Coulomb’s Law

Course- PHY 2105 / PHY 105

Lecture 11

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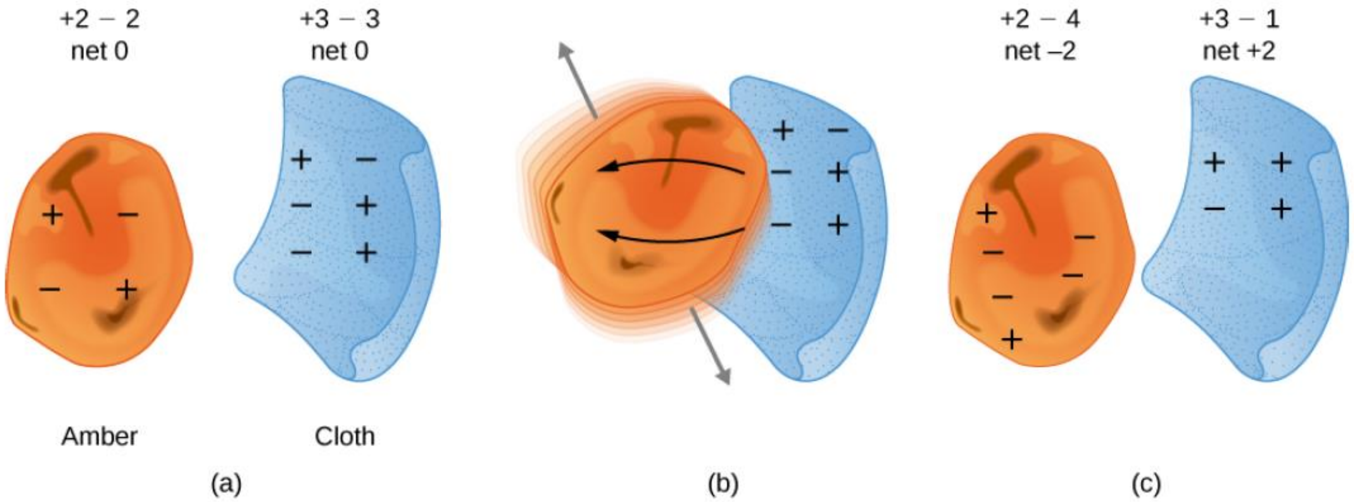
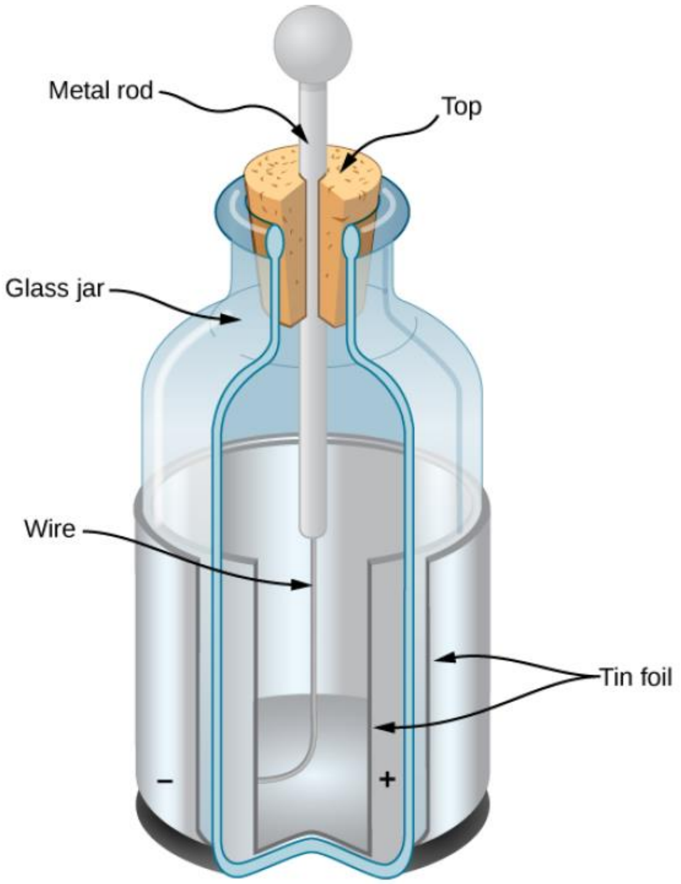
Early instances of Electrostatics

