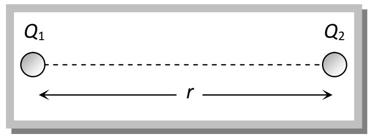
Coulomb's Law.

If two stationary and point charges Q_1 and Q_2 are kept at a distance r, then it is found that force of attraction



or repulsion between them is $F \propto \frac{Q_1 Q_2}{r^2}$ i.e., $F = \frac{kQ_1 Q_2}{r^2}$; (k = Proportionality constant)

(1) **Dependence of k:**Constant k depends upon system of units and medium between the two charges.

(i) **Effect of units**

(a) In C.G.S. for air $k = 1,$ $F = \frac{Q_1 Q_2}{r^2}$ Dyne

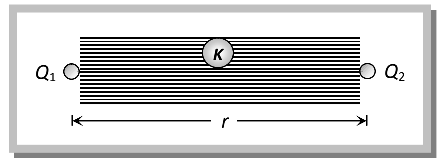
(b) In S.I. for air $k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \frac{N-m^2}{C^2}$, $F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Q_1 Q_2}{r^2}$ Newton (1 Newton = 10^5 Dyne)

Note: $\varepsilon_0 =$ Absolute permittivity of air or free space = $8.85 \times 10^{-12} \frac{C^2}{N-m^2} \left(= \frac{Farad}{m}\right)$. Its Dimension is $[ML^{-3}T^4A^2]$

ε_0 Relates with absolute magnetic permeability (μ_0) and velocity of light (c) according to the following relation $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

(ii) **Effect of medium**

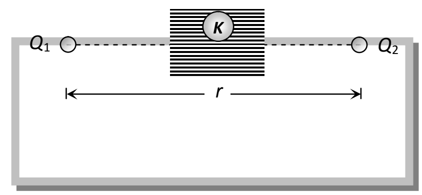
(a) When a dielectric medium is completely filled in between charges rearrangement of the charges inside the dielectric medium takes place and the force between the same two charges decreases by a factor of K known as **dielectric constant** or specific inductive capacity **(SIC)** of the medium, K is also called relative permittivity ε_r of the medium (relative means with respect to free space).



Hence in the presence of medium $F_m = \frac{F_{air}}{K} = \frac{1}{4\pi\varepsilon_0 K} \cdot \frac{Q_1 Q_2}{r^2}$

Here $\varepsilon_0 K = \varepsilon_0\, \varepsilon_r = \varepsilon$ (permittivity of medium)

(b) If a dielectric medium (dielectric constant K, thickness t) is partially filled between the charges then effective air separation between the charges becomes $(r - t + t\sqrt{K})$



Hence force $F = \frac{1}{4\pi\varepsilon_0} \frac{Q_1 Q_2}{(r - t + t\sqrt{K})^2}$

(2) **Vector form of coulomb's law:**Vector form of Coulomb's law is $\vec{F}_{12} = K.\frac{q_1 q_2}{r^3} \vec{r}_{12} = K.\frac{q_1 q_2}{r^2} \hat{r}_{12}$, where $\hat{r}_{12}$ is the unit vector from first charge to second charge along the line joining the two charges.

(3) **A comparative study of fundamental forces of nature**

S.No.	**Force**	**Nature and formula**	**Range**	**Relative strength**
(i)	Force of gravitation between two masses	Attractive $F = Gm_1m_2/r^2$, obey's Newton's third law of motion, it's a conservative force	Long range (between planets and between electron and proton)	1
(ii)	Electromagnetic force (for stationary and moving charges)	Attractive as well as repulsive, obey's Newton's third law of motion, it's a conservative force	Long (up to few kelometers)	10^{37}
(iii)	Nuclear force (between nucleons)	Exact expression is not known till date. However in some cases empirical	Short (of the order of nuclear size 10^{-15} m)	10^{39} (strongest)

		formula $U_0 e^{r/r_0}$ can be utilized for nuclear potential energy U_0 and r_0 are constant.		
(iv)	Weak force (for processes like β decay)	Formula not known	Short (upto 10^{-15}m)	10^{24}

Note: Coulombs law is not valid for moving charges because moving charges produces magnetic field also.

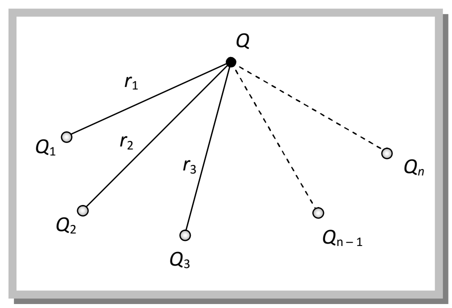
Coulombs law is valid at a distance greater than $10^{-15}\, m$.

A charge Q_1 exert some force on a second charge Q_2. If third charge Q_3 is brought near, the force of Q_1 exerted on Q_2 remains unchanged.

Ratio of gravitational force and electrostatic force between (i) Two electrons is **10^{-43}/1.** (ii) Two protons is **10^{-36}/1** (iii) One proton and one electron **10^{-39}/1**.

Decreasing order to fundamental forces $F_{Nuclear} > F_{Electromagnetic} > F_{Weak} > F_{Gravitational}$

(4) **Principle of superposition:**According to the principle of super position, total force acting on a given charge due to number of charges is the vector sum of the individual forces acting on that charge due to all the charges.



Consider number of charge Q_1, Q_2, Q_3 ...are applying force on a charge Q

Net force on Q will be

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + ... + \vec{F}_{n-1} + \vec{F}_n$$

Concepts

☞ Two point charges separated by a distance r in vacuum and a force F acting between them. After filling a dielectric medium having dielectric constant K completely between the charges, force between them decreases. To maintain the force as before separation between them changes to $r\sqrt{K}$. This distance known as effective air separation.