Electric Charge

"Dangerous, therefore, is it to take shelter under a tree, during a thunder-gust. It has been fatal to many, both men and beasts."

- *Benjamin Franklin*

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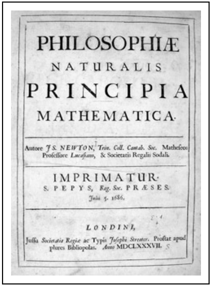
PHYS 212

Review

- Pre-requisite: Mechanics (PHYS 211)
- We learned all about the contributions of Newton:



- Position: $\vec{r}(t)$, Velocity: $\vec{v}(t)$ and Acceleration: $\vec{a}(t)$
- Forces: $\vec{F}_{net} = m\vec{a}$
- Momentum: $\vec{P} = m\vec{v}$

Review

- Angular position: $\vec{\theta}(t)$, Angular velocity: $\vec{\omega}(t)$ and Angular acceleration: $\vec{\alpha}(t)$
- Angular momentum: $\vec{L} = \vec{r} \times \vec{p}$ or $L = I\omega$
- Torque: $\vec{\tau} = \vec{r} \times \vec{F}$, $\vec{\tau}_{net} = I\vec{\alpha}$
- Work: $W = \vec{F} \cdot \vec{d}$
- Kinetic Energy: $K = \frac{1}{2}mv^2$
- Potential Energy:
  - Gravitational: $U_g = mgh$
  - Gravitational, large distances: $U_G = -\frac{Gm_1m_2}{r}$
  - Spring: $U_s = \frac{1}{2}kx^2$
- Conservation Laws:
  - energy
  - momentum and angular momentum

Electric Charge

From gizmodo.com, by Bertrand Kulik

- What is lightning?
- Lightning is the motion of electric charge through the air.

Electric Charge

What is charge?

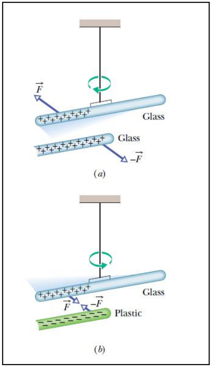
- A proton has one unit of positive charge
- An electron has one unit of negative charge
- A neutron is charge-free
- The charge on an electron (or proton) is -1.6×10^{-19} C ($+1.6 \times 10^{-19}$ C)
- The unit of charge is the coulomb, named after Charles-Augustin de Coulomb.

Electric Charge

- Glass rods hold "positive" charge
- Plastic rods hold "negative" charge
- Metallic rods can hold either

1	2											3	4	5	6	7	0
							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

Transition metals



Electric Charge

The truth about charge:

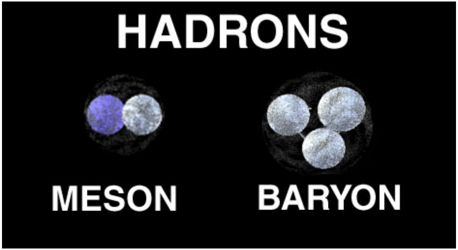
- Opposites attract: positive and negative charges pull on each other, like gravity
- Like charges repel: negative and negative or positive and positive push each other away
- The size of the charge matters: the **bigger** the charge, the **bigger** the force
- Charge and mass are unrelated; a large object may have a small charge, and a small object may have a large charge.

Charge is Quantized

Charge comes in packets of $\pm e$ (one proton/electron charge).

- An electron has charge $-e$
- A proton has charge $+e$
- A neutron has charge 0
- Most matter is made of these three constituents
- (Inside of protons and neutrons there are quarks, which have charges $\frac{2}{3}e$ and $-\frac{1}{3}e$)

Charge is Quantized



Mesons $q\bar{q}$

Mesons are bosonic hadrons.
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	−1	1.672	3/2

Charge is Quantized

Charge is not a "substance" like water or food; it is a property of an object!

Consider the following phrases:

- "Charge on a sphere"
- "Charge transferred"
- "Amount of charge"

The charge is counted/transferred by counting/transferring the particles that have the property "charge."

Charge is Conserved

We see all sorts of reactions in experiments, converting one species to another. But in each, **charge is conserved**.

Here are some examples:

- $\gamma \to e^+ + e^-$ (pair production)
- $e^+ + e^- \to \gamma + \gamma$ (annihilation)
- $^{238}\text{U} \to {}^{234}\text{Th} + {}^{4}\text{He}$ (radioactive decay)

Conductor vs. Insulator

Conductors and Insulators

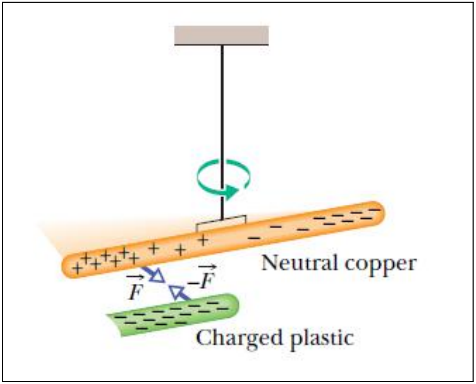
- **Conductor**: a material through which charge can move freely
- **Insulator**: a material through which charge *does not* move
- **Semiconductors**: a material that can be a conductor or an insulator, depending on the situation (At least 1 Nobel Prize, 1956)
- **Superconductor**: a material that conducts charge perfectly, with no resistance (5 Nobel Prizes, as recent as 2003)

What makes a material one or the other?

Conduction Electrons!

Conductor vs. Insulator

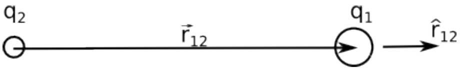
Charge is free to move on a conductor, so it moves around when a charged object is nearby:



Coulomb's Law

How do we determine the forces involved in charge interactions? Let's first define some variables:

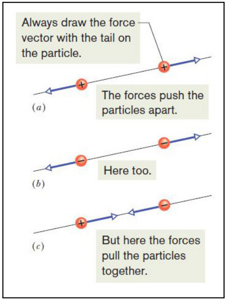
- Charge is q
- The distance between two objects 1 and 2 is r_{12}
- The unit vector, pointing to charge 1 from charge 2 is $\hat{r}_{12}$ (so $\vec{r}_{12} = r_{12}\hat{r}_{12}$).



- We also need to know the universal constant: $\epsilon_0 = 8.85 \times 10^{-12}$ F/m called the **vacuum permittivity** or **electric constant**.

Coulomb's Law

Consider two "point charges":



The force on charge 1 from charge 2 is just:

$$\vec{F}_{12} = k\frac{q_1 q_2}{r_{12}^2}\hat{r}_{12} \quad (1)$$

where $k = 1/4\pi\epsilon_0$.

Coulomb's Law

If you replace k with G, and the q's with m's, we have gravity:

$$\vec{F}_{12} = G\frac{m_1 m_2}{r_{12}^2}\hat{r}_{12} \tag{2}$$

In fact, just like with gravity, these forces obey the principle of superposition:

$$\vec{F}_{net} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + ... + \vec{F}_{1n} \tag{3}$$

This is the force on charged particle 1 from all the other charged particles nearby.