Amber: a hard, translucent, fossilized resin from extinct trees



The ancient Greek philosopher Thales of Miletus (624–546 BCE) recorded that when amber was vigorously rubbed with a piece of fur, a force was created that caused the fur and the amber to be attracted to each other

Early instances of Electrostatics



Leyden Jar: An early form of a charge storage device

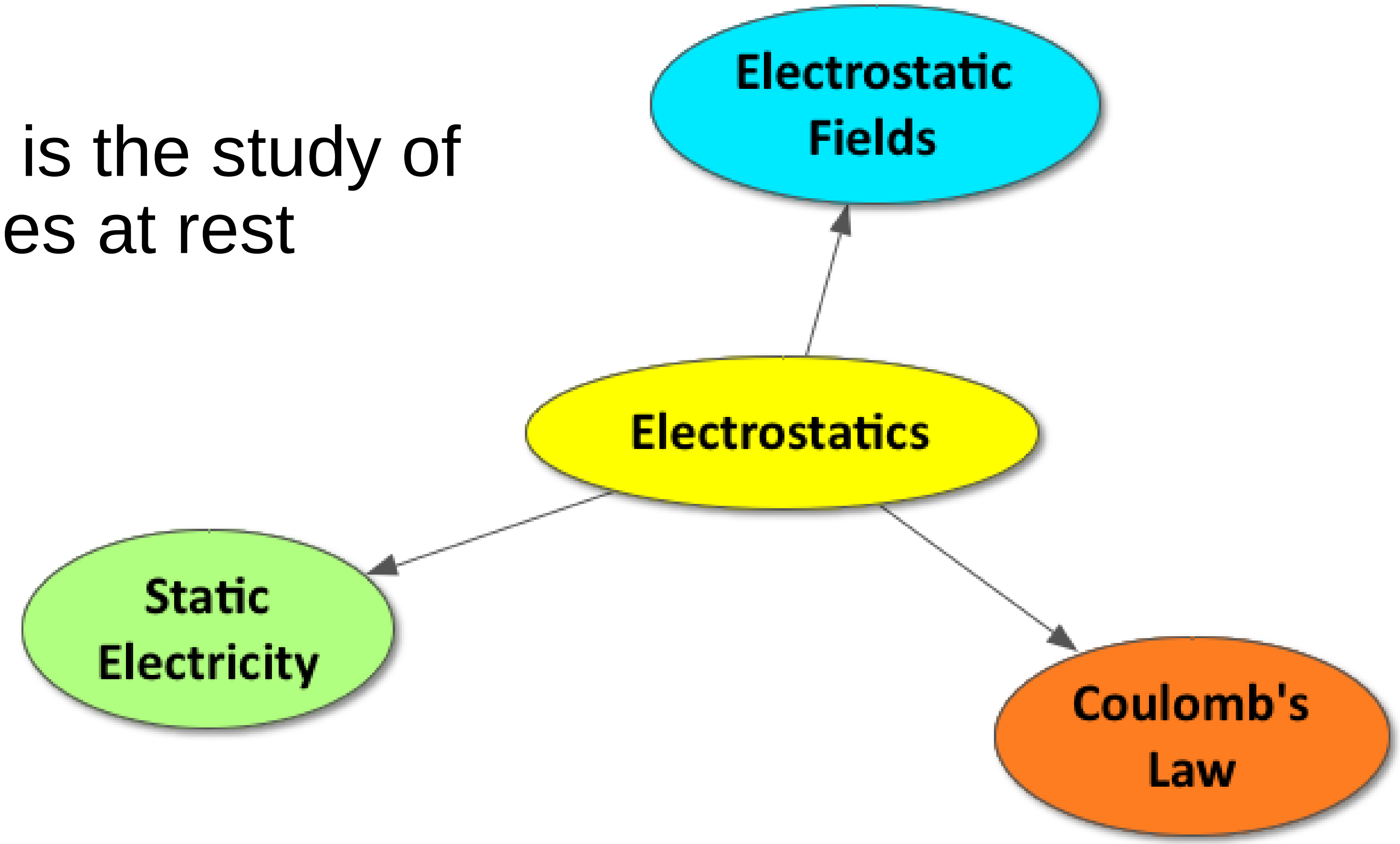
Benjamin Franklin demonstrated that in a Leyden jar with two sheets of metal foil, one inside and one outside, with the glass between them, we could see a large electric force between the two foil sheets

one of the two types of charge remained motionless, while the other type of charge flowed from one piece of foil to the other

