#5: More Coulomb's Law

Electric force: one of the fundamental forces of nature
Electric charge: property that determines the strength the electric force

Charge is analogous to mass for gravity
But 2 kinds of electric charge: positive and negative

Electric force can be **attractive** or **repulsive**

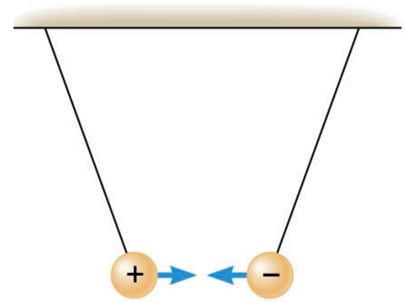
A positively charged body is attracted to a negatively charged body

Like charges repel each other

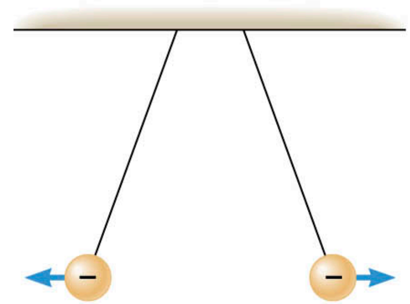
Force is directed along a line between charges

The ***magnitude*** of the force between 2 charged bodies is:

$$\left|\vec{F}\right| = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}$$ ***Coulomb's law***



(a)



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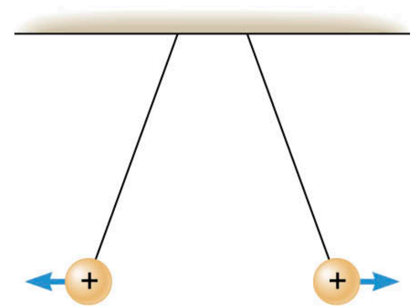
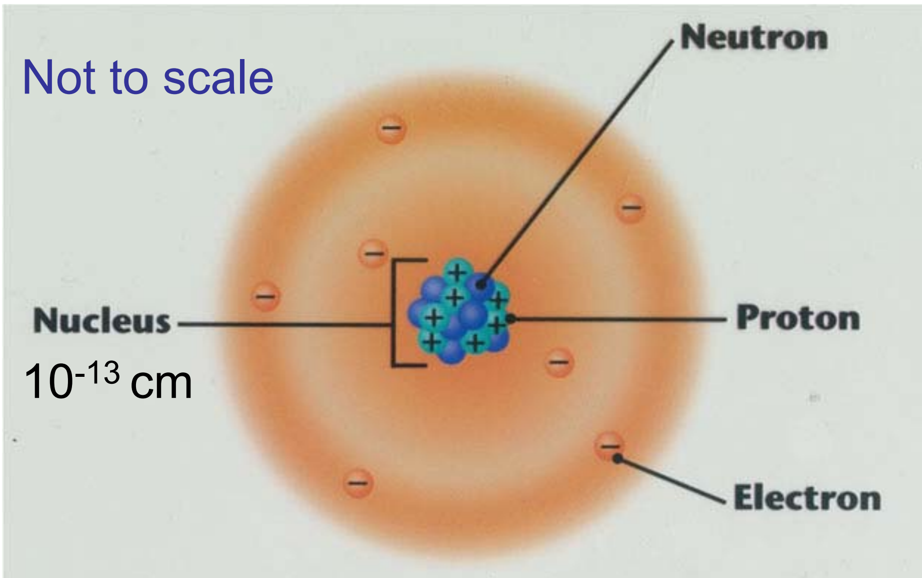


(c)

Constants and units



$$\left|\vec{F}\right| = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}$$

$$\frac{1}{4\pi\varepsilon_0} = k = 9\times10^9\,\frac{N\cdot m^2}{C^2}$$

$$\varepsilon_0 = 8.85\times10^{-12}\,\frac{C^2}{N\cdot m^2}$$

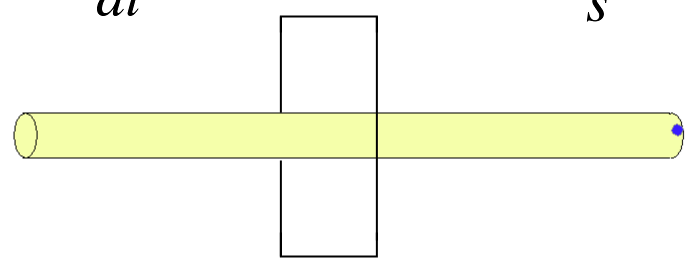
ε_0 Vacuum permittivity or "permittivity of free space"

