdot m^2}{kg^2}$$ (in MKS units)

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k is the electrostatic constant.

$$k = 8.99 \times 10^{9} \ \frac{N \cdot m^2}{C^2}$$

for later convenience

$$k \equiv \frac{1}{4\pi \epsilon_0} \qquad \epsilon_0 = \frac{1}{4\pi k}$$

ϵ_0 (epsilon nought) is the permittivity of free space

$$\epsilon_0 = 8.85 \times 10^{-12} \ \frac{C^2}{N \cdot m^2}$$

$$F_E = \frac{1}{4\pi\epsilon_0} \frac{|q_1|\ |q_2|}{(r_{12})^2}$$

Vector nature of $\vec{F}_E$.

$$\vec{F}_{\text{of 1 on 2}} = \frac{1}{4\pi\epsilon_0} \frac{q_1\ q_2}{(r_{12})^2}\ \hat{r}_{12}$$

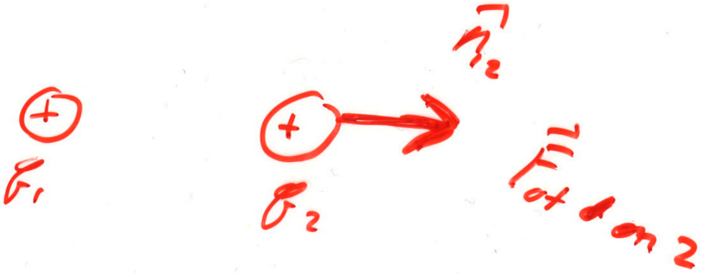
q_1, q_2 can be positive <u>or</u> negative

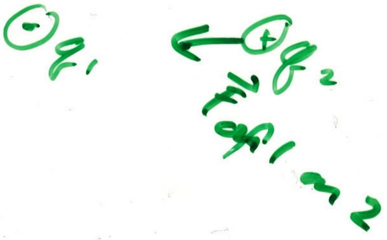
r_{12} is the distance between q_1 and q_2

$\hat{r}_{12}$ is a <u>unit vector</u> pointing from q_1 to q_2

$\hat{r}_{12} \cdot \hat{r}_{12} = 1$

Ex.





The MKS unit of charge

is the coulomb (C)

1 C is an enormous amount of charge.

Ex Find the force between two 1 C charges separated by 1 m.

$$F_E = k\frac{|q_1|\,|q_2|}{(r_{12})^2} = 8.99\times10^9\,\frac{N\cdot m^2}{C^2}\,\frac{(1\,C)(1\,C)}{(1\,m)^2}$$

$$\approx 9\times10^9\,\cancel{N}\left(\frac{0.225\ lb}{1\,\cancel{N}}\right)$$

$$= 2\times10^9\ lbs\left(\frac{1\ ton}{2000\ lb}\right)$$

$$= 10^6\ tons.$$

The coulomb (C) is not one of the fundamental units (base units):

meter	m	
kilogram	kg	
second	s	
ampere	A	(amp) unit of current

The coulomb is a derived unit

$$1\ \mathrm{C} = 1\ \mathrm{A \cdot s}$$

like the newton (N)

$$1\ \mathrm{N} = 1\ \frac{\mathrm{kg \cdot m}}{\mathrm{s^2}}$$

Electric charge is a scalar quantity, like mass. The only difference is that mass is always positive while charge can be positive or negative.

Charge adds like a scalar:

Ex. $3\,\mathrm{C} + (-4\,\mathrm{C}) = -1\,\mathrm{C}$

Ex. $3\,\mathrm{kg} + 5\,\mathrm{kg} = 8\,\mathrm{kg}$ (mass)

Ex. $1.2\,\mathrm{kg\cdot m^2} + 2.7\,\mathrm{kg\cdot m^2} = 3.9\,\mathrm{kg\cdot m^2}$

(moment of inertia
or
rotational inertia)

The forces on one charge due to all the rest add like vectors.

$$\vec{F}_{\substack{\text{total}\\\text{on } 1}} = \vec{F}_{\substack{\text{of } 2\\\text{on } 1}} + \vec{F}_{\substack{\text{of } 3\\\text{on } 1}} + \dots + \vec{F}_{\substack{\text{of } 87\\\text{on } 1}} + \dots$$

$$\vec{F}_{\substack{\text{of } 87\\\text{on } 1}} = \frac{1}{4\pi\epsilon_0} \frac{q_{87}\, q_1}{\left(r_{87,1}\right)^2} \hat{r}_{87,1}$$

$\hat{r}_{87,1}$ points from q_{87} to q_1.

