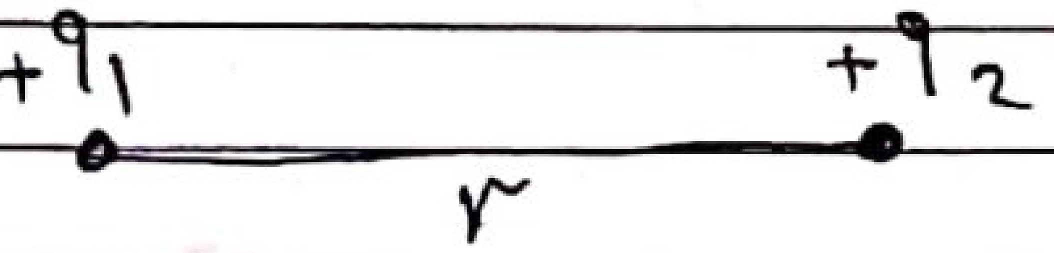
Chapter 16

Electric Forces, Fields and Potentials

☐ Coulomb's Law

the electrical force between two stationary point charges is given by Coulomb's law

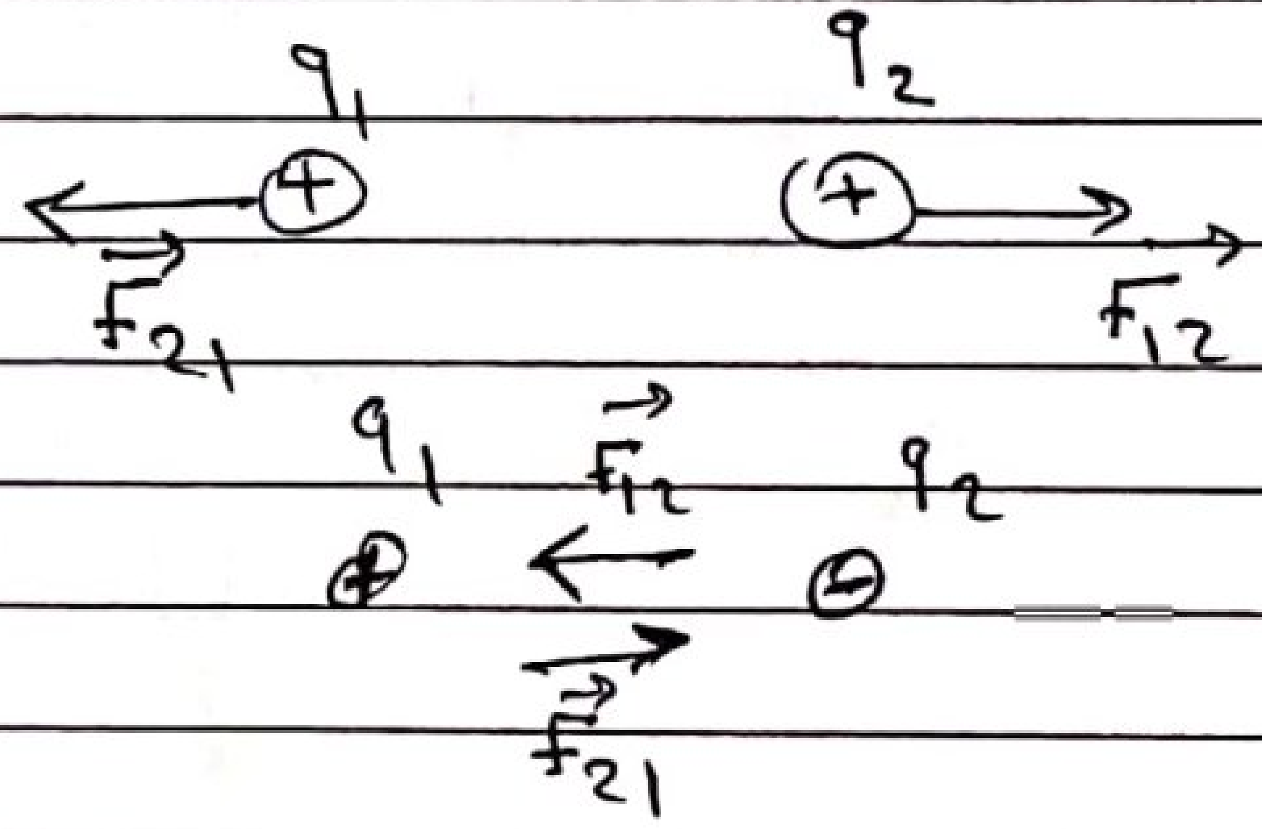
$$F = k\frac{|q_1|\,|q_2|}{r^2}$$



where $k = 9\times10^{9}\ N.m^2/C^2$ (Coulomb's constant)

