CHARGE - ELECTROSTATIC (COULOMB FORCE)

So for our economical description of the universe (which we began on the first day of PHYS121) has been based on the four fundamental dimensions

Length (L)
Time (T)
Mass (M)
and Temperature (Θ)

and the only fundamental force we have studied is Newton's Universal Gravitational force between two point masses:

$$\underset{\rightarrow}{F_G} = -\frac{GM_1M_2}{r^2}\hat{r}$$

with

$$G = 6.7 \times 10^{-11}\frac{N-m^2}{(kg)^2}$$

And its application to spherical masses (planetary motion and Earth satellites).

To proceed further, we need to introduce a "5^{th}" player in order to describe our Universe.

$\longrightarrow$ CHARGE $\longleftarrow$

The assertion is that in addition to mass (M), matter has another intrinsic property called charge (Q).

QTY	Dimension	Unit	S/V
Charge	Q	Coulomb (C)	Scalar

Properties of Charge

1. Charge can be positive or negative (the names were proposed by Ben Franklin and are now universally adopted). This was shown by simple experiments we did in the class using friction to "charge" rods – glass rod rubbed with silk repels another glass rod similarly charged. However, plastic rod rubbed with fur will attract the rubbed glass rod. You can, of course, "charge" yourself, especially during winter when heated homes are very dry, by walking up and down on a carpet or by "brushing" your hair with a dry comb. In either case sparks are observed when the split charges in the air molecules recombine: In class the Van de Graaf generator did the trick.

2. Charge is quantized: All charges are integer multiples of a fundamental charge of

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

That is the charge on any object can be expressed as

$$Q = [N_+ - N_-] \times 1.6 \times 10^{-19} C$$

Where N_+ is the number of positive charges and N_- is the number of negative charges. Let us make a table of elementary charges

	Mass	N	Charge
Electron	9×10^{-31} Kg	$N_- = 1, N_+ = 0$	-1.6×10^{-19} C
Positron	9×10^{-31} Kg	$N_- = 0, N_+ = 1$	$+1.6 \times 10^{-19}$ C
Proton	1.6×10^{-27} Kg	$N_+ = 1, N_- = 0$	$+1.6 \times 10^{-19}$ C
Antiproton	1.6×10^{-27} Kg	$N_- = 1, N_+ = 0$	-1.6×10^{-19} C
Neutron	$m_N > m_P$	$N_- = N_+$	0
Atom		$N_- = N_+$	0
Na^+ (ion)		Sodium atom with one electron removed	$+1.6 \times 10^{-19}$ C
Cl^- (ion)		Chlorine atom with one electron added	-1.6×10^{-19} C
Any Neutral Object		$N_- = N_+$	0

3. Charge is conserved:
The total amount of charge is constant. Charge cannot be created or destroyed. Of course, because of two signs charges can be created in pairs

$$Q = 0 \rightarrow \text{(Electron + Positron)}$$
$$Q = 0 \rightarrow \text{Proton + Antiproton}$$

4. Like charges repel, unlike charges attract one another – Coulomb's law will be discussed in great detail later.

Charges in Matter

Although full details will be developed later, it is useful at this stage to recognize the following:

Conductors – mostly metals – consist of positive ions which have large masses and are essentially constrained to vibrate about their equilibrium positions and electron which are relatively free to move throughout the material. [Electrolytes and the cells in biological systems actually have mobile ions suspended in a liquid host.]

Insulators have no mobile electrons. All the electrons are strongly bound to their parent atoms/molecules – NaCl $(Na^+ + Cl^-)$ is a common case.

Grounding

The earth is a large conductor and since like charges repel, any charges placed on Earth will spread over its enormous surface and hence connecting any charged conductor (spheres in pictures below) to Earth using a conductor will cause the object to be discharged: Grounded

Coulomb Force

The force between two point charges located at a distance r from one another bears a striking resemblance to the Gravitational force – it is also proportional to the two charges, it also varies as $\frac{1}{r^2}$ and it also acts along the line joining Q_1 and Q_2. It is called the Coulomb force

$$\underset{\longrightarrow}{F_E} = \frac{K_e Q_1 Q_2}{r^2} \hat{r}$$

with

$$k_e = 9 \times 10^9 \frac{N-m^2}{C^2}$$

However notable differences are:

If Q_1, Q_2 have the same sign (like charges)

$$\underrightarrow{F_E} \parallel +\hat{r}$$

And will push Q_1, Q_2 apart:

REPLUSIVE force

If Q_1, Q_2 have opposite signs (unlike charges)

$$\underrightarrow{F_E} \parallel -\hat{r}$$

Pulls Q_1, Q_2 together:

ATTRACTIVE force

It is instructive to compare the Gravitational force and the Coulomb force between a proton and an electron separated by $0.5\times10^{-10}\,m$, the radius of the hydrogen atom

Gravitational Force	Coulomb Force
$\underrightarrow{F_G} = -\dfrac{6.7\times10^{-11} \times 1.6\times10^{-27} \times 9\times10^{-31}}{(0.5\times10^{-10})^2} N\hat{r}$	$\underrightarrow{F_E} = \dfrac{-9\times10^{9} \times 1.6\times10^{-19} \times 1.6\times10^{-19}}{(0.5\times10^{-10})^2} N\hat{r}$

Both are attractive but the electrostatic force is much bigger:

$\underrightarrow{F_E}$ is larger by a factor of $\underline{10^{39}}$!

<u>Note</u>

For a given r:

(Magnitude of $\underrightarrow{F_E}$ between two protons)

= (Magnitude of $\underrightarrow{F_E}$ between two Electrons)

= (Magnitude of $\underrightarrow{F_E}$ between Electron and Proton)

The only difference is that in the first two cases $\underrightarrow{F_E} \parallel +\hat{r}$ (repulsion) and in the last case $\underrightarrow{F_E} \parallel -\hat{r}$ (attraction)!