-Charge on an electron ***exactly*** equals that of a proton (1.602x10^{-19} ***Coulombs***)

Coulomb is the SI unit for charge

$$i = \frac{dq}{dt} \qquad A = \frac{C}{s}$$

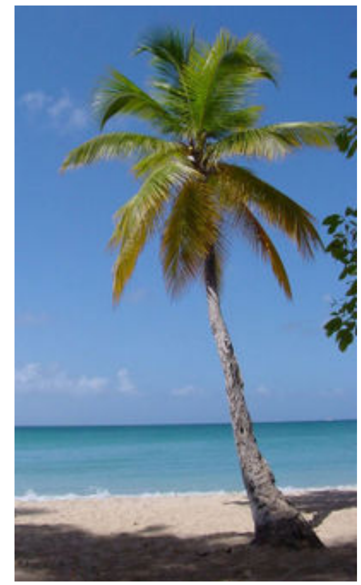
Current (SI unit = Ampere) is the amount of charge that moves through a point or region in a given time



Charles Coulomb

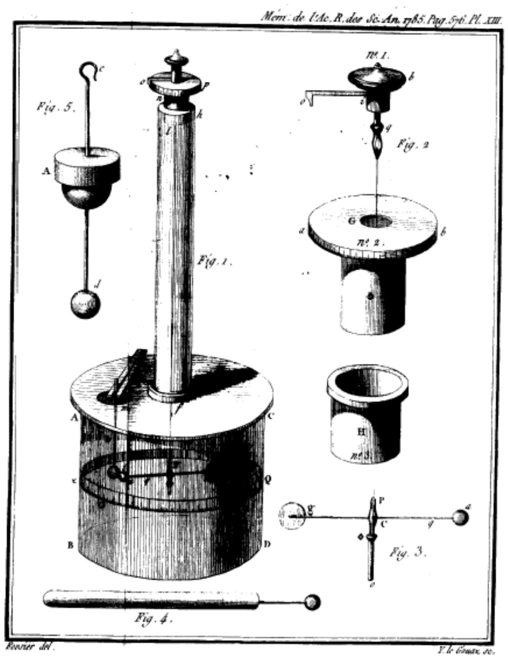
(1736-1806)
Born: Angoulême, Fr

1764-1772 Military assignment in Martinique



Favorite invention:

Theory of retaining walls (1776)



Used a torsion balance to show:

$$F = k\frac{|q_1||q_2|}{r^2}$$

The SI unit of charge is named for him

One of 72 French scientists commemorated by Gustave Eiffel

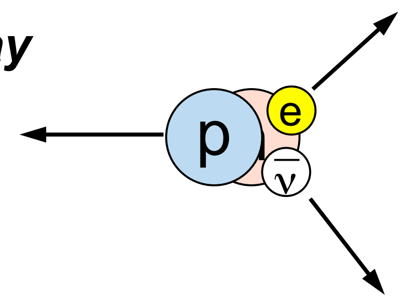
Conservation of Charge

Electric charge is a fundamental property of particles, but is it really conserved?

Particles can be created and destroyed.

Neutrons are unstable! They "live" for about 816 seconds

β decay



A neutron spontaneously changes itself into 3 particles: proton, electron and antineutrino

This process is called beta (β) decay

But the charge on an electron and the charge on a proton are equal and opposite so charge is conserved in the process.

The conservation of electric charge is one of the most fundamental laws and results directly from inherent symmetries in quantum electrodynamics.

In nuclei, beta decay can also convert protons into neutrons: $p \rightarrow n + e^+ + \nu$

Antimatter & PET

All particles have a corresponding antiparticle - which differs only by its charge.

A particle and its antiparticle can ***annihilate***, producing only EM waves - γ rays!

