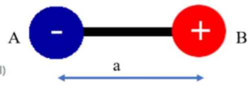
ELECTRIC DIPOLE

Electric Dipole:- An electric dipole consists of two equal and opposite charges situated very close to each other.

Dipole Moment:- Dipole moment ($\vec{p}$) of an electric dipole is defined as the product of the magnitude of one of the charges and the vector distance from negative to positive charge.

$\vec{P} = q\vec{a}$



Unit of Dipole Moment:- coulomb meter (S.I), stat coulomb cm (non S.I)

⇒ An arrangement of two equal and opposite charges

$-q$ ——— $+q$

⇒ Dipole ⇒ due to conservation ⇒ ⊕ and ⊖ charge are always equal

⇒ Practically dipole exists only. Salt molecule

$G = ?$

Examples :- Na^{+1} ——— Cl^{-1}

$+1$ ——— -1
$+1e$ $-1e$

H_2O

Na^{+1} ⇒ deficiency of 1 electron
Cl^{-1} ⇒ excess of 1 electrons

H_2O ⇒ 2 Dipoles

NaCl ⇒ Na^{+1} ——— Cl^{-1}
$+1.6\times10^{-19}C$ $-1.6\times10^{-19}C$

$H_2O \rightarrow H^+ \; OH^-$

H_2O ⇒ O (-1, -1) with H^{+1}, H^{+1} ⇒ O (-2) with H^{+1}, H^{+1} ⇒ H_2O has two dipoles

CH_4 H—C—H (with H above and below)   4 Dipole

CO_2 -   O⇌C⇌O → two Dipole

Dipole

$\underset{-q}{\bullet} \xleftarrow{\quad d \quad} \underset{+q}{\bullet}$ = Dipole

Dipole Moment $\vec{P}$:- Product of magnitude of charge and distance

$$\boxed{P = qd}$$ Coulomb × m

P is a vector always ⇒ Direction ⇒ −q to +q

−q → → → +q → → → → → →

$\boxed{P = qd}$

Ex: +3μC ——— −3μC (10 cm)

$q = 3\times10^{-6}$ $d = 10\times10^{-2} = 10^{-1}$

P = ?

$P = qd = 3\times10^{-6}\times10^{-1} = 3\times10^{-7}$ C.m

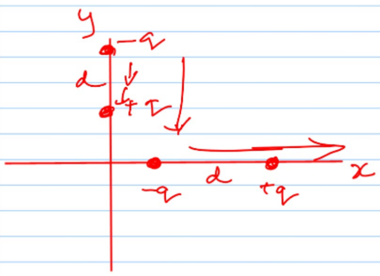
Na^{+1} ——— 2Å ——— Cl^{-1} $\vec{P}$ = ?

−2e ——— 1m ——— +3e P = ? No Dipole

Dipole Moment is vector :-

$\vec{P} = q\vec{d}$ −q to +q

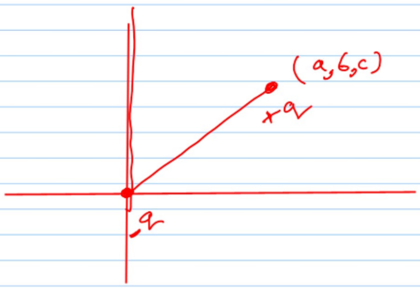
$\vec{d}$ = vector ⇒ −q to +q



Two Dipole ① x axis ② y axis

$\vec{P} = qd(\hat{i})$

$$\boxed{\vec{P} = qd(-\hat{j})}$$



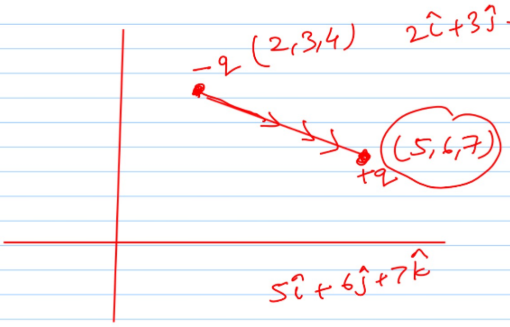
$\vec{P}$ = ?

