B.Sc. Physics Notes

Subject	Physics
Paper	B
Chapter 2	Electric Field
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Topics

1. Electric field due point charge and n-point charge.
2. Electric field due electric dipole.
3. Electric field due to ring of charge.
4. Electric field due to disk of charge.

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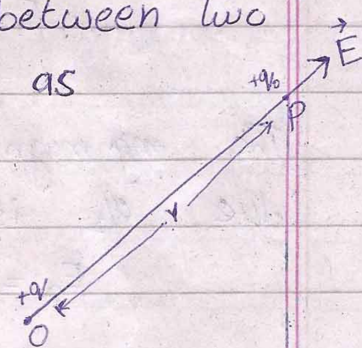
Q Calculate electric field due to point charge and due to n-point charges?

Electric field Due to Point CHarge

Consider a $+q$ chareg placed at a point "O". Now place a test charge $+q_0$ at point "P" having distance r from charge q. The electric force between two charges is given as



$$\vec{F} = \frac{kqq_0}{r^2}\hat{r}$$

$$\frac{\vec{F}}{q_0} = \frac{kq}{\cancel{q_0} r^2}\hat{r}$$

The electric force per unit charge is called electric field which is denoted by $\vec{E}$.

$$\frac{\vec{F}}{q_0} = \vec{E}$$

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

Thus the ~~mang~~ magnitude of electric field is

$$E = \frac{kq}{r^2}$$

Electric Field Due To N-Point Charges

Consider charges $q_1, q_2, q_3, \ldots, q_n$ having distanc $r_1, r_2, r_3, \ldots, r_n$ from point P. The magnitude of electricfield at P due to charge q_1 is

$$E_1 = \frac{kq_1}{r_1^2}$$

The ~~mg~~ magnitude of electricfield due q_2 is

$$E_2 = \frac{kq_2}{r_2^2}$$

Net magnitude of electric field

$$E = E_1 + E_2 + \ldots + E_n$$

$$E = \frac{kq_1}{r_1^2} + \frac{kq_2}{r_2^2} + \ldots + \frac{kq_n}{r_n^2}$$

$$= k\left(\frac{q_1}{r_1^2} + \frac{q_2}{r_2^2} + \ldots + \frac{q_n}{r_n^2}\right)$$

$$= k\sum_{i=1}^{n} \frac{q_i}{r_i^2}$$

Q What is an electric dipole?
Calculate electric field at a point due to electric dipole?

Ans Electric Dipole:-

A pair of positive charge and negative charge having constant distance between them is called electric dipole.

Electric dipole Moment:-

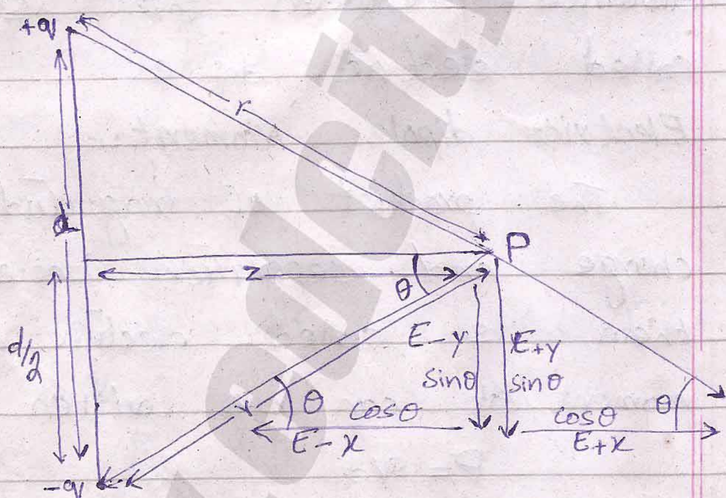
The product of magnitude of charge and separation between them is called electric dipole moment. It can be written as

$$P = qd$$

Electric dipole moment is a vector quantity and its direction is from -ve to +ve charge.

Electric field due to electric dipole:-

Consider a +q and -q charge having distance "d" between them. This is called electric dipole. Electric dipole moment is $P = qd$. We have to calculate electric field at "P" having distance "z" which is perpendicular of distance d.



The electric field at P due +q charge having distance r from point +q is

$$E_+ = \frac{Kq}{r^2} \quad \text{——— (i)}$$

The direction of E_+ is from +q towards point P.

The electric field at P due to $-q$ charge having distance r is

$$E_- = \frac{kq}{r^2} \quad \text{———} (2)$$

Direction of E_- is from point P to $-q$ charge.