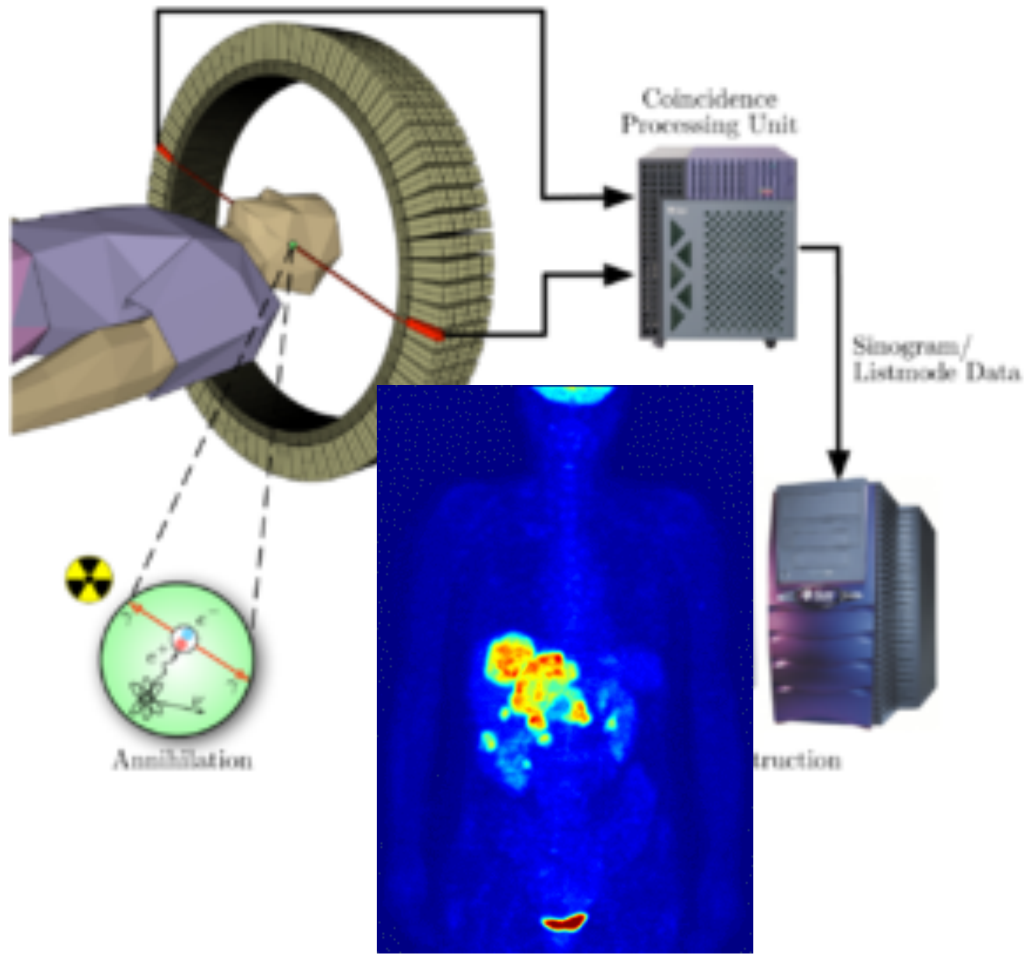
$e^- + e^+ \rightarrow \gamma + \gamma$ Is the basis for ***PET (Positron-Emission Tomography)***

For example, you might inject a liquid that contains glucose manufactured with an isotope that decays by β^+ emission

The positron travels only a short distance before annihilating.

Two gamma rays leave in opposite directions and are detected by a ring of detectors.

A full 3D image can be constructed of metabolic processes!

