-:(Applied Physics):-

Semester 01:-

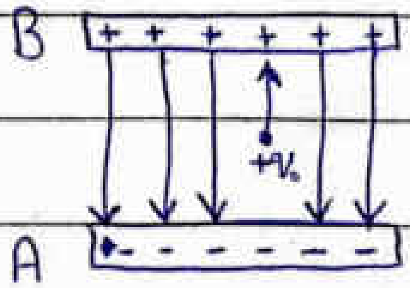
Q No 25:-

What is electric potential?

Ans:-

Electric Potential:-

Consider a +ve test charge is placed between two oppositely charged plates A and B.
The electric field lines come out from positive plate and enter into negative plate.



$$\Delta U = U_f - U_i$$

$$\Delta U = -W$$

"The negative work done by the electric force to move unit test charge with constant velocity from one point to other point is called Potential Difference between these points."

$$\Delta V = -\frac{W}{q_o}$$

$$V_f - V_i = -\frac{W}{q_o}$$

The electric potential V_f is zero when final position f is shifted at infinity. So,

$$0 - V_i = -\frac{W}{q_o}$$

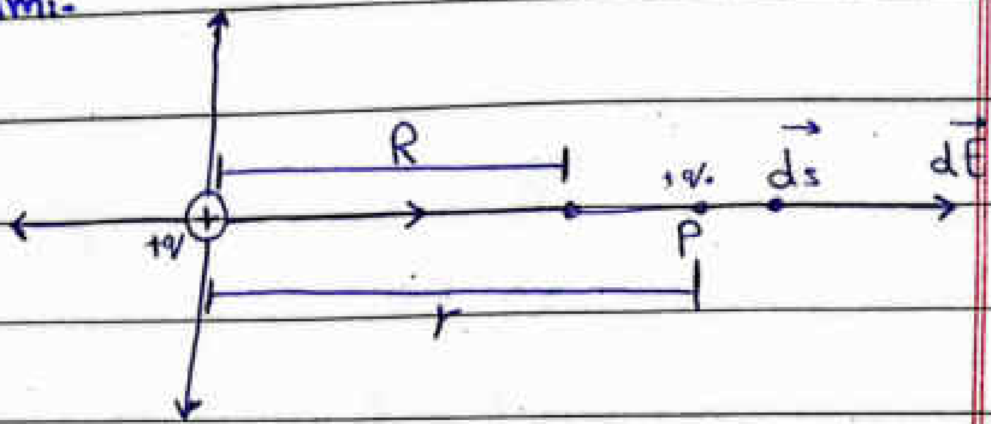
$$\boxed{V = \frac{W}{q_o}}$$

Q No 26:-

Calculate electric potential due to point charge?

Ans:-

Diagram:-



The electric field lines come out radially from positive charge. Consider such a line which extends radially from charge +q through point P to infinity distance.

Now place a test charge $+q_0$ at point P having distance 'r' from charge +q.

The work done on test charge $+q_0$ due to electric force $\vec{F_e}$ when it moves $+q_0$ through displacement $\vec{ds}$

between Initial position and final position is:

$$W = \int \vec{F} \cdot \vec{dr}$$

$$\{ \because \theta = 180 \}$$

$$W = \int F dr \cos(180)$$

$$W = -\int F dr$$

we Know that:

$$E = \frac{F}{q_0} \Rightarrow F = Eq_0$$

$$W = -\int Eq_0 \, dr$$

$$\left\{ E = \frac{Kq}{r^2} \right\}$$

$$W = -q_0 \int \frac{Kq}{r^2} dr$$

$$\frac{W}{q_0} = -\int \frac{Kq}{r^2} dr$$

$$\Delta V = -Kq \int r^{-2} dr$$

Applying Limit:

$$\Delta V = -Kq \int_{r_A}^{r_B} r^{-2} dr$$

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$$\Delta V = -Kq\left[\frac{r^{-1}}{-1}\right]_{r_A}^{r_B}$$

