Electricity & Magnetism

* Fundamental Forces of Nature

1) Strong Nuclear Force (Short Range)
2) Electromagnetic Force (Long Range)
3) Weak Nuclear Force
4) Gravitation (Feeble/Weakest)

* CHAPTER 21: Coulomb's law

Charge:
- Intrinsic/physical property of matter that causes it to experience a force when it is placed in an EM field.
- In an ED, objects interact through a field. So, to describe the ability of an object to generate EM to fill this field, we introduce the charge.
- Electric charge is thought of as the source of electric force, just as mass is the source of gravitational force.
- Attractive, Repulsive, Zero (Neutral)
- SI unit: Coulomb (C)

Fundamental Value: $e = 1.60 \times 10^{-19}$ C

Charge $q = ne >$ integer
Charges

\[ \begin{array}{c}
-ve \\
+ve
\end{array} \rightarrow \text{ions (deficiency \& excess of electrons)} \]

* Charge Quantization & Conservation

- Particles and anti-particles

  By convention, particles have electric charges that are opposite to those of corresponding particles.

  E.g., electron has \(-e\) charge (particle)\n
  Anti-electron (positron) has \(+e\) charge (anti-particle)

- In the leptons frame of reference, all the known particles have charges that are some integer multiple of the fundamental charge.

\[ 0, \pm e, \pm 2e, \pm 3 \text{ etc.} \]

Why no other charges? Mystery for which classical physics offers no explanation.

\[ \Rightarrow \text{Charges exist in discrete packets} \]

\[ \Rightarrow \text{charge is quantized} \]

\[ \Rightarrow \text{discretized.} \]
Charge Conservation

"Total charge before and after the reaction are always same"

e.g.,
(i) matter - anti-matter annihilation
\[
\text{[electron]} + \text{[anti-electron]} \rightarrow 2 \text{[Photons]}
\]
charges: \(e^- + e^+ \rightarrow 0\)

(ii) lead-acid battery
\[
Pb + \text{SO}_4^{2-} \rightarrow PbSO_4 + 2 \text{[electrons]}
\]
charges: \(0 + (-2e) \rightarrow 0 + (-2e)\)

Conductors and Insulators

(i) Conductors: Charge can move. e.g., metals (Iron, Lead)
(ii) Non-conductors (Insulators): e.g., Plastic, Rubber
(iii) Semi-conductors: Intermediate e.g., Silicon, Germanium
(iv) Super-conductors: Perfect conductors.

For a conductor, charge can move freely and find an equilibrium distribution.

For an insulator, charge cannot move freely and easily.

Changing by Induction: Electrostatic Induction.
Coulomb's law

- Empirically discovered law
  - Based on repeated observations

- **Point charge**
  - charge with volume $\rightarrow 0$

- The distance $\propto$ changes $\gg$ radius of charges

**Statement**

hypothetical axis

\[ F_{21} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2} \]

Consider these charges are embedded into a matrix/rigid framework so that these cannot move but they exist.

- Limitations: (i) Point charges (ii) Rest charges
- Also called Inverse square law.

Here

\[ \varepsilon_0 : \text{Permitivity of free space} \sim 8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2 \]

- Capability of the vacuum to permit Electric field lines
Some authors say $\frac{1}{4\pi \varepsilon_0} = R \sim 9 \times 10^9 \text{N m}^2/\text{C}^2$

Now

$$F_{12} = \frac{1}{4\pi \varepsilon_0} \frac{q_1 q_2}{r^2} (-\hat{r}) = -F_{21}$$

Force on charge 1 due to 2.
\[ F_{21} = -F_{12} \]

\Rightarrow Forces are equal but opposite in direction and they act on different objects, so it is just the manifestation of Newton's 3rd law.

- Principle of Superposition

- If we have \( n \) charged particles, they interact independently in pairs, and force on any one of them, let us say particle 1 is:

\[ F_{1, \text{net}} = F_{12} + F_{13} + F_{14} + \ldots + F_{1n} \]