"Electrical fluid"

Electrostatics

Electrostatics is the study of electric charges at rest



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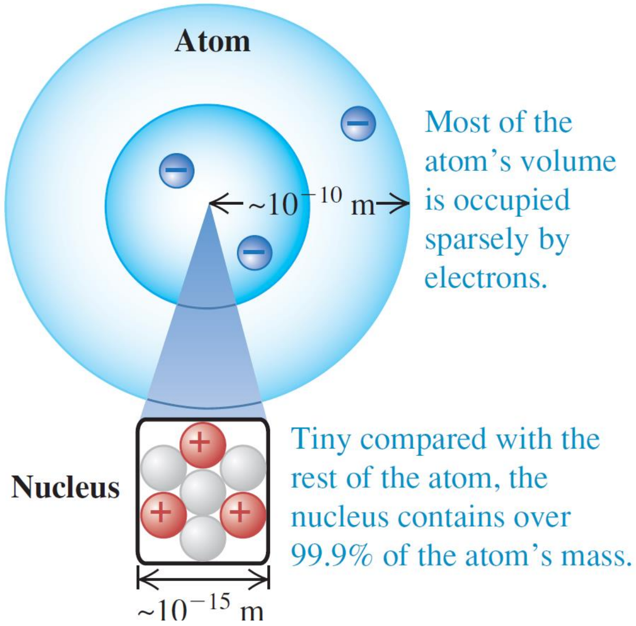
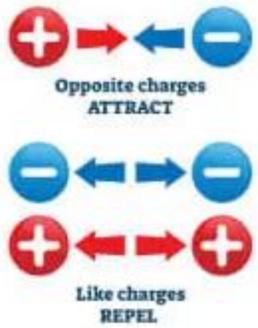
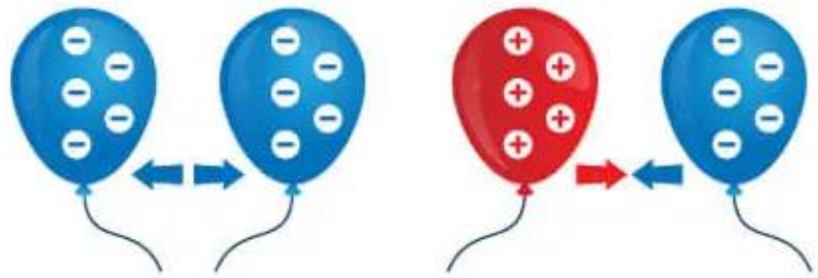
Electrical Charge

The strength of a particle's electrical interaction with objects around it depends on its electric charge







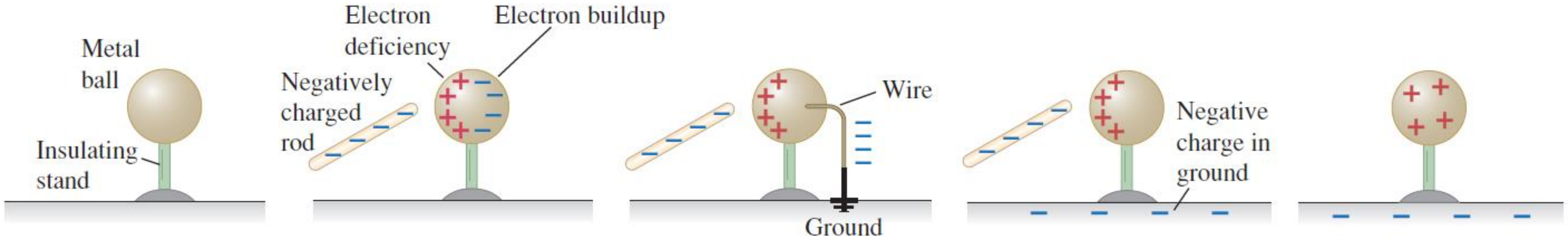
Quantities of charge

Neutral Charge

when there is equal amounts of both types of charge.