$$\Delta V = Kq\left[\frac{1}{r}\right]_{r_A}^{r_B}$$

$$\Delta V = Kq\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$$

if $r_A = \infty$; $V_A = 0$

$\{\because \Delta V = V_B - V_A\}$

$$V_B - V_A = Kq\left(\frac{1}{r_B} - \frac{1}{\infty}\right)$$

$$V_B - 0 = Kq\left(\frac{1}{r_B}\right)$$

$$\boxed{V_B = \frac{Kq}{r_B}}$$

$$\boxed{V = \frac{Kq}{r}} \Rightarrow \boxed{V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}}$$

-:(Applied Physics):-

Semester 01:-

QNo17:-

What is electric dipole? Calculate electric potential due to dipole at a point having diameter?

Answer:-

Electric Dipole:-

"Two equal charges of opposite sign ($\pm q$) seperated by distance 'd' is called Electric Dipole."

Electric dipole Moment:-

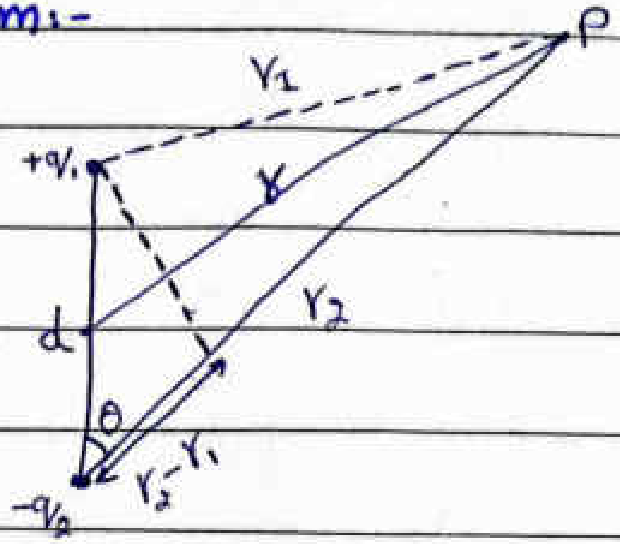
"The product of magnitude of either charge and separation between them is called electric dipole moment."

$$P = qd$$

It is a vector quantity. Its direction is from negative charges towards positive charges.

Electric Potential due to electric dipole:-

Diagram:-



Consider a +q charge and -q charge seperated by distance 'd' placed on x-axis. Take a point P having distance r_1 from +q and r_2 from -q charge

The electric potential due to +q charge is:

$$V_1 = \frac{Kq}{r_1}$$

The electric potential due to -q charge is: $V_2 = -\frac{Kq}{r_2}$

The net electric potential is:

$$V = V_1 + V_2$$

$$V = \frac{Kq}{r_1} - \frac{Kq}{r_2}$$

$$V = Kq\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$V = Kq\left(\frac{r_2 - r_1}{r_1 r_2}\right)$$

From the diagram

$$r_2 - r_1 = d\cos\theta$$

So,

$$V = Kq\left(\frac{d\cos\theta}{r_1 r_2}\right)$$

$$V = K\left(\frac{qd\cos\theta}{r_1 r_2}\right)$$

$$\{\because P = qd\}$$

$$\boxed{V = K\left(\frac{P\cos\theta}{r_1 r_2}\right)}$$

-:(Applied Physics):-

Semester 01:-

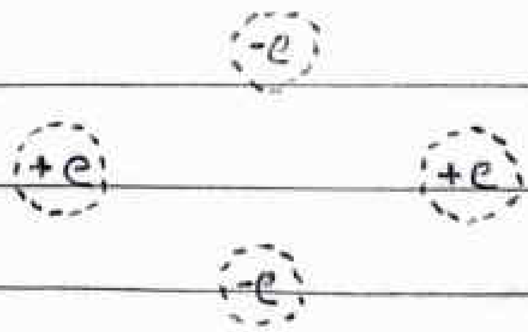
QNo18:-

Calculate Electric Potential due to quadrupole?

