Electromagnetism and Modern Physics

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February 17, 2020

Preface

This is not a holy text. So if there is a mistake, solve it by your own judgement.

Contents

1 Coulomb's Law

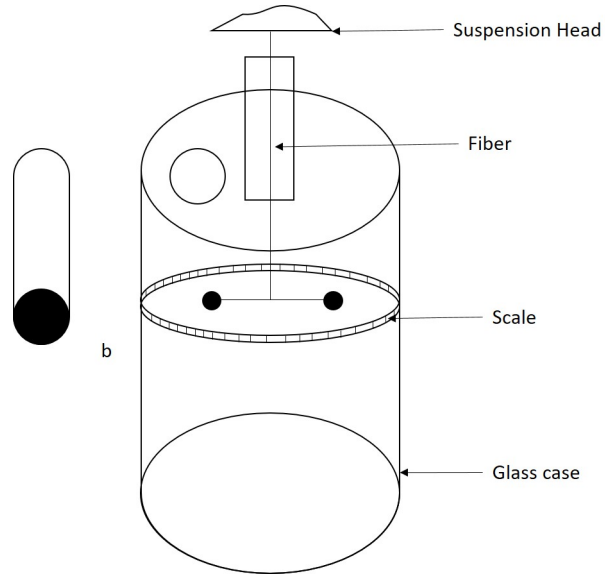## 1.1 Coulomb's Torsion Balance Experiment

Figure 1: Coulomb's torsion balance experiment

The force of attraction or repulsion between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.

The direction of the force on each charged body is always along the line joining them,

$$F \propto \frac{q_1 q_2}{r^2} \Rightarrow F = \frac{K q_1 q_2}{r^2} \left| \begin{array}{l} k = \dfrac{1}{4\pi\varepsilon_0} \\ \quad = 8.99 \times 10^9 Nm^2 C^{-2} \\ \varepsilon_0 = 8.854 \times 10^{-12} C^2 N^{-1} m^{-2} \end{array} \right.$$
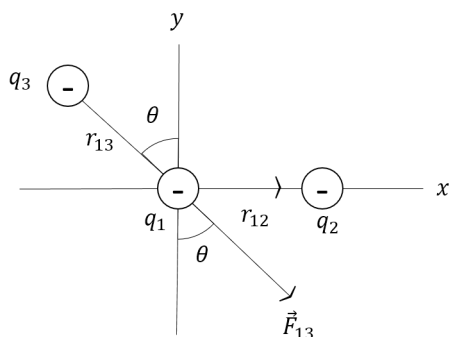
1.2 Vector form of Coulomb's Law
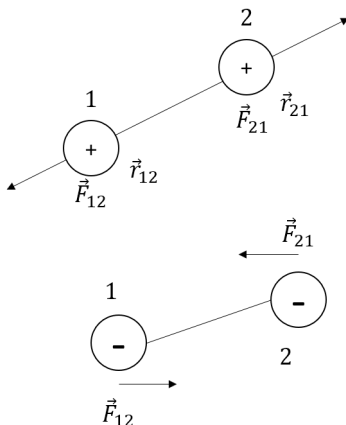
$$\vec{F} = \frac{kq_1q_2}{r^2}\hat{r}$$

$$\vec{F} = \frac{kq_1q_2}{r^3}\vec{r} \qquad \hat{r} = \frac{\vec{r}}{r}$$

Problem 1.1. Three charged particles held in places by forces (not shown in the figure). What electrostatic force owing to the other two charges acts on q_1? Where $q_1 = -1.2\mu c$, $q_2 = 3.7\mu c$, $q_3 = -2.3\mu c$, $r_{12} = 15$ cm, $r_{13} = 10$ cm and $\theta = 32°$

Solution. Let us compute the magnitudes of the forces that q_2 and q_3 exert on q_1.