Net Charge

when there is an excess of either positive or negative charge.



(a) Uncharged metal ball

(b) Negative charge on rod repels electrons, creating zones of negative and positive **induced charge**.

(c) Wire lets electron build-up (induced negative charge) flow into ground.

(d) Wire removed; ball now has only an electron-deficient region of positive charge.

(e) Rod removed; electrons rearrange themselves, ball has overall electron deficiency (net positive charge).

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Charge is Quantized

When a physical quantity such as charge can have only discrete values rather than any value, we say that the quantity is **quantized**

The charge of a particle, can be written as q = *ne*, where *n* is a positive or negative integer

$$e = 1.6 \times 10^{-19}\ C$$

Charles Coulomb

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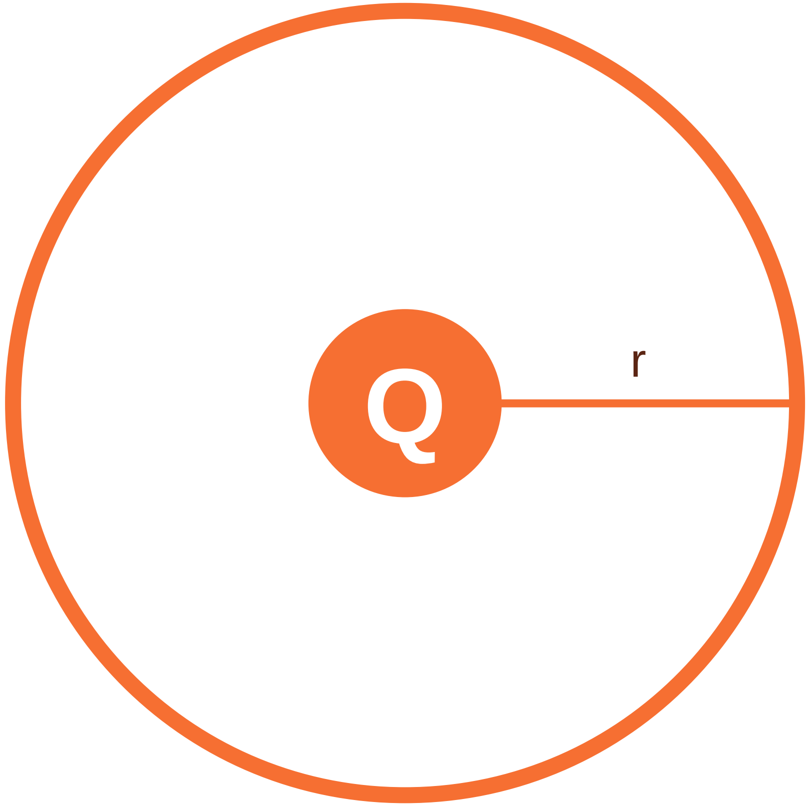
Charge Distribution: Shell theorem



Shell theorem 1:

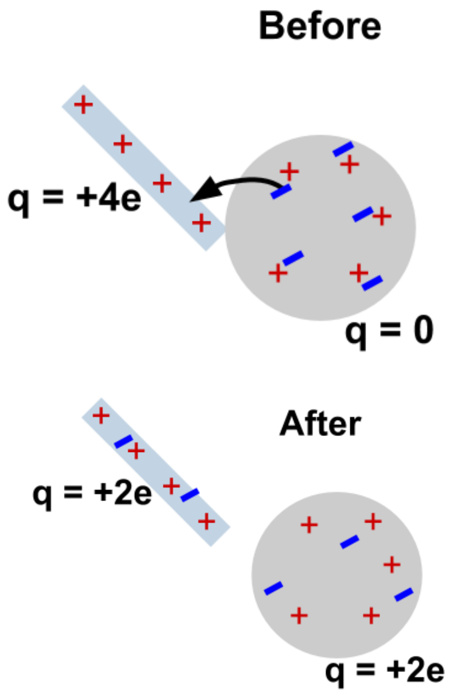
A charged particle outside a shell with charge uniformly distributed on its surface is attracted or repelled as if the shell's charge were concentrated as a particle at its center.