Answer:-

The two electric dipoles arranged in such a way that they almost cancel electric effects of each other at distant points is called Quadrupole.

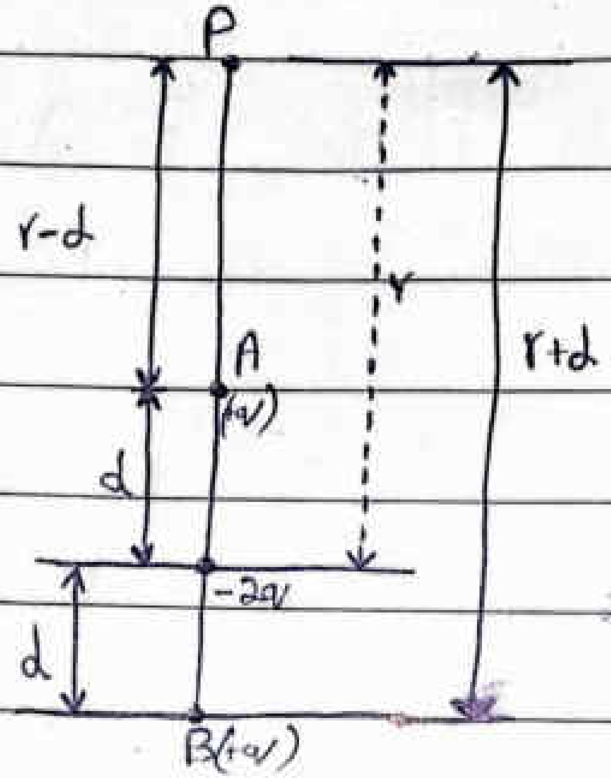
Diagram:-



An elementary quadrupole can be represented as two dipoles oriented antiparallel. The most important uses of quadrupole is the characterization of nuclei.

Electric Potential due to Quadrupole:-

Diagram:-



Explanation:-

Consider two charges each of value $-q$ are placed at origin on x-axis.

Now place $+q$ charge at point A having distance 'd' from '$-2q$'.

Similarly place an other charge ($+q$) at point B having distance 'd' from '$-2q$'.

Now take a point P on z-axis having distance 'r' from $-2q$ and [diameter]* distance $(r+d)$ from $+q$ charges at B.

The electric potential at P due to $+q$ at A is:

$$V_1 = \frac{Kq}{r-d}$$

Similarly due to $+q$ at B.

$$V_2 = \frac{Kq}{r+d}$$

due to $-2q$ charge.

$$V_3 = \frac{K(-2q)}{r}$$

The total electric potential is:

$$V = V_1 + V_2 + V_3$$

$$V = \frac{Kq}{r-d} + \frac{Kq}{r+d} - \frac{2Kq}{r}$$

$$V = Kq\left(\frac{1}{r-d} + \frac{1}{r+d} - \frac{2}{r}\right)$$

$$V = Kq\left(\frac{r^2 + dr + r^2 - dr - 2(r^2 - d^2)}{r(r-d)(r+d)}\right)$$

$$V = Kq\left(\frac{\cancel{2r^2} - \cancel{2r^2} + 2d^2}{r(r^2 - d^2)}\right)$$

$$V = \frac{Kq(2d^2)}{r(r^2 - d^2)}$$

$$V = \frac{K(2qd^2)}{r^3\left(1 - \frac{d^2}{r^2}\right)}$$

$$\left\{\because \begin{array}{l} P = qd \\ Q = 2qd^2 \end{array}\right\}$$

$$V = \frac{KQ}{r^3}\left(1 - \frac{d^2}{r^2}\right)^{-1}$$

By Binomial :-

$$V = \frac{KQ}{r^3}\left(1 + (-1)\left(\frac{-d^2}{r^2}\right) + \ldots\ldots\ldots\right)$$