$\vec{d}$ = −q to +q

$= a\hat{i} + b\hat{j} + c\hat{k}$

$\vec{P} = q\vec{d} = q[a\hat{i} + b\hat{j} + c\hat{k}]$

$2\hat{i}+3\hat{j}+4\hat{k}$



$5\hat{i}+6\hat{j}+7\hat{k}$

$\vec{P}=?$

$\vec{P}=q\vec{d}$

$\vec{d}=-q$ to $+q$

⇓

Position vector of q − Position vector of −q

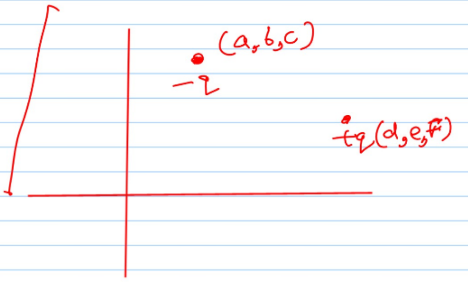
$\vec{d}=3\hat{i}+3\hat{j}+3\hat{k}$

$\vec{P}=q(3\hat{i}+3\hat{j}+3\hat{k})$

$P=qd$ $\vec{P}=q\vec{d}$

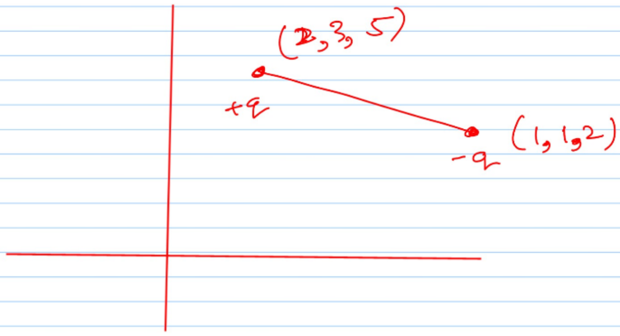
$\vec{d}=-q$ to $+q$

$\vec{d}=$ [Position vector of (+q)] − [Position vector of −q]



d, of +q ⇒ $d\hat{i}+e\hat{j}+f\hat{k}$

d of −q ⇒ $a\hat{i}+b\hat{j}+c\hat{k}$



$P=?$

[+q] ⇒ $2\hat{i}+3\hat{j}+5\hat{k}$

[−q] $\hat{i}+\hat{j}+2\hat{k}$

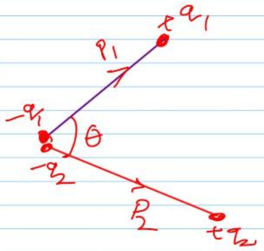
$\vec{P}=q[\hat{i}+2\hat{j}+3\hat{k}]$

If More than One dipole is present :-

$$\vec{P} = \vec{P_1} + \vec{P_2} + \vec{P_3} - - - - -$$

Net dipole Moment is the vector sum of all dipole moments.

Important Case



If two dipoles are at angle θ, net dipole moment

$$P = \sqrt{P_1^2 + P_2^2 + 2P_1P_2\cos\theta}$$

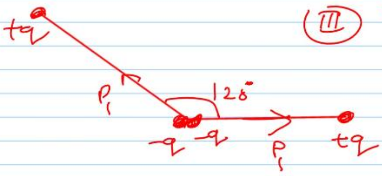
$$P = \sqrt{P_1^2 + P_2^2 + 2P_1P_2\cos\theta}$$

Special :- If $P_1 = P_2$, (I) $\theta = 60^\circ$ $P_{net} = \sqrt{3}P_1$

$$P = \sqrt{P_1^2 + P_1^2 + 2P_1^2 \times \frac{1}{2}} = \sqrt{3}P_1$$

(II) $\theta = 90^\circ$ $P_{net} = \sqrt{2}P_1$

(III) $\theta = 120^\circ$ $P_{net} = P_1$

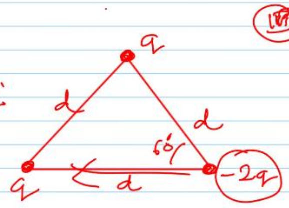


$\Rightarrow$ $P_{net} = P_1 = qd$

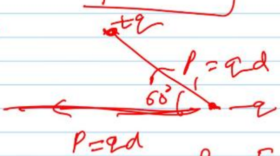
(IV) $\theta = 180^\circ$ $[CO_2]$

$P_{net} = 0$

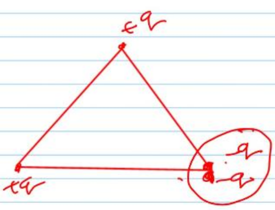
Ex:



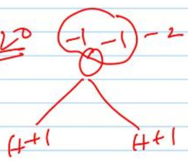
$P = ?$

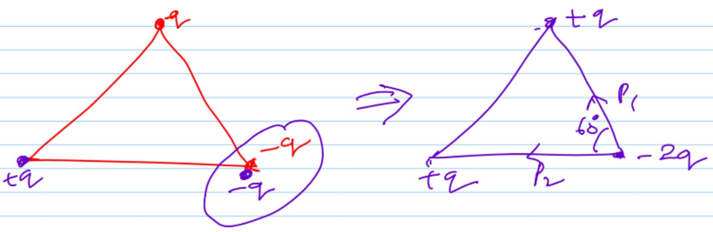


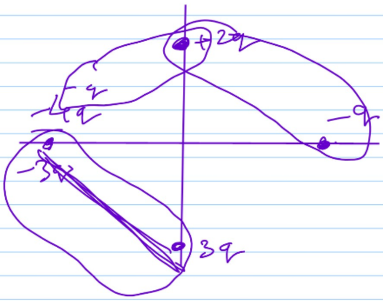
$P = \sqrt{3}qd$



H_2O

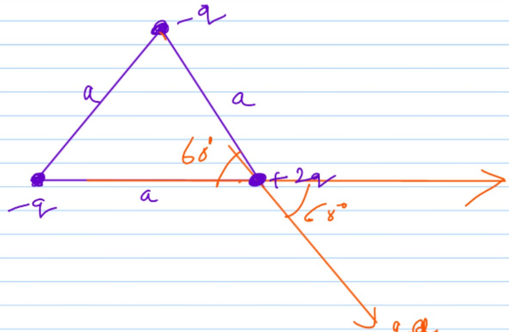




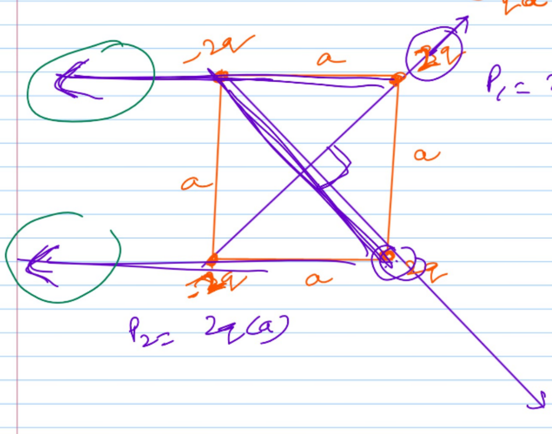


Three dipoles

+3q	-3q
+q	-q
+q	-q
+5q	-5q



$P = \sqrt{3}\, qa$



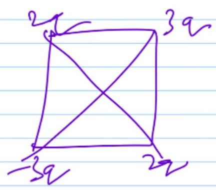
$P_1 = 2qa,\ P_2 = 2qa$

$P = P_1 + P_2 = 4qa$

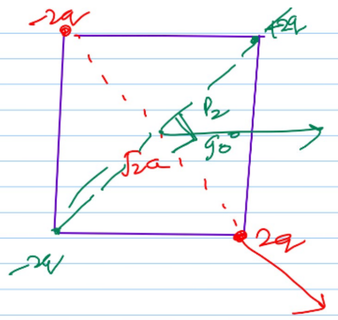
$P = ?$

$P_2 = 2q(a)$

$P_1 = (2q)(\sqrt{2}a)$



$P = \sqrt{2}[2\sqrt{2}\, qa] = 4qa$



$P_2 = 2q[\sqrt{2}a] = 2\sqrt{2}qa$

$P_1 = 2q[\sqrt{2}a] = 2\sqrt{2}qa$

angle = 90°

$P_{net} = \sqrt{2}P_1 = \sqrt{2}[2\sqrt{2}qa]$

$= 4qa$

(I) $P = qd$

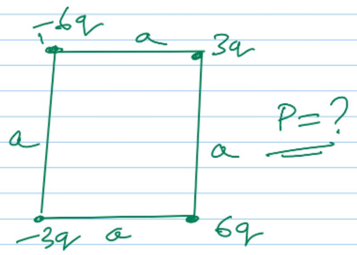
(II) $\vec{P} = q\vec{d}$

$\vec{d} = -q$ to $+q$

$\vec{d}$ = position vector of +q − position vector of −q

(III) $P = \sqrt{P_1^2 + P_2^2 + 2P_1P_2\cos\theta}$

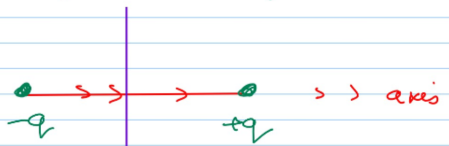
Home work



P = ?