$$\begin{aligned}
F_{12} &= \frac{1}{4\pi\varepsilon_0}\frac{|q_1q_2|}{r_{12}^2} \\
&= 8.99 \times 10^9 Nm^2C^{-2}\frac{|-1.2\times 10^{-6}c \cdot 3.7 \times 10^{-6}c|}{15 \times 10^{-2}} \\
&= 1.77 \text{ N}
\end{aligned}$$

Again,

$$F_{13} = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_3|}{r_{13}^2}$$

$$= 8.99 \times 10^9 Nm^2 C^{-2}\frac{|-1.2 \times 10^{-6}c \cdot -2.3 \times 10^{-6}c|}{10 \times 10^{-2}}$$

$$= 2.48 \text{ N}$$

The component of resultant forces F_1 acting on q_1 are determined by the corresponding components.

$F_{1x} = F_{12x} + F_{13x} = 1.77 + (2.48 \sin 32°) = 3.08\text{N}$
$F_{1y} = F_{12y} + F_{13y} = 0 - (2.48 \cos 32°) = -2.10\text{N}$

From the components we can find the magnitude amd direction of $\vec{F}_1$.

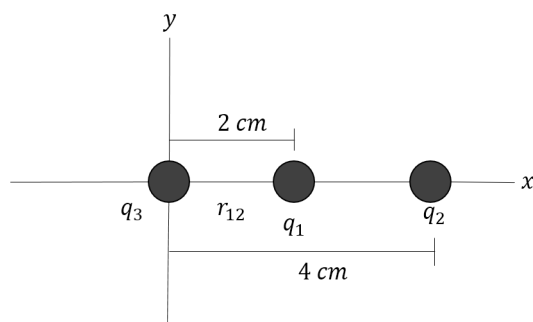$$F_1 = \sqrt{F_{1x}^2 + F_{1y}^2}$$

$$= \sqrt{3.08^2 N + (-2.10)^2 N}$$

$$= 3.73N$$

and,

$$\theta = \tan^{-1}\frac{F_{1y}}{F_{1x}}$$

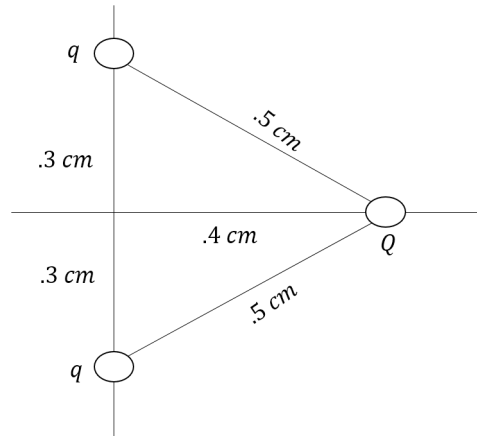$$= \tan^{-1}\frac{-2.10N}{3.08N}$$

$$= -34°$$

$\vec{F}_1$ vector makes an angle of $-34°$ with x-axis

Problem 1.2. What is the total force expected by the two charges on the charge q_3 located at origin? Where, $q_1 = 2 \times 10^{-9}$c, $q_2 = -3 \times 10^{-9}$c and $q_3 = 5 \times 10^{-9}$c.

Solution. TODO::Solve this

Problem 1.3. Find the magnitude and direction of the total force on Q. Where, $q = 20 \times 10^{-6}$c and $Q = 4.0 \times 10^{6}$c.

Solution. TODO::Solve this

1.3   Charge is Quantized

When a physical quantity such as charge exists only in discrete 'packets' rather than incontinously variable amounts we that quantity is quantized.

Any charge q can be measured from $q = ne;\ n = 0, \pm1, \pm2, \ldots$ Where e is the unit of elementary charge $e = 1.6 \times 10^{-19}$c. $q = 1.2e$ is not correct but $q = 1.2\mu c$ is correct.
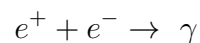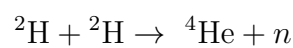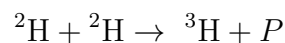
up quark has $+2/3$e and down quark has $-1/3$e charge.