Combining equation (1) and (2)

$$|E_+| = |E_-|$$

To calculate net electric field, Resolve electric field E_+ and E_- into components.

~~Resut~~ Rectangular component of E_+ are

$\cancel{E_{+x} = E_+ \sin\theta}$, $E_{+y} = E_+ \sin\theta$

$E_{+x} = E_+ \cos\theta$

Rectangular component of E_- are

$E_{-x} = E_- \cos\theta$, $E_{-y} = E_- \sin\theta$

Resultant x-components will be cancelled due to opposite direction.

Resultant y-components will be

$$E_y = E_{+y} \sin\theta + E_{-y} \sin\theta$$
$$= 2E_{+y} \sin\theta$$

Magnitude of electric field is

$$E = \sqrt{E_x^2 + E_y^2}$$

$$= \sqrt{(0)^2 + (2E_+ \sin\theta)^2}$$

$$= \sqrt{(2E_+ \sin\theta)^2}$$

$$E = 2E_+ \sin\theta$$

$$= \cancel{2} \frac{kq}{r^2} \cdot \frac{d/\cancel{2}}{r}$$

$$= \frac{kqd}{r^3}$$

$$= \frac{kP}{r^3} \qquad [\because qd = P$$

$$= \frac{kP}{\left[z^2 + \frac{d^2}{4}\right]^{3/2}} \qquad [\because r^2 = z^2 + \frac{d^2}{4}$$

$$= kP\left[z^2 + \frac{d^2}{4}\right]^{-3/2}$$

$$= kPz^{-3}\left[1 + d^2/4z^2\right]^{-3/2}$$

Expand term using binomial theorem

$$E = \frac{kP}{z^3}\left[1 - \left(\frac{3}{2}\right)\frac{d^2}{4z^2} + \cdots\cdots\right]$$

Neglect the higher order term

$$E = \frac{kP}{z^3}$$

This is electric field at P due to electric dipole.

Q Calculate electric field due to ring of charge?

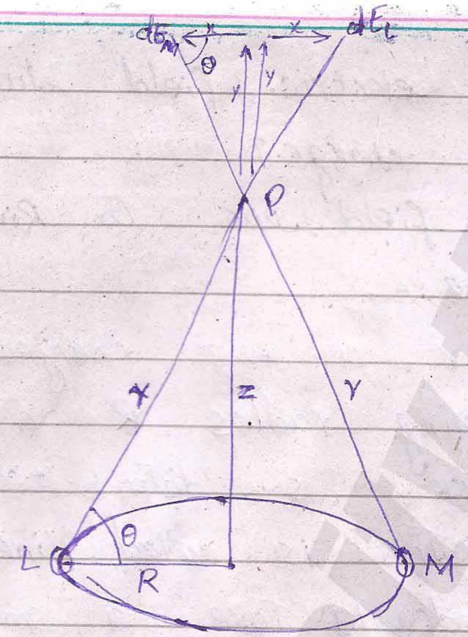
Ans Electric field Due to Ring of charge:-

Consider a +vly charged ring having radius R on which +ve charge is distributed uniformly. This is called linear charge density. Take a small length element ds of ring having charge dq is

$$\lambda = \frac{dq}{ds}$$

$$dq = \lambda ds$$

Now consider two length element ds at opposite ends which is denoted by L and M. We have to calculat electric field at P having distance z which is perpendicular of joining line of two length elements.



Electric field at P due to L length elements is

$$dE_L = \frac{Kdq}{r^2} \quad \text{——— (1)}$$

Direction of dE_L is from L elemet to point P

Electric field at P due to charge element M is

$$dE_M = \frac{Kdq}{r^2} \quad \text{——— (2)}$$

Combining eq (1) and (2)

$$|dE_L| = |dE_M|$$

Now to calculate electric field resolve dE_L and dE_M into components

Rectangular components of dE_L are

$dE_{Lx} = dE_L \cos\theta$, $dE_{Ly} = dE_L \sin\theta$

Rectangular components of dE_M are

$dE_{Mx} = dE_M \cos\theta$, $dE_{My} = dE_M \sin\theta$

Resultant x-components will be cancelled due to opposite direction.