Shell theorem 2:

A charged particle inside a shell with charge uniformly distributed on its surface has no net force acting on it due to the shell.

Charge is Conserved

The net electric charge of any isolated system is always conserved.



Another example of charge conservation occurs when an electron e^- (charge $-e$) and its antiparticle, the *positron* e^+ (charge $+e$), undergo an *annihilation process*, transforming into two *gamma rays* (high-energy light):

$$e^- + e^+ \rightarrow \gamma + \gamma \quad \text{(annihilation)}. \tag{21-14}$$

In applying the conservation-of-charge principle, we must add the charges algebraically, with due regard for their signs. In the annihilation process of Eq. 21-14 then, the net charge of the system is zero both before and after the event. Charge is conserved.

In *pair production*, the converse of annihilation, charge is also conserved. In this process a gamma ray transforms into an electron and a positron:

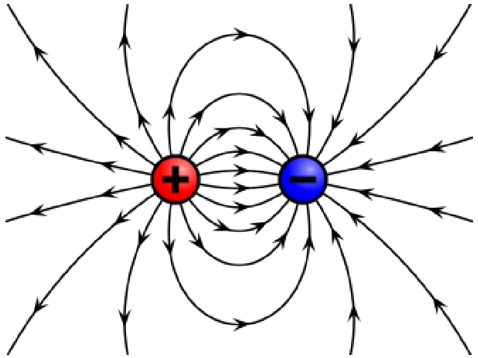
$$\gamma \rightarrow e^- + e^+ \quad \text{(pair production)}. \tag{21-15}$$

Electric Force

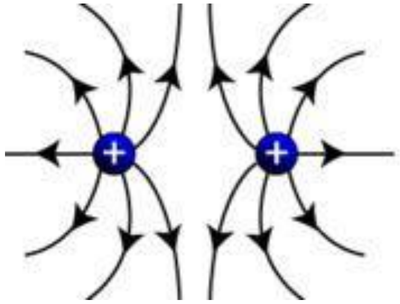
The electric force on a charged body is exerted by the electric field created by *other* charged bodies.

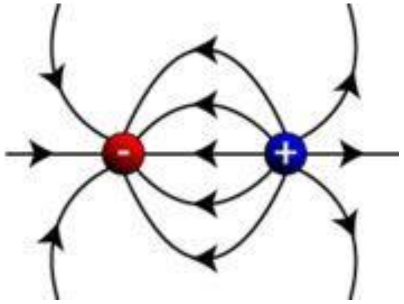
- ❑ The force acts without physical contact between the two objects
- ❑ The force can be either attractive or repulsive

$$\text{When two charged bodies are brought together} = \begin{cases} \text{positive - positive} & \text{repel} \\ \text{negative - negative} & \text{repel} \\ \text{positive - negative} & \text{attract.} \end{cases}$$