Proton $\rightarrow +\dfrac{2}{3}e \times 2 + -\dfrac{1}{3}e = \dfrac{4}{3} - \dfrac{1}{3} = \dfrac{3}{3} = 1$

Neutron $\rightarrow +\dfrac{2}{3}e \times 2 + -\dfrac{1}{3} \times 2e = \dfrac{2}{3} - \dfrac{2}{3} = 0$

There is no evidence for the release of a free quark. A group of quarks are bounds so strongly in protons and neutrons and give the electrical charge in units of "e".

1.4   Charge is Conserved

$$^{2}\text{H} + {}^{2}\text{H} \rightarrow\ ^{3}\text{H} + P$$
$$^{2}\text{H} + {}^{2}\text{H} \rightarrow\ ^{4}\text{He} + n$$
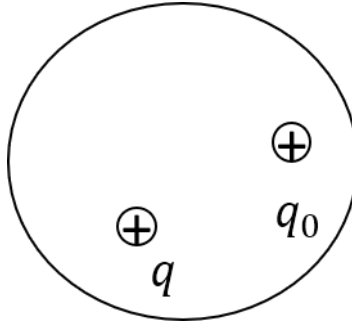$$e^{+} + e^{-} \rightarrow\ \gamma$$

2   Electric Field or Electric Field Intensity

Coulomb's law $\rightarrow$ charge $\rightleftharpoons$ charge.
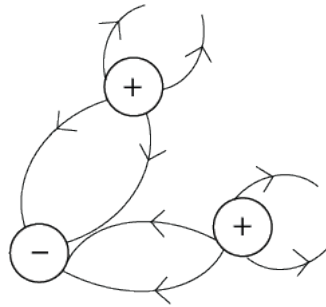Introducing the field as an intermediary between charges. charge $\rightleftharpoons$ field $\rightleftharpoons$ charge.

The first charge sets up an electric field and the second charge interacts with the electric field on the first charge.
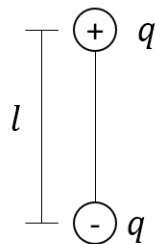
$$q_0 \!\!\!\rule[0.4ex]{1.2em}{0.4pt}\!\!\! F$$

$$1 \!\!\!\rule[0.4ex]{1.2em}{0.4pt}\!\!\! \frac{F}{q_0}$$

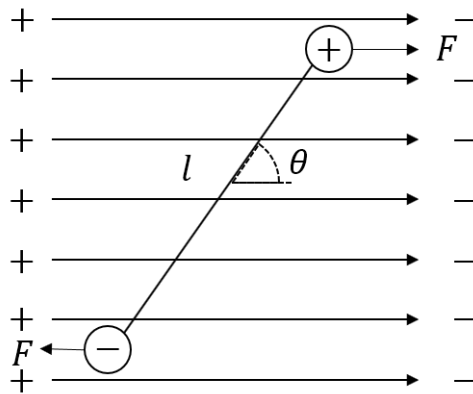$$E = \frac{F}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

3   Electric Dipole

A positive and negative charge of equal magnitude q placed a distance l apart, this configuration is called electric dipole.

4   Electric Dipole in a Electric Field

Net force zero.

There is net torque about its center of mass that tends to rotate the dipole to bring alignment with $\vec{E}$.

The magnitude of net torque,

$$\begin{aligned}
\tau &= F\frac{l}{2}\sin\theta + F\frac{l}{2}\sin\theta \\
&= F\ l\ \sin\theta \\
&= q\ E\ l\sin\theta \\
&= q\ l\ E\sin\theta \\
&= p\ E\sin\theta \\
\vec{\tau} &= \vec{p} \times \vec{E} \qquad [\because \vec{\tau} = \vec{r} \times \vec{F}]
\end{aligned}$$