The term $\left(\frac{-d^2}{r^2}\right) = 0$ because $r >>> d$

$$\boxed{V = \frac{KQ}{r^3}}$$

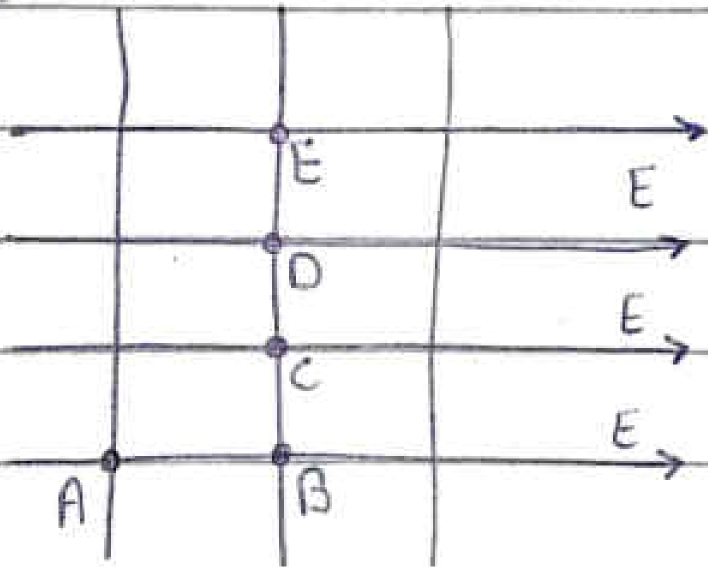
Topic:-

Equipotential Surfaces :-

The family of surfaces that connect points having same value of the electric potential are called equipotential surfaces.

Due to Uniform field:-

Diagram:-



Explanation:-

Consider uniform electric field indicated by horizontal electric lines of force. The perpendicular dashed lines are cross-section of equipotential surface.

Take two points having distance l.

$$\Delta V = -\int_A^B E \cdot ds$$

$$\Delta V = -El$$

Potential difference b/w B and C:

Electric potential at B is $V_B = \frac{Kq}{r_B}$

Electric potential at C is $V_c = \frac{Kq}{r_c}$

$$\Delta V = V_B - V_c$$

$$V_B - V_c = \frac{Kq}{r_B} - \frac{Kq}{r_c} \qquad \{\because r_B = r_c\}$$

$$V_B - V_c = \cancel{\frac{Kq}{r_B}} - \cancel{\frac{Kq}{r_B}}$$

$$V_B - V_c = 0$$

$$\boxed{V_B = V_c}$$

Since $\Delta V = \frac{-W_{BC}}{q_o} = 0$, So $W_{BC} = 0$

Hence no work is done by electric field when q_o is moved from B to C.