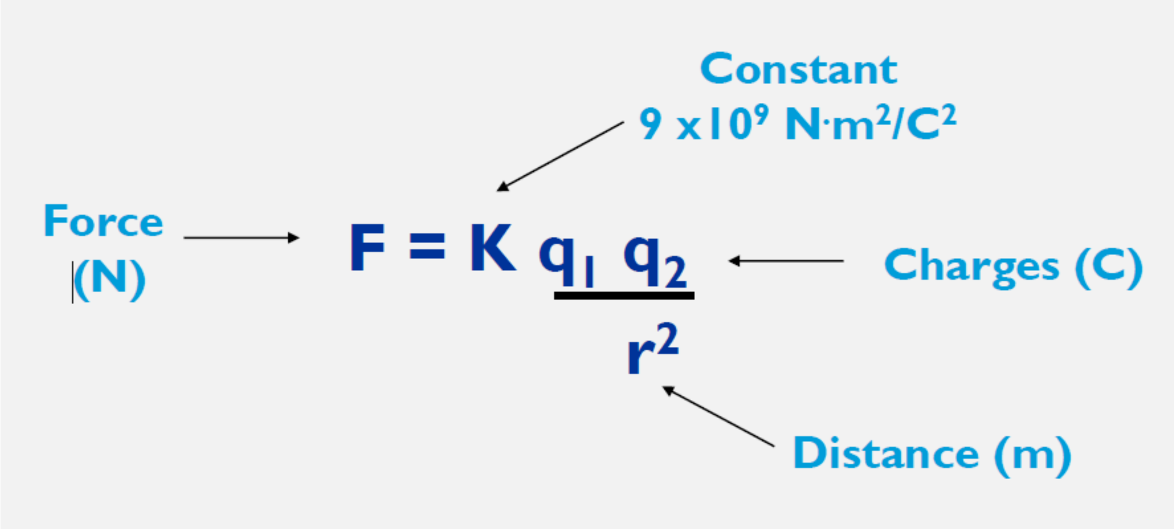
Electric field lines help visualize the electric field. Field lines begin on a positive charge and terminate on a negative charge. Electric field lines are parallel to the direction of the electric field





Coulomb's Law

The electrostatic force between two charged object is directly proportional to the product of the amount of charges and inversely proportional to the square of the distance between them



$$k = \frac{1}{4\pi\varepsilon_0}$$

- *Experimental law*
- *Valid for point charges only*
- *Obeys Inverse Square Law*
- *Valid for only charges at rest*

$$Electrostatic\ constant, k = 9 \times 10^{9}\ \frac{Nm^2}{C^2}$$

$$Permittivity\ constant, \varepsilon_0 = 8.854 \times 10^{-12}\ \frac{C^2}{Nm^2}$$