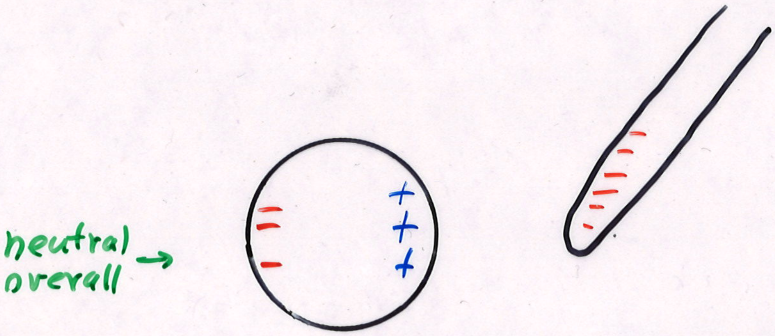
Charge q_1 cannot exert a force on itself!

This additive property of the vector force is called "super position."

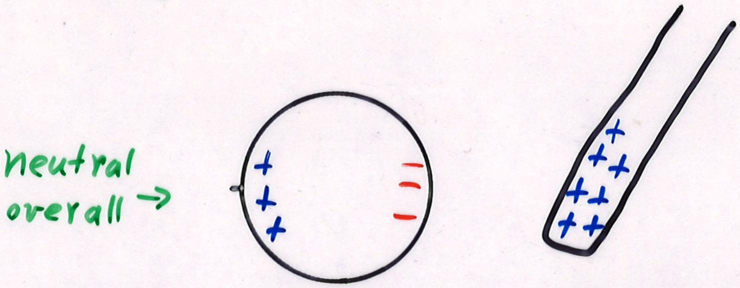
Ex Consider 3 identical positive q charges at the corners of an equilateral triangle of side d. What is the force on one charge due to the other two?

An uncharged metal can is <u>attracted</u> by each kind of charge, never repelled.

What's going on?



charge is induced (moved around) in the metal can.

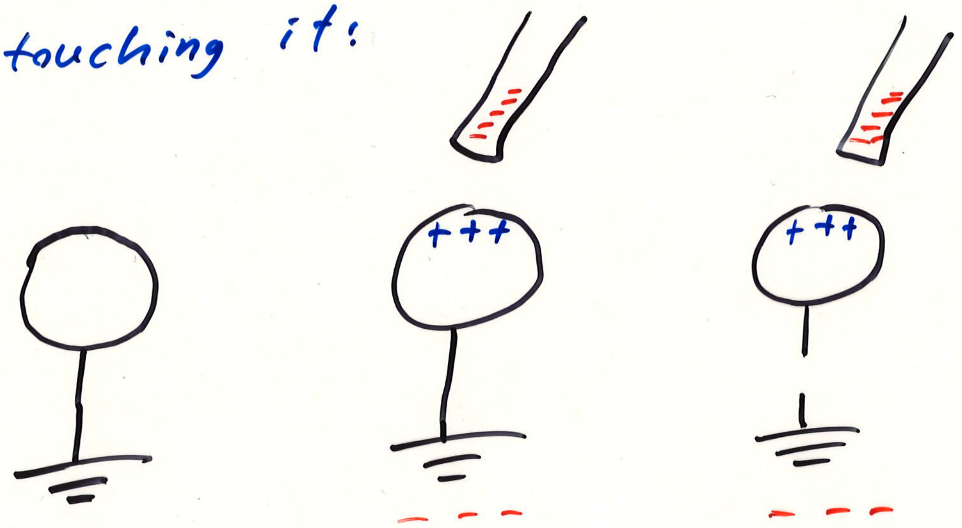


In a <u>conductor</u>, charge can flow freely.

In an <u>insulator</u>, charge is stuck in place.

A conductor that can take as many electrons as it needs from a large supply (like the earth), or give up as many electrons as it needs is said to be grounded.

How to charge a conductor without touching it:



Charging by *induction.*

Ex How much charge is in you?

$m = 75\ kg = 75{,}000g$ all water

molecular mass of water $18g$

I contain $\frac{75{,}000g}{18\ g} = 4100$ moles of water

each mole 6.02×10^{23} molecules

I have 2.5×10^{27} molecules

$$H_2O \qquad \left.\begin{array}{l} 1e \text{ in } H \\ 8e \text{ in } O \end{array}\right\} \text{10 electrons in } H_2O \text{ molecule}$$

How many C of negative charge.

$$2.5 \times 10^{27} \cdot 10 \cdot \underbrace{(-1.6 \times 10^{-19}\ C)}_{\text{charge on electron}}$$

$$= -4 \times 10^{9}\ C$$