Axis and Equator of Dipole :-

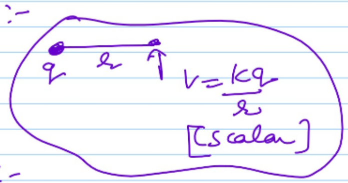
Axis = line joins the charges



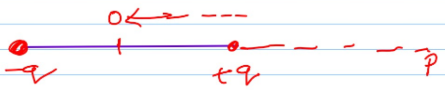
Equator → Perpendicular to axis, Passing through the center

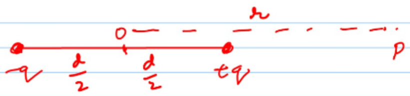
Equator

Potential due to dipole :-



(I) At the axis of dipole :-





Potential due to +q $\Rightarrow V_1 = \dfrac{kq}{r - \frac{d}{2}}$

Potential due to −q $\Rightarrow V_2 = \dfrac{-kq}{r + \frac{d}{2}}$

Net potential at P $\Rightarrow V = V_1 + V_2$

$$= kq\left[\frac{1}{r - \frac{d}{2}} - \frac{1}{r + \frac{d}{2}}\right]$$

$$V = kq\left[\frac{(r + \frac{d}{2}) - (r - \frac{d}{2})}{(r + \frac{d}{2})(r - \frac{d}{2})}\right]$$

$$V = kq\left[\frac{r + \frac{d}{2} - r + \frac{d}{2}}{(r^2 - \frac{d^2}{4})}\right] = kq\left[\frac{d}{r^2 - \frac{d^2}{4}}\right]$$

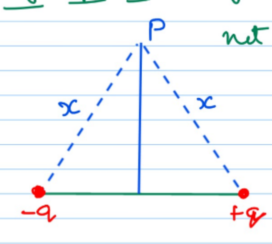
$$\boxed{V = \frac{kqd}{r^2 - \frac{d^2}{4}}}$$

In special case if $r >>> d$

$\frac{d^2}{4}$ = neglected

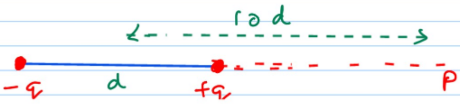
$$\boxed{V_{axis} = \frac{kqd}{r^2} = \frac{kP}{r^2}}$$

At Equator of dipole :- If Point P is at equator of dipole net potential will be zero



$$V = \frac{kq}{x} - \frac{kq}{x} = 0$$

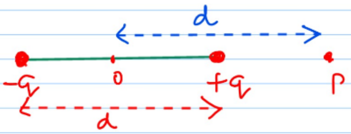
Example :- Point P is at distance 10d from center of dipole at the axis. Find out the potential?



In this case $r >>> d$ $\quad V = \frac{kP}{r^2}$

$$= \frac{k[qd]}{100d^2} = \frac{kq}{100d}$$

Ex:



$r = d$

If Point P is at distance d from the center of dipole at the axis find out the Potential.

Here r is not so greater therefore

$$V = \frac{kP}{r^2 - \frac{d^2}{4}} = \frac{k[qd]}{d^2 - \frac{d^2}{4}} = \frac{4kqd}{3d^2}$$

$$= \frac{4kq}{3d}$$

Summary :-

1. $P = qd$
2. $\vec{P} = q\vec{d}$ $\quad \vec{d} \Rightarrow$ from $-q$ to $+q$

   $\vec{d} = [\text{Position vector of } +q] - [\text{Position vector of } -q]$
3. $P = \sqrt{P_1^2 + P_2^2 + 2P_1P_2\cos\theta}$
4. $V_{axis} = \frac{kP}{r^2 - \frac{d^2}{4}}$ $\quad$ If $r >> d$ $\quad V = \frac{kP}{r^2}$ at axis
5. $V_{eq} = 0$