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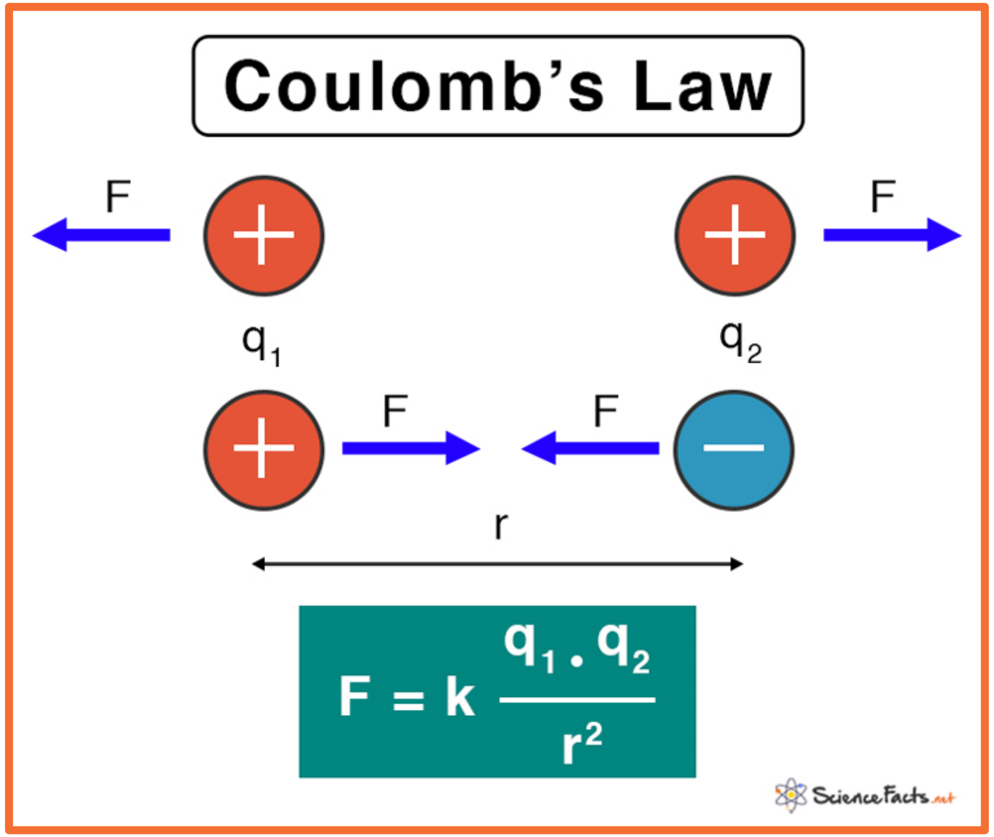
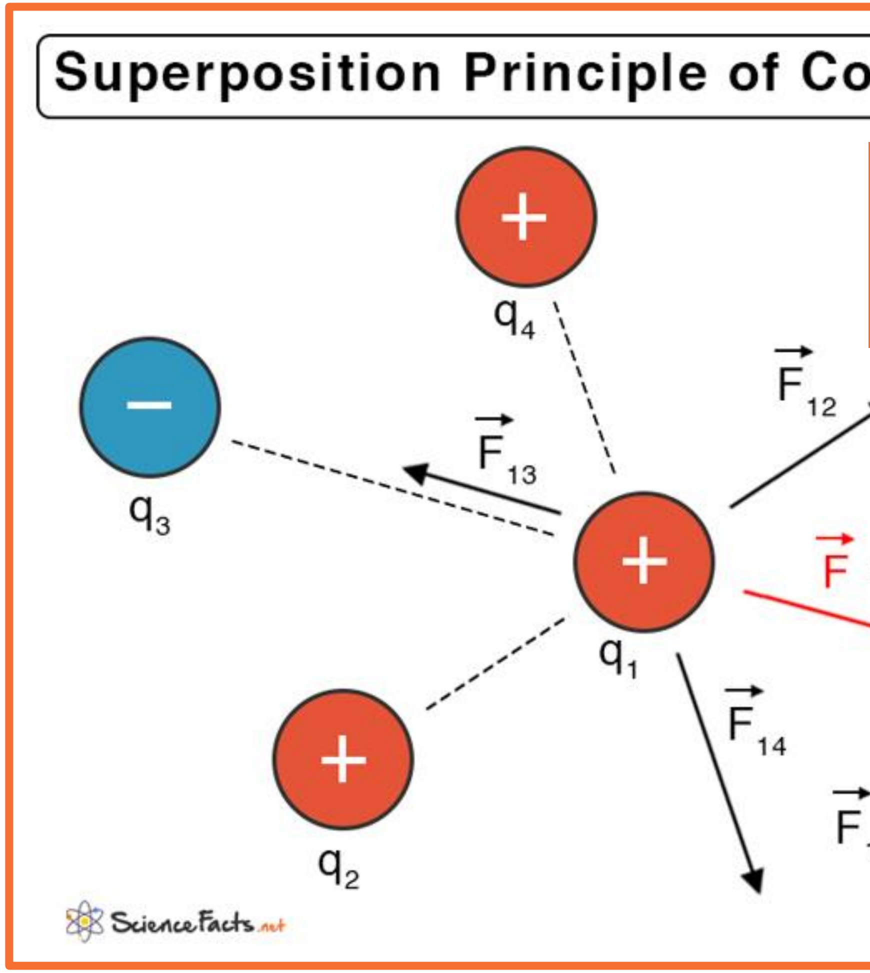
Coulomb’s Law: Superposition





$$\overrightarrow{F_{ij}} = \sum_{\substack{i=1 \\ i \neq j}}^{N} \frac{k q_i q_j}{{r_{ij}}^2}$$

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Basic Properties of Electrostatics

- Like charges repel, opposites attract
- The algebraic sum of all electric charges in any closed system is constant [***Conservation***]
- The magnitude of charge of an electron or proton is the natural fundamental unit of charge [***Quantization***]
- The electric force on a charged object is exerted by the electric field created by other charged objects

Example 11.1

A positive charge of 6×10^6 C is 0.040 m from a second positive charge of 4×10^6 C. Calculate the force between these charges.