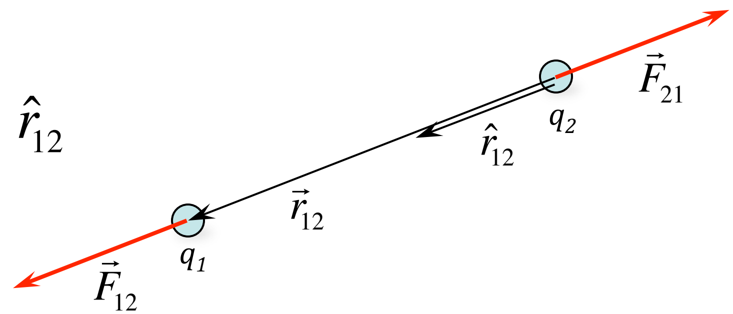


Coulomb's Law - Vector Form

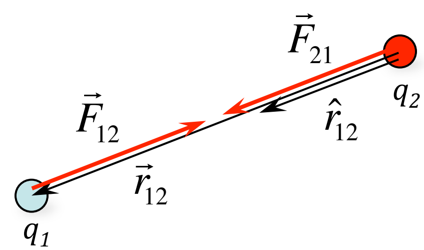
Force is directed along a line between charges

The force on particle 2 is equal in magnitude but opposite in direction from the force on particle 1

Vector $\vec{r}_{12}$ is location of particle 1 relative to particle 2



Like charges → force in direction of ***unit vector*** $\hat{r}_{12}$

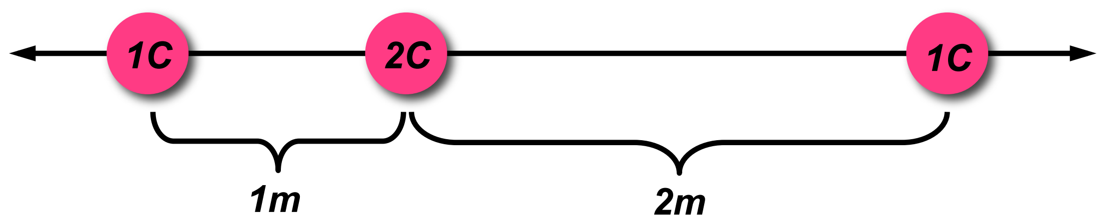


Opposite charges → force in opposite direction of ***unit vector*** $\hat{r}_{12}$

In either case, we can write the force as $\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}^2}\hat{r}_{12}$

More than 2 particles? Add vectors!! $\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \cdots$

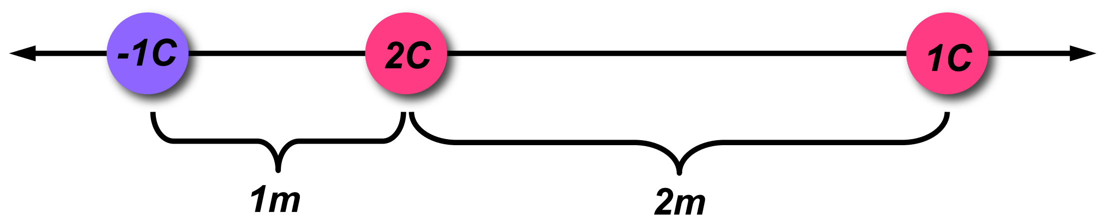
Concept question
Three positive charges are arranged in a line as shown.
Which particle feels the greatest force?