Resultant y-components will be

$$dE_y = dE_L \sin\theta + dE_M \sin\theta$$

$$= 2dE_L \sin\theta$$

$$\cancel{= 2}$$

Magnitude of electric field is

$$dE = \sqrt{dE_x^2 + dE_y^2}$$

$$= \sqrt{(0)^2 + (2dE_L \sin\theta)^2}$$

$$dE = 2dE_L \sin\theta$$

$$= 2\frac{Kdq}{r^2} \cdot \frac{z}{r}$$

Net magnitude of electric field is

$$E = \int \frac{2zKdq}{r^3}$$

$$E = \int \frac{2zk\lambda ds}{(z^2+R^2)^{3/2}}$$

$\because dq = \lambda ds$
$r^3 = (r^2)^{3/2}$
$= (z^2+R^2)^{3/2}$

$$E = \frac{2zk\lambda}{(z^2+R^2)^{3/2}} \int ds$$

$$= \frac{2zk\lambda}{(z^2+R^2)^{3/2}} \cdot \pi R$$

As $\lambda = \frac{dq}{ds}$

$$dq = \lambda ds$$

$$q = \lambda \int ds = \lambda (2\pi R)$$

So $E = \frac{zk(\lambda 2\pi R)}{(z^2+R^2)^{3/2}}$

$$= \frac{zkq}{(z^2+R^2)^{3/2}}$$

The term R^2 can be neglected as compared to z^2

$$= \frac{zkq}{z^3} = \frac{kq}{z^2}$$

$$E = \frac{kq}{z^2}$$

This is electric field at P due to ring of charge.

Q calculate Electric field due to disk of charge.

Ans Electric field due to disk of charge.

Consider a positively charged disk ~~on~~ having radius R on which +ve charge distributed uniformly. Divide the disk into small rings. Take such a small ring having radius ω (omega) and width dω.

Take a pair of small area element da at oppsite ends of diameter ~~tow~~ which is denoted by L and M. The area of the element having radius ω and width dω and length $S = \omega d\alpha$ is given as

$$da = \omega d\alpha d\omega$$

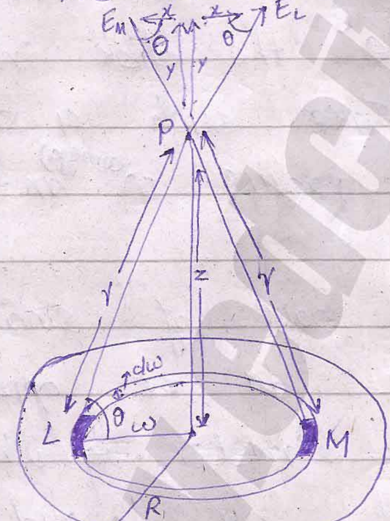
The area element da has charge dq. The charge per unit area is called surface charge density.

$$\sigma = \frac{dq}{da}$$

$$dq = \sigma da$$

$$dq = \sigma \omega d\alpha d\omega$$

we have to calculate electric field at point P having distance z from plane of the ~~ring~~ disk along its axis.



The electric field at P due to area element L having distance r is

$$dE_L = \frac{Kdq}{r^2} \quad \text{——} (1)$$

The electric field due to area element M is

$$dE = 2\frac{zk\,dq}{r^3}$$

Now to calculate net electric field

$$E = \int 2\frac{zk\,dq}{r^3}$$

$$= \int 2\frac{zk\sigma\,d\alpha\,d\omega\cdot\omega}{(z^2+\omega^2)^{3/2}}$$

$$= kz\sigma\int\frac{2\omega\,d\omega}{(z^2+\omega^2)^{3/2}}\cdot\int d\alpha$$

$$= \sigma zk\left|\frac{(z^2+\omega^2)^{-3/2+1}}{-3/2+1}\right|_0^R\cdot(\pi)$$

$$= \sigma zk\pi\left(\frac{-2}{1}\right)\left|\frac{1}{\sqrt{z^2+\omega^2}}\right|_0^R$$

$$= -2\sigma zk\pi\left[\frac{1}{\sqrt{z^2+R^2}}-\frac{1}{\sqrt{z^2}}\right]$$

$$= 2\sigma zk\pi\left[\frac{1}{z}-\frac{1}{\sqrt{z^2+R^2}}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}2\sigma z\pi\left[\frac{1}{z}-\frac{1}{\sqrt{z^2+R^2}}\right]$$

$$= \frac{\sigma z}{2\varepsilon_0}\cdot\frac{1}{z}\left[1-\frac{z}{\sqrt{z^2+R^2}}\right]$$

$$= \frac{\sigma}{2\varepsilon_0}\left[1-\frac{z}{\sqrt{z^2+R^2}}\right]$$

When $R > z$; the term $\frac{z}{\sqrt{z^2+R^2}}$ goes to zero

$$E = \frac{\sigma}{2\varepsilon_0}$$