(ii) **Due to positive point charge:-**

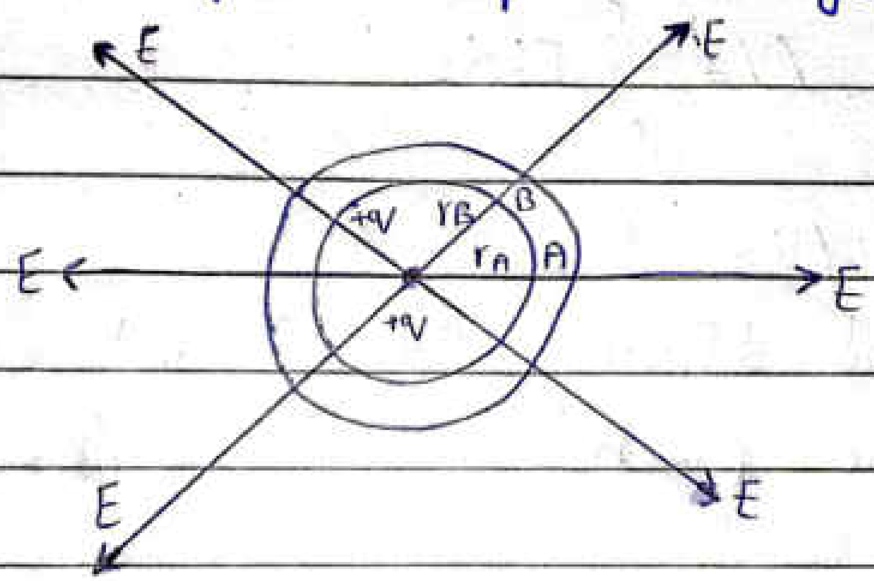


Diagram:-

In this way all the points on the line containing points A, B, C etc have same potential. The surface passing through these points are called equipotential surface.

Consider a +q charge is placed at the center of sphere. The electric field is along ~~radius~~ direction.

Potential difference b/w A and B.

$$V_A - V_B = Kq\left(\frac{1}{r_A} - \frac{1}{r_B}\right)$$

when points A and B lies on the surface of same sphere $r_A = r_B$

In this case:-

$$V_A - V_B = Kq\left(\frac{1}{r_A} - \frac{1}{r_A}\right)$$

$$V_A - V_B = 0$$

$$\boxed{V_A = V_B}$$

It means all points at a given radius have the same potential. Therefore, the equipotential surface of a given charge from a family of concentric sphere.

For a dipole, the equipotential surfaces are more complicated.

-:(Applied Physics):-

Semester 01:-

QNo19:-

What is continous charge distribution? Derive an expression to calculate electric potential at a point due to continous charge distribution?

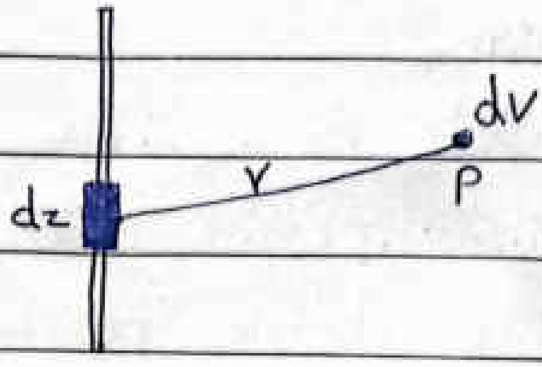
Ans:-

Electric Potential due to Continous charge distribution:-

The electric charge is quantized. The collection of large number of charges is called continous charge distribution. The continous charge distribution has three types.

- Linear charge distribution
- Surface charge distribution
- Volume charge distribution

(i) Electric Potential due to Linear charge Distribution:-



Consider a linear charge distribution. Take a small length element 'dz' of this distribution having charge 'dq'.

$$\lambda = \frac{dq}{dz} \Rightarrow dq = \lambda dz$$

The electric potential at P due to charge dq is

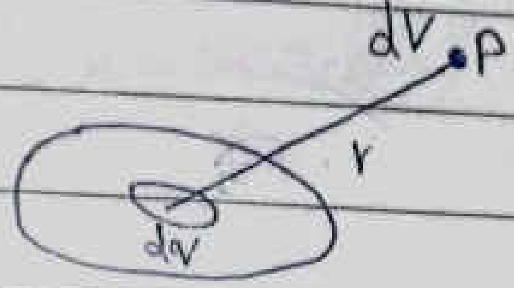
$$dV = \frac{K\,dq}{r}$$

$$dV = \frac{K\lambda dz}{r}$$

Integrate:

$$\boxed{V = \int \frac{K\lambda}{r} dz}$$

(ii) Electric Potential due to Surface charge Distribution:-



Consider a surface charge distribution. Take a small area element 'da' of this distribution having charge "dq"

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

The electric potential at P due to charge dq is:

