Chapter 5

Four fundamental forces of nature:

1. gravity
2. electro-magnetism
3. strong nuclear
4. weak nuclear

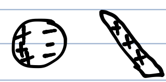
electromagnetic and weak force unified in 1967 → "electroweak"

Grand Unified Theory

electric charge

2 suspended objects → like charges repel, opposites attract

single metal ball → can get an induced charge w/out touching it

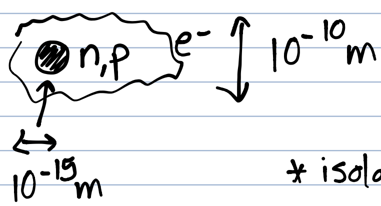


Caveat: some of these demos involve a <u>net</u> charge

You and I have an incredible amount of positive and negative charges, but usually they cancel – we are usually neutral.

typically, $\frac{\text{net charge}}{\text{total charge}} \sim 10^{-12}$

Atomic building blocks



	mass	charge
proton	m_p	$+1q$
electron	$m_p/1836$	$-1q$
neutron	$\sim m_p$	neutral

$q = 1.60 \cdot 10^{-19} C$

* isolated charges only come quantized in units of q → can't observe fractional charges [but we believe that p and n are comprised of "up" and "down" quarks, with charges $+\frac{2}{3}q$ & $-\frac{1}{3}q$]

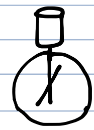
conductors and insulators

Q: Why are some objects more easily ionized than others?

A: Matter that easily transfers electrons is a <u>conductor</u> — tap water, copper wiring

A perfect insulator does not transfer charge → e^- can't move

styrofoam
chemically pure H_2O

demo  Note that excess charge resides on the <u>surface</u> of conductors

Q: Two identical metal spheres are mounted on insulating stands. How could you get them to have <u>exactly</u> the same net charge?

A: charge one ball and then momentarily touch them together

<u>ActivPhysics simulation 11.1</u>

We learned:

- electric force between two charges falls with distance as r^{-2}
- force proportional to product of the charges

$$F_e \propto \frac{|q_1 q_2|}{r^2} \quad \text{Coulomb's Law}$$

Believe it or not, the constant of proportionality is $k_e = \frac{1}{4\pi\epsilon_0} \sim 9.0 \cdot 10^9 \, \frac{N m^2}{C^2}$

Conceptually similar to gravity: $F_g = \frac{G m_1 m_2}{r^2}$

Take 2 e^- a distance r apart:

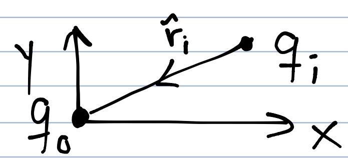
$$\frac{F_e}{F_g} = \frac{\frac{1}{4\pi\epsilon_0}|e^- e^-|/r^2}{G m_e m_e / r^2} = 10^{42}$$

So why does gravity dominate in so many (cosmic) instances?

<u>Principle of Superposition</u>

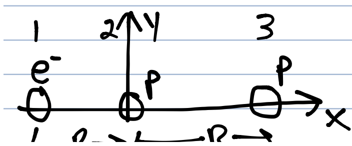
If q_0 is a test charge at the origin, then the total electric force on q_0 due to N charges is

$$\vec{F}_{total\ on\ q_0} = \sum_{i=1}^{N} \vec{F}_{q_i\ on\ q_0} = \sum_{i=1}^{N} \frac{1}{4\pi\epsilon_0} \frac{q_0 q_i}{r_i^2} \hat{r}_i$$



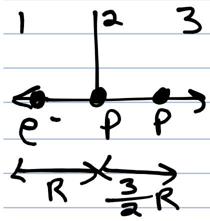
$\hat{r} = \frac{\vec{r}}{r}$

<u>example</u> What is the net electrostatic force on the central proton?



$$\vec{F}_{total\ on\ 2} = \vec{F}_{1\ on\ 2} + \vec{F}_{3\ on\ 2} = \frac{1}{4\pi\epsilon_0} \frac{|e^2|}{R^2}(-\hat{\imath}) + \frac{1}{4\pi\epsilon_0} \frac{|e^2|}{R^2}(-\hat{\imath})$$

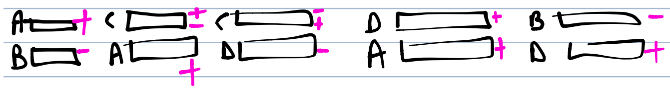
$$= \frac{-2}{4\pi\epsilon_0}\frac{|e^2|}{R^2}(\hat{\imath})$$



$$\vec{F}_{total\ on\ 2} = \vec{F}_{1on2} + \vec{F}_{3on2}$$

$$= \frac{Ke^2(-\hat{\imath})}{R^2} + \frac{Ke^2(-\hat{\imath})}{9/4\,R^2} = \frac{-13}{9}\frac{Ke^2}{R^2}(\hat{\imath})$$

s1.html



S2.html (B) i > iii > ii

Case i $F_x = \frac{K|e||e^-|}{d^2} + \frac{K|e||e^-|}{D^2} = Ke^2\left(\frac{1}{d^2} + \frac{1}{D^2}\right)$ $F_y = 0$

Case ii $F_x = \frac{-K|e||e^-|}{d^2} + \frac{K|e||e|}{D^2}$ $F_y = 0$

$$= Ke^2\left(\frac{1}{D^2} - \frac{1}{d^2}\right)$$

Case iii $F_x = \frac{K|e||e^-|}{D^2}$ $F_y = -\frac{K|e||e|}{d^2}$

$$F_{net} = \sqrt{F_x^2 + F_y^2} = \sqrt{\left(\frac{Ke^2}{D^2}\right)^2 + \left(\frac{-ke^2}{d^2}\right)^2} = Ke^2\sqrt{\frac{1}{D^4} + \frac{1}{d^4}}$$

e.g. $D = d = 1 \Rightarrow$ $2Ke^2$ (i), 0 (ii), $\sqrt{2}\,ke^2$ (iii)