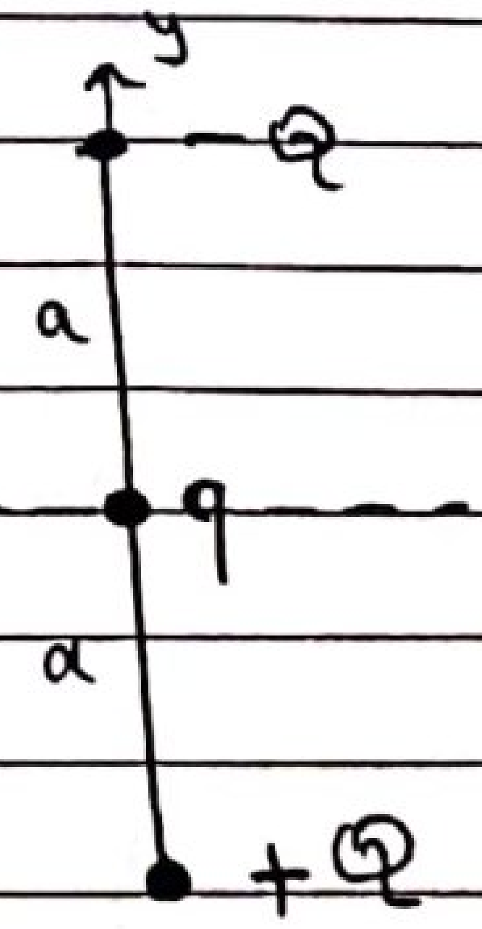
$k = \frac{1}{4\pi\varepsilon_0}$, ε_0 is permitivity of free space

$$\vec{F}_{12} = -\vec{F}_{21}$$



Example:
A positive charge Q and a negative charge $-Q$ located as shown in figure. Find their resultant force on the third charge q

$Q = 2\times10^{-6}$, $q = 1\times10^{-6}$, $a = 1\ m$



$$F_+ = \frac{kqQ}{r^2} = \frac{(9\times10^{9})(1\times10^{-6})(2\times10^{-6})}{(1)^2}$$

$$F_+ = 1.8\times10^{-2},\ \vec{F}_+ = 1.8\times10^{-2}\,\hat{y}\ N$$

$$F_- = \frac{kqQ}{r^2} = \frac{(9\times10^{9})(1\times10^{-6})(2\times10^{-6})}{(1)^2}$$

$$F_- = 1.8\times10^{-2},\ \vec{F}_- = 1.8\times10^{-2}\ N\ \hat{y}$$

$$\vec{F}_{total} = \vec{F}_+ + \vec{F}_- = 3.6\times10^{-2}\ N\ \hat{y}$$

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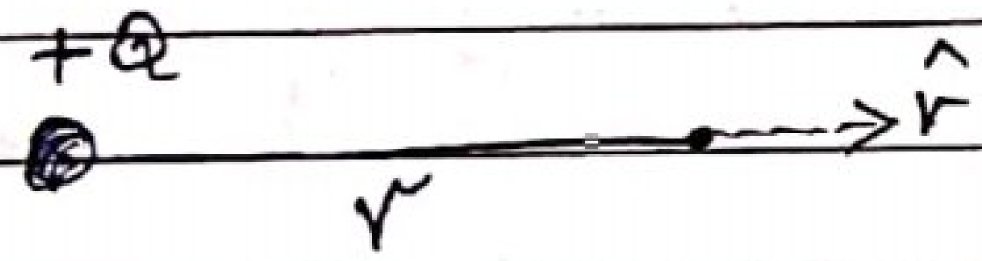
□ Electric Field: is defined as the electric Force acting on a unit positive Charge