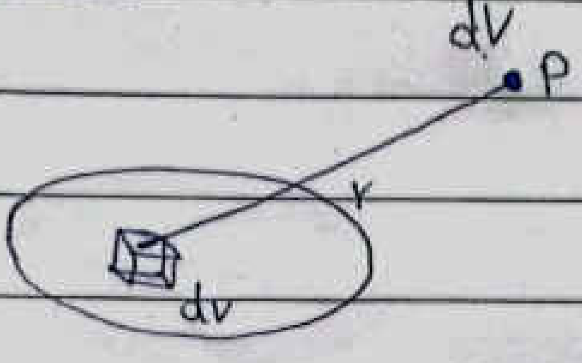
$$dV = \frac{K dq}{r}$$

$$dV = \frac{K \sigma da}{r}$$

Integrate:

$$\boxed{V = \int \frac{K \sigma da}{r}}$$

Electric Potential due to Volume charge distribution:-



Consider a volume charge distribution. Take a small volume element 'dV_e' of the distribution having charge 'dq'.

$$\rho = \frac{dq}{dV} \rightarrow dq = \rho dV_e$$

The electric potential at P due to charge dq is:

$$dV = \frac{K dq}{r}$$

$$dV = \frac{K \rho dV_e}{r}$$

Integrate:

$$\boxed{V = \int \frac{K\rho}{r} dV_e}$$

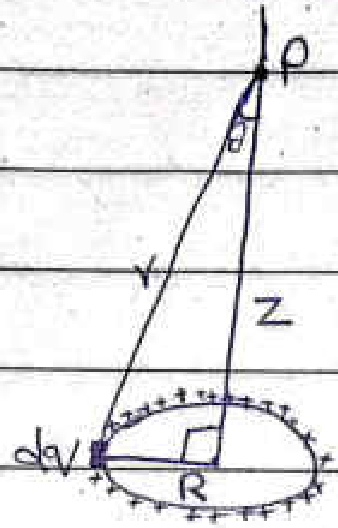
-:(Applied Physics):-

Semester 01:-

Qno20:-

Calculate electric potential at a point due to ring of charges?

Answer:-



Consider a uniformly charged ring having radius R. Take a small length element ds of ring having charge dq. The linear charge density is:

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

By Integration:

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

Now take a point on z-axis having distance 'z' from the plane of ring. Electric potential dV due to charge dq is:

$$dV = \frac{K\,dq}{r}$$

$$dV = \frac{K\,\lambda\,ds}{r}$$

By Integration:

$$V = \int \frac{K\,\lambda\,ds}{r}$$

$$\left\{\begin{aligned} c^2 &= a^2 + b^2 \\ r^2 &= R^2 + z^2 \\ r &= \sqrt{R^2 + z^2} \end{aligned}\right\} \rightarrow V = \frac{K\lambda}{(R^2+z^2)^{\frac{1}{2}}} \int ds$$

$$V = \frac{K\lambda(2\pi R)}{(R^2+z^2)^{\frac{1}{2}}}$$

$$\boxed{V = \frac{Kq}{\sqrt{R^2+z^2}}}$$

This is the electric potential due to a ring of charges

The electric field at point P due to ring of charges is:

$$E = -\frac{dV}{dz} = -\frac{d}{dz}\left(\frac{Kq}{(R^2+z^2)^{\frac{1}{2}}}\right)$$

$$E = -Kq \frac{d}{dz} (R^2+z^2)^{-\frac{1}{2}}$$

$$E = -Kq\left(\frac{-1}{2}\right)(R^2+z^2)^{-3/2}(2z)$$

$$E = \frac{Kq\,\cancel{2}z}{\cancel{2}(R^2+z^2)^{3/2}}$$

$$\boxed{E = \frac{Kqz}{(R^2+z^2)^{3/2}}}$$

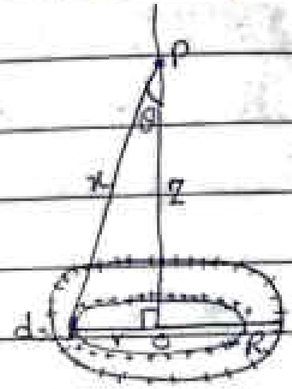
-:(Applied Physics):-

Semester 01:-

Q.no 21:-

Calculate electric Potential due to disk of charges?

