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Intro to E & M,

ALL of E & M is contained in the following equations

$$\nabla \cdot \vec{E} = \rho / \epsilon_0$$

$$\nabla \times \vec{E} = -\partial \vec{B} / \partial t$$

$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{B} = \frac{1}{c^2} \frac{\partial \vec{E}}{\partial t} + \frac{1}{c^2 \epsilon_0} \vec{j}$$

we will no longer look at these beautiful equations & instead focus on the algebraic results of the Equations applied to various situations. My hope is that you will someday dig into Maxwell's eqs & admire the beauty of what was accomplished in the 1800's

History

E & M has fascinated humanity for thousands of years. Gods of E & M were worshipped & feared. People were struck down by bolts from the sky; villages burned. Mysticism abound!

Thales of Miletus was one of the first philosophers to think deeply about E & M in 600 BCE.

Confusion ruled the subject without careful experimentation until the 1800s. Probably the first systematic use of E&M was in the Iraq area between 200 BCE - 200 AD with the so called "Bagdad Battery" whose purpose is unknown but may have been used for electroplating.

It ~~not~~ would not be until the Enlightenment in Europe that a scientific approach to E&M would begin. Gilbert in the 1600s showed the fundamental difference b/w magnetism & static electricity, and introduced the word electricity to humanity.

In the 1700s Franklin came up with the idea of charged & performed experiments that showed lightning was an electrical phenomenon!

After ~~Frank~~ Franklin research exploded & mathematical physics of E&M slowly built up. Myriad scientists in the 1800s would create the phenomenological theory of E&M. I shall only list them:

~~1799 - ~~Volta's~~ Volta's battery~~

1752 - Franklin's kite

1780 - Galvani - electro-corrosion

* 1785 - Coulomb - Coulomb's law

1800 - Volta's Battery

1804 - ~~wave~~ Young - wave theory of light

1808 - ~~eto~~ Dalton - atomic theory

1816 - Ronalds - telegraph

* 1820 - Oersted - changing $\vec{E}$ -field creates $\vec{B}$

* 1820 - Ampere - Ampere's Law explaining Oersted

1825 - Sturgeon - electro magnet

* 1827 - Ohm - Ohm's law

* 1831 - Faraday - induction law, Field concept

* 1833 - Faraday - electrolysis, thermistor

* 1845 - Kirchhoff - Kirchhoff laws

★ 1862 - Maxwell - Maxwell's Laws ★

every thing else to follow were consequences
 $\S$ inventions from Maxwell's Laws.

Maxwell is the Newton of $\vec{E} \& \vec{M}$.

Intro to $\vec{E} \propto M$

When we studied gravity we found that the force b/w two objects is related to the product of ~~mass~~ a quantity we call "mass". We all have an intuitive understanding of mass but when we think deeper on it we come to find it being a very abstract concept. It is some number, which is conserved, that turns out to be handy in describing the happenings in our universe.

$$F_g = -G \frac{m_1 m_2}{r^2}$$

This was Newton's brilliant insight (among others!) one might argue that mass is the most important idea here!

Benjamin Franklin began studying Electricity in 1742 & was lead to postulate the existence of a quantity "carried" by matter called "charge". He viewed this as a fluid but we atomists know better!

it so happens that charge is very much analogous to mass but it is much different!

The value of a charge can be positive or negative. We define a single unit of electric charge as the amount carried by an electron

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

where C is a new unit of nature we call the Coulomb (Koo-lohm).

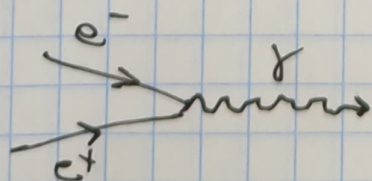
Benjamin Franklin, while knowing nothing of electrons, defined their presence to be associated with Negative charge. This was an arbitrary (and unfortunate) choice but we have stuck with it!

Now, if the electron is negatively charged then its electric "opposite" will have positive charge.

The object with the same mass but exactly opposite charge of the electron is called the "positron"

if an electron collides with a positron then they will disappear & create a large energy in the form

of light



light (γ) has zero charge.

every object we know of in our universe has either positive, negative, or zero charge.

	charge	mass
e^-	$-1 q_e$	0.5 MeV
e^+	$+1 q_e$	0.5 MeV
proton	$+1 q_e$	938 MeV
neutron	0	940 MeV
light	0	0
up quark	$+\frac{2}{3} q_e$	2. MeV
down quark	$-\frac{1}{3} q_e$	4.7 MeV

Now, it turns out that charges will interact and attract or repel each other.

In the 1780's Coulomb was lead via experiments the the very familiar equation for the force b/w two charges

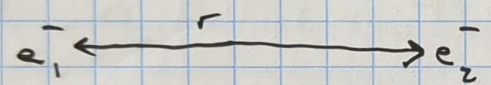
$$F_e = k \frac{q_1 q_2}{r^2}$$

where k is a fundamental constant of nature.

This is known as 'Coulomb's law' & it has tantalized generations of ~~physicists~~ physicists ever since.

Recall, if a force is negative then the two objects will attract (like gravity) & if it is positive they will repell.

lets see for two electrons.



the charge of an electron is $-q_e$

plugging in

$$F_e = k \frac{(-q_e)(-q_e)}{r^2} = \frac{k q_e^2}{r^2}$$

k is positive & r^2 is certainly positive, therefore the electrons will repell each other,

similarly for an electron & proton we have

$$F_e = - \frac{k q_e^2}{r^2}$$

they will attract.

(7)

We notice an amazing similarity b/w gravity and this new force b/w charges

$$F_g = -G \frac{m_1 m_2}{r^2}$$

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

a natural question is "which is stronger"?

we can check using an electron & positron separated 1m

$$m_e = m_p = 9 \times 10^{-31} \text{ kg} \approx 10^{-30} \text{ kg}$$

$$q_e = -q_p \quad q_e = 1.6 \times 10^{-19} \text{ C} \approx 2 \times 10^{-19} \text{ C}$$

$$F_g = -G \frac{10^{-30} 10^{-30}}{1^2} = -G 10^{-60}$$

$$F_e = -k \frac{2 \times 10^{-19} \times 2 \times 10^{-19}}{1^2} = -4k 10^{-38}$$

$$\text{but } G = 6.7 \times 10^{-11}$$

$$\& \quad k = 8.8 \times 10^{-12}$$

$\therefore$

$$F_g = -6.7 \times 10^{-71}$$

$$F_e = -35 \times 10^{-29}$$

The electric force is MASSIVELY greater than gravity! by some 42 orders of magnitude!

How funny! If we are made of electrons and protons then why don't we "feel" this everyday like we do gravity!?

It turns out that all the charges in our bodies & most matter nicely "cancel" out. the number of electrons in our body equals the number of protons (on average).

If this careful balance were upset even a little then you would have some problems!

If you had just 1% more electrons than protons then the total repelling force would be enough to lift the ENTIRE EARTH!

Now, like mass, charge is conserved.

if we keep careful counts of charges before and after some process then the total count stays the same. if we create an electron out of thin air then there MUST be a positron created in order to balance mass & charge.

Types of Matter

From experience you know there are two main types of matter: those that allow charge to freely move & those that don't like charge to freely move.

We call these "conductors" & "insulators". Tap water is a very good conductor & we've all been warned early on to be careful of electricity & water.

The earth itself ~~is~~ is a very good conductor and often we use it as a reservoir for charge.

Charge can move from one object to another in a variety of ways. we will see examples of this in the lectures to come.

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