$$E = \frac{F}{q} \text{ , the unit of } E \text{ is } N/C$$

$$E = \frac{kqQ}{qr^2} = \frac{kQ}{r^2}$$

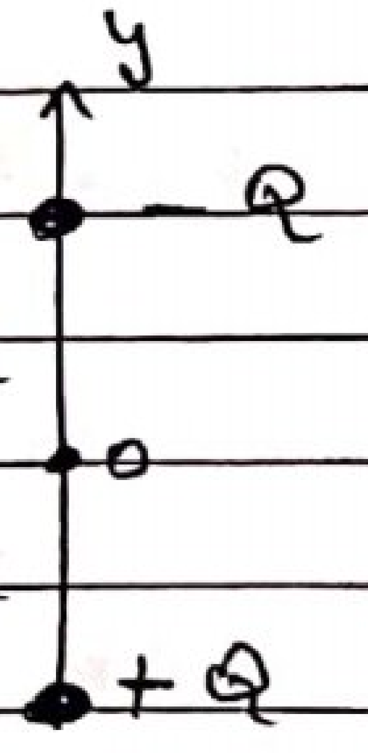
$$\vec{E} = \frac{kQ}{r^2}\hat{r}$$



if we have more than one charge the total $\vec{E}$ is the vector sum of the fields of all charges

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \dots + \vec{E}_N$$

Example:



if $Q = 2\times10^{-6}\,C$, $a = 1\,m$

a) Find the electric field at the origin

$$\vec{E}_+ = \frac{kQ}{r^2}\hat{y} = \frac{(9\times10^9)(2\times10^{-6})}{(1)^2} = 1.8\times10^4 \,\frac{N}{C}\,\hat{y}$$

$$\vec{E}_- = \frac{kQ}{r^2}\hat{y} = \frac{(9\times10^9)(2\times10^{-6})}{(1)^2} = 1.8\times10^4 \,\frac{N}{C}\,\hat{y}$$

$$\vec{E}_{total} = 3.6\times10^4 \,\frac{N}{C}\,\hat{y}$$

b) The Force on $q = 1\times10^{-6}$ at the origin

$$\vec{F} = q\vec{E} = (1\times10^{-6})(3.6\times10^4)$$

$$\vec{F} = 3.6\times10^{-2}\,N\,\hat{y}$$

Electric Potential

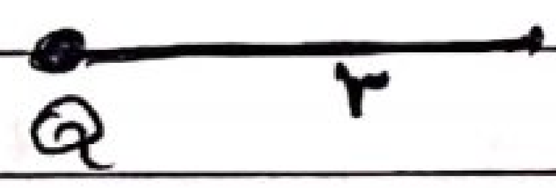
electric potential is defined as the electric potential energy divided by the charge q

$$V = \frac{U}{q}$$

it has the unit volt (V), $1V = J/c$

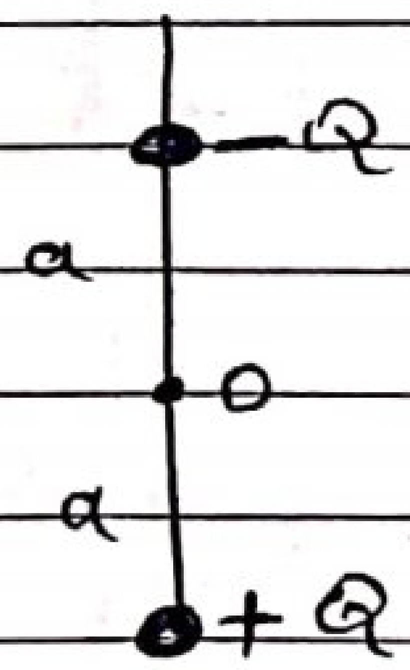
the electric potential due to a point charge is

$$V = \frac{KQ}{r}$$



Example;

Find the electric potential at the origin



$$V_+ = \frac{KQ}{r} = \frac{(9\times10^{9})(2\times10^{-6})}{1} = 1.8\times10^{4}\,V$$

$$V_- = \frac{K(-Q)}{r} = \frac{(9\times10^{9})(-2\times10^{-6})}{1} = -1.8\times10^{4}\,V$$