Ans:-



Consider a disk of radius R having uniform charge density 'σ' on its top surface.

Take a point P on the central axis of disk having distance 'z'.

Now, take such a ring having radius 'r'.

The surface charge density is:

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

$$dq = \sigma\, da \Rightarrow \{ da = (2\pi r)dr \}$$

$$dq = \sigma(2\pi r)dr \quad \text{(i)}$$

The electric potential at a point P due to charge dq of ring having distance 'x' is:

$$dV = \frac{Kdq}{x}$$

Value of 'x' by phtcogeron theorem.

$$c^2 = a^2 + b^2$$

$$x^2 = r^2 + z^2$$

$$x = \sqrt{r^2 + z^2}$$

So,

$$dv = \frac{Kdq}{\sqrt{r^2+z^2}}$$

$$dv = \frac{K\sigma da}{\sqrt{r^2+z^2}} = \frac{K\sigma(2\pi r)dr}{\sqrt{r^2+z^2}}$$

$$dV = \frac{1}{4\pi\varepsilon_0} \frac{\sigma(2\pi r)dr}{\sqrt{r^2+z^2}}$$

$$dV = \frac{\sigma r}{2\varepsilon_0} \frac{dr}{\sqrt{r^2+z^2}}$$

By Integration:

$$V = \frac{\sigma}{2\varepsilon_0} \int_0^R \frac{r\,dr}{(r^2+z^2)^{\frac{1}{2}}}$$

$$V = \frac{\sigma}{2\varepsilon_0} \int_0^R (r^2+z^2)^{-1/2}\, r\,dr$$

$$V = \frac{\sigma}{2\varepsilon_0} \frac{1}{2} \int_0^R (r^2+z^2)^{-\frac{1}{2}} (2r)dr$$

$$V = \frac{\sigma}{4\varepsilon_0} \left[\frac{(r^2+z^2)^{\frac{1}{2}}}{\frac{1}{2}} \right]_0^R$$

$$V = \frac{\sigma}{4\varepsilon_0} 2 \left[(r^2+z^2)^{\frac{1}{2}} \right]_0^R$$

$$V = \frac{\sigma}{2\varepsilon_0} \left[(R^2+z^2)^{\frac{1}{2}} - (0^2-z^2)^{\frac{1}{2}} \right]$$

$$\boxed{V = \frac{\sigma}{2\varepsilon_0} \left(\sqrt{R^2+z^2} - z \right)} \quad \text{(ii)}$$

By Binomial Series

$$(z^2+R^2)^{\frac{1}{2}} = z\left(1+\frac{R^2}{z^2}\right)^{\frac{1}{2}}$$

$$= z\left(1+\frac{1}{2}\frac{R^2}{z^2}+\ldots\ldots\right)$$

$$= z\left(1+\frac{R^2}{2z^2}\right)$$

$$(z^2+R^2)^{\frac{1}{2}} = \left(z+\frac{R^2}{2z}\right)$$

Put in eq (ii)

$$V = \frac{\sigma}{2\varepsilon_0}\left(\cancel{z}+\frac{R^2}{2z}-\cancel{z}\right)$$

$$\boxed{V = \frac{\sigma R^2}{4z\varepsilon_0}}$$

Let make assumption:

$$V = \frac{\sigma \pi R^2}{4\pi\varepsilon_0 z}$$

$$V = K\sigma\left(\frac{\pi R^2}{z}\right) \qquad \left\{\begin{array}{l} dq = \sigma da \\ q = \sigma(2\pi R^2) \end{array}\right.$$

$$\boxed{V = \frac{Kq}{z}}$$