Example 11.2

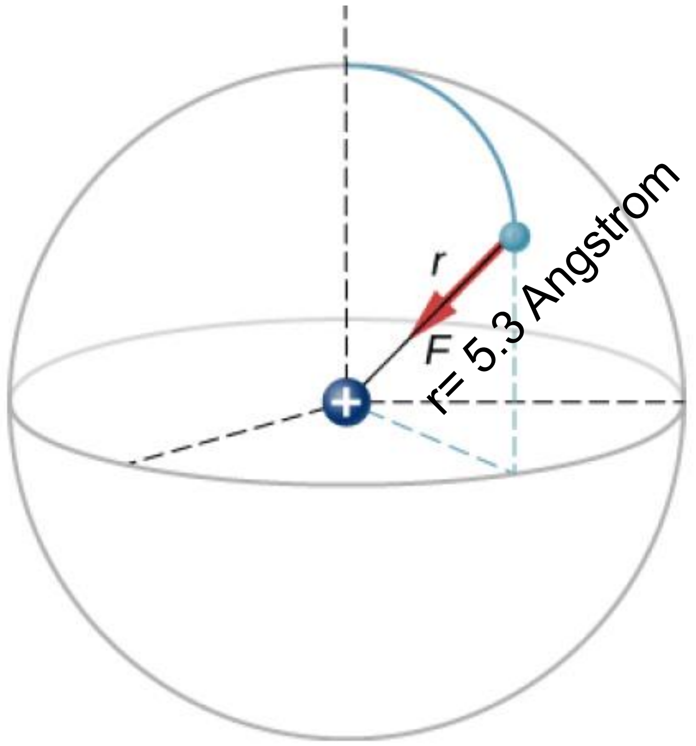
The nucleus in an iron atom has a radius of about 4.0x10^-15 m and contains 26 protons.

(a) What is the magnitude of the repulsive electrostatic force between two of the protons that are separated by 2.0x10-15 m?

(b) Which force is stronger between the two protons: electrostatic force or gravitational force? Justify your answer.

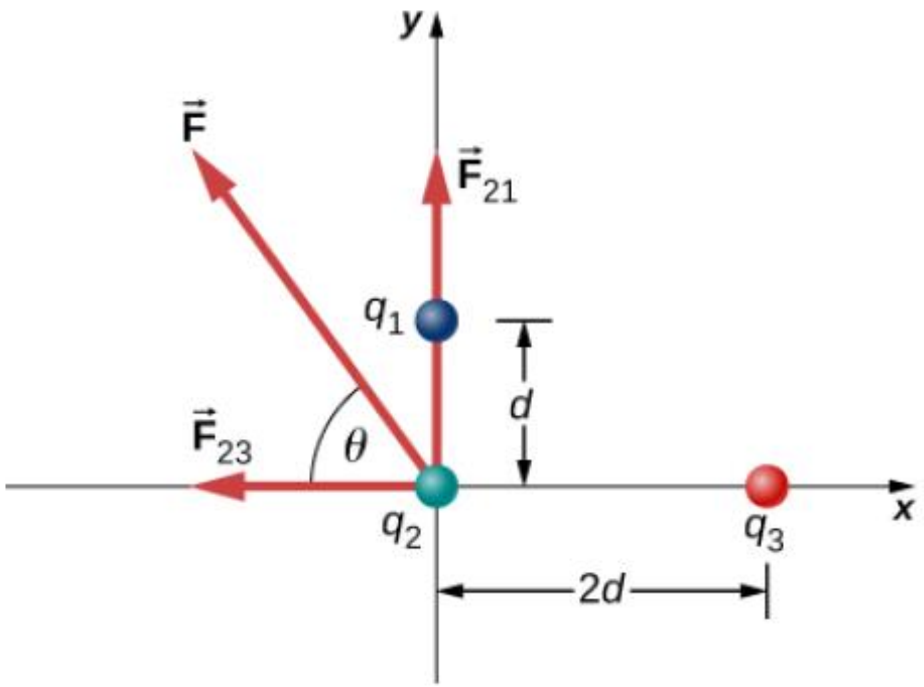
Example 11.3

Calculate the electric force on the sole electron of a Hydrogen atom shown in the following figure.



Example 11.4

The charges q1 and q2 are fixed in place; q3 is free to move. Given q1=2e, q2=-3e, and q3=-5e, and d= 200nm, what is the net force on the middle charge q2?



F= 4.08x10^-14 N at angle -58°


That's all Folks!