$$V_{tot} = \text{zero}$$

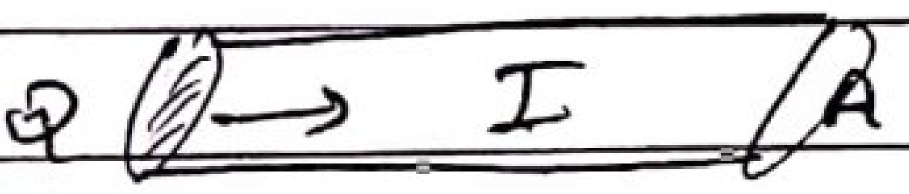
$Q = 2\times10^{-6}\,C$
$a = 1m$

Chapter 17
Direct Currents

- **Electric current:** is defined as rate of change of charge

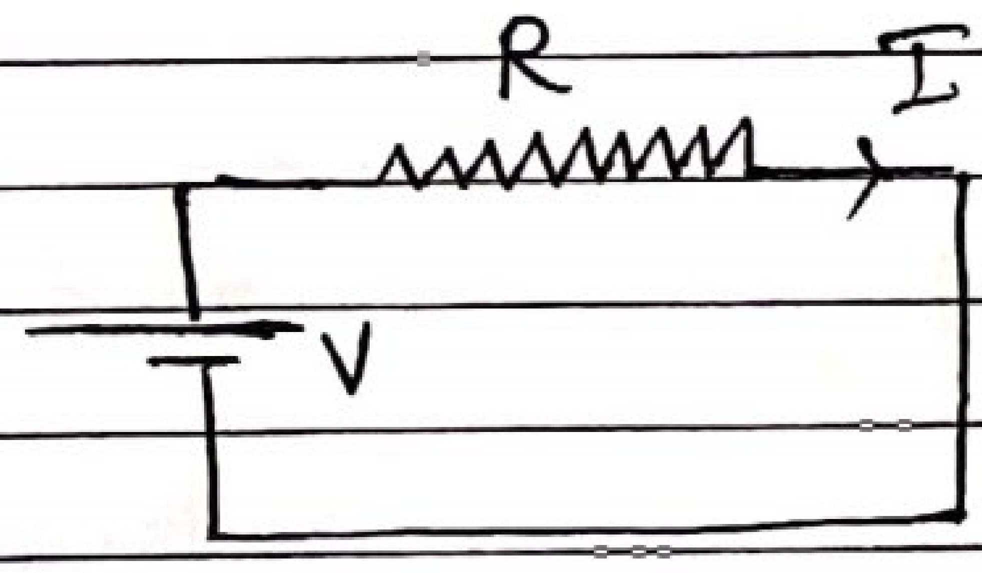
$$\bar{I} = \frac{\Delta Q}{\Delta t} \qquad \text{average current}$$

$$I = \frac{dQ}{dt} \qquad \text{instantaneous current}$$



Q is the amount of charge that passes through a cross sectional area A.
The current has unit of Ampere (A), where $1\ A = 1C/s$

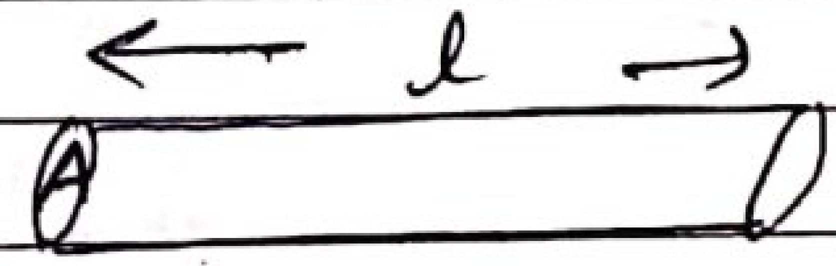
- **Resistance**



Ohm's law: $V = IR$

$$R = \frac{\rho l}{A}$$

$$\sigma = \frac{1}{\rho}$$



$A = r^2\pi$

R: resistance
ρ: resistivity
σ: conductivity

unit of R is Ohm (Ω), $1\ \Omega = \frac{V}{A}$

Example

a) calculate the resistance per unit length of a nichrome wire ($\rho = 1.5 \times 10^{-6}\ \Omega.m$) of radius 0.32 m

b) Find the potential difference across a 1 m length of nichrome wire when the current passing through it is 2.2 A.

solution

$$R = \frac{\rho l}{A}$$

$$\frac{R}{l} = \frac{\rho}{A} = \frac{\rho}{r^2\pi} = \frac{1.5 \times 10^{-6}}{(0.32)^2\pi} = 4.6\ \frac{\Omega}{m}$$

b) $V = IR = (2.2)(4.6) = 10\ V$

Example:

Given $Q = (2t^2 - 3t)$ C. Find the current at $t = 2$ s.

$$I = \frac{dQ}{dt} = 4t - 3$$

$$I(2) = 4(2) - 3 = 5\ A$$

Example: if $I(t) = 2t + 1$, Find the charge Q in the interval $t = 0$ to $t = 1$ s.

$$I = \frac{dQ}{dt}$$

$$dQ = I\,dt \Rightarrow \Delta Q = \int I\,dt = \int_0^1 (2t+1)\,dt$$

$$\Delta Q = t^2 + t \Big|_0^1 = 2\ C$$