A. Left
B. Middle
C. Right
D. All feel the same force.
E. The two 1C charges feel the same (larger) force.

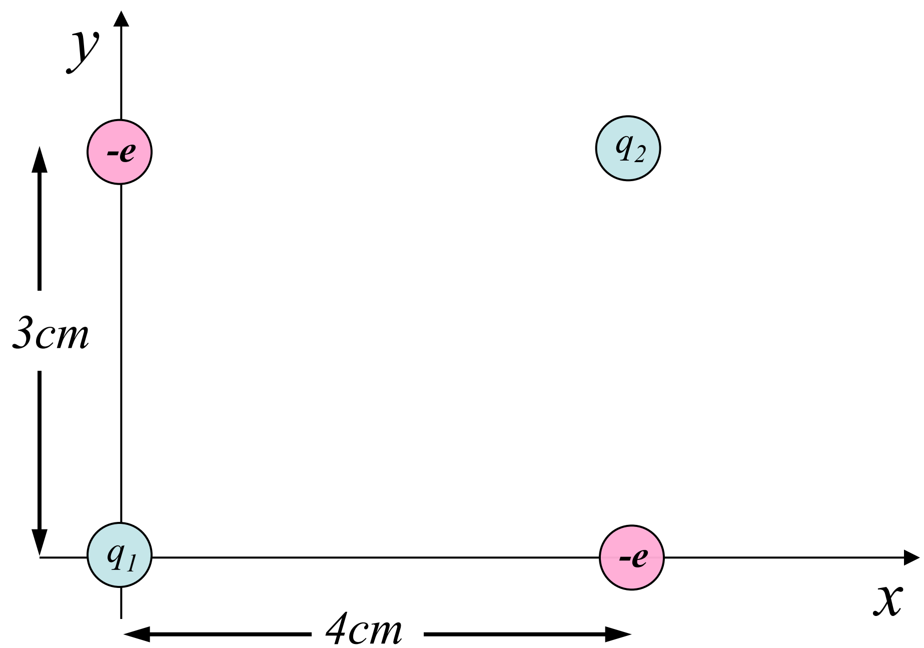
Concept question

Same situation, but the left charge is ***negative***. Which particle feels the greatest force?



A. Left
B. Middle
C. Right
D. All feel the same force.
E. The +1C and -1C charges feel the same (larger) force.

Four charges are arranged at the corners of a rectangle as shown in the figure. If q_1 and q_2 are alpha particles (helium nuclei with charge $+2e$), then (a) What is the magnitude and direction of the force on q_2? (b) Write the force on q_2 in unit vector notation. (c) What is the magnitude and direction of the net force on the electron that lies on the x-axis?



How neutral are atoms?

Suppose that two objects weighing one gram are separated by 10 m.

If we remove an electron from 1 out of every million atoms in each object, what is the force between the two objects?

If the objects are made out of carbon, then they contain

$$1g \cdot \frac{mole}{12g} = \frac{1}{12} mole = \frac{1}{12} 6.0 \times 10^{23} atoms = 0.5 \times 10^{23} atoms$$

The charge q on each object is then:

$$q = \frac{1}{10^6}\left(0.5 \times 10^{23} atoms\right)\left(1.6 \times 10^{-19} C\right) = 0.8 \times 10^{-2} C = 8mC$$

We can then calculate the force using Coulomb's Law

$$F = \left(9 \times 10^9 \frac{N \cdot m^2}{C^2}\right)\frac{|q_1||q_2|}{r^2} = \left(9 \times 10^9 \frac{N \cdot \cancel{m^2}}{\cancel{C^2}}\right)\frac{\left(8 \times 10^{-3} \cancel{C}\right)\left(8 \times 10^{-3} \cancel{C}\right)}{\left(10\cancel{m}\right)^2}$$

5760 N

(a) Two tiny conducting spheres are identical and carry charges of -20.0 μC and +53.0 μC. They are separated by a distance of 2.50 cm. What is the magnitude of the force each sphere experiences, and is it attractive or repulsive?

$$F = k\frac{|q_1||q_2|}{r^2}$$

$$k = 9\times10^9\,\frac{N\cdot m^2}{C^2}$$

$$q_1 = -20\mu C\left(\frac{10^{-6}C}{\mu C}\right) = -2.0\times10^{-5}C$$

$$q_2 = 53\mu C\left(\frac{10^{-6}C}{\mu C}\right) = 5.3\times10^{-5}C$$

$$r = 2.5cm\left(\frac{1m}{100cm}\right) = 0.025m$$

$$F = \left(9\times10^9\,\frac{N\cdot m^2}{C^2}\right)\frac{(2.0\times10^{-5}C)(5.3\times10^{-5}C)}{(0.025m)^2}$$

$$= 15{,}000N$$ ***Attractive***

(b) If we touch the two spheres to each other and then place them back 2.50 cm apart, what is the force between them?

$$Q_{tot} = -20\mu C + 53\mu C = 33\mu C$$

When we touch the two spheres the total charge becomes shared equally between the two:

$$q_1 = q_2 = \frac{1}{2}\cdot 33\mu C\left(\frac{10^{-6}C}{\mu C}\right) = 1.65\times10^{-5}C$$

$$F = \left(9\times10^9\,\frac{N\cdot m^2}{C^2}\right)\frac{(1.65\times10^{-5}C)(1.65\times10^{-5}C)}{(0.025m)^2}$$

$$= 3900N$$ ***Respulsive***