PHY103 MIDSEM-1 18 Sept 2013

Time : 120 min Max Marks: 80

Name YNM Roll No. Instructor.

PHY103 Tutorial Section No. Model Solution

I pledge my honour as a gentleman / lady that during the examination I shall not resort to any unfair means, and will neither give nor receive assistance.

____

(Signature)

Check that there are numbered 18 pages.

There are 4 questions each with several parts. Write your answers in the space provided.

Your rough work elsewhere will NOT be graded.

You are free to make use of the formulae provided, the responsibility of its correct interpretation is yours.

No other paper must be in your possession. No calculators or cell phones are allowed.

$$\vec{dl} = h_1\, du_1 \hat{u}_1 + h_2 du_2\, \hat{u}_2 + h_3 du_3\, \hat{u}_3$$

$$\vec{\nabla} T = \frac{1}{h_1}\frac{\partial T}{\partial u_1}\hat{u}_1 + \frac{1}{h_2}\frac{\partial T}{\partial u_2}\hat{u}_2 + \frac{1}{h_3}\frac{\partial T}{\partial u_3}\hat{u}_3$$

$$\nabla^2 T = \frac{1}{h_1 h_2 h_3}\left[\frac{\partial}{\partial u_1}\left(\frac{h_2 h_3}{h_1}\frac{\partial T}{\partial u_1}\right) + \frac{\partial}{\partial u_2}\left(\frac{h_1 h_3}{h_2}\frac{\partial T}{\partial u_2}\right) + \frac{\partial}{\partial u_3}\left(\frac{h_1 h_2}{h_3}\frac{\partial T}{\partial u_3}\right)\right]$$

$$\vec{\nabla}.\vec{A} = \frac{1}{h_1 h_2 h_3}\left[\frac{\partial}{\partial u_1}(h_2 h_3 A_1) + \frac{\partial}{\partial u_2}(h_1 h_3 A_2) + \frac{\partial}{\partial u_3}(h_1 h_2 A_3)\right]$$

$$\vec{\nabla}\times\vec{A} = \frac{1}{h_1 h_2 h_3}\begin{vmatrix} h_1\hat{u}_1 & h_2\hat{u}_2 & h_3\hat{u}_3 \\ \frac{\partial}{\partial u_1} & \frac{\partial}{\partial u_2} & \frac{\partial}{\partial u_3} \\ h_1 A_1 & h_2 A_2 & h_3 A_3 \end{vmatrix}$$

-------------------------------For Examiners only (Do not write below)-------------------------------

Q.1.	
Q.2.	
Q.3	
Q.4.	
TOTAL	

1. a) A charge distribution of total charge Q in spherical co-ordinates is given as $\rho(r) = A\delta(r - R)$, where R is the radius of a sphere, and A is a constant.

   i) Find A in terms of Q, and

   ii) Obtain total energy of the configuration. (4)

i) $$Q = \int \rho(r)\, 4\pi r^2\, dr = A \int \delta(r-R)\, 4\pi r^2 dr = 4\pi R^2 \cdot A.$$

$$\therefore \quad A = \frac{Q}{4\pi R^2}$$; i.e. a spherical shell of radius R (2)

$$U = \frac{\epsilon_0}{2} \int_R^\infty \frac{1}{(4\pi\epsilon_0)^2} \frac{Q^2}{r^4}\, 4\pi r^2 dr$$

Since, $\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \hat{r}, \; r \cancel{>} R$

$= 0 \quad ; r < R$

or. $$U = \frac{1}{2} \int V\, dq = \frac{1}{2} Q\, V(R) = \frac{1}{2} \frac{Q^2}{4\pi\epsilon_0 R}$$ (2)

$$U = \frac{Q^2}{8\pi\epsilon_0 R}$$

b) Calculate the charge distribution $\rho(r,\theta,\varphi)$, and the potential $V(r,\theta,\varphi)$ with an appropriate choice of reference for the electric field $\vec{E} = \frac{\alpha}{r}\,\hat{r} + \frac{\beta}{r\,sin\theta}\,cos\varphi\,\hat{\varphi}$, where α and β are constants. (4)

$$\rho = \epsilon_0\, \vec{\nabla}\cdot\vec{E}$$

$$= \epsilon_0 \left\{ \frac{1}{r^2 \sin\theta} \left[\frac{\partial}{\partial r}\left(r^2 \sin\theta\, \frac{\alpha}{r}\right) + \frac{\partial}{\partial \varphi}\left(r\ \frac{\beta\cos\varphi}{r\sin\theta}\right)\right]\right\}$$

2

$$= \frac{\epsilon_0}{r^2}\left(\alpha - \beta\,\frac{\sin\varphi}{\sin^2\theta}\right)$$

$$V = -\int_{\text{Ref.}}^{P} \vec{E}\cdot\vec{dl} = -\int_{r_0}^{r} \frac{\alpha}{r'}\,dr' - \int_{0}^{\varphi} \beta\cos\varphi'\,d\varphi'$$

$$= -\alpha \ln\left(\frac{r}{r_0}\right) - \beta\sin\varphi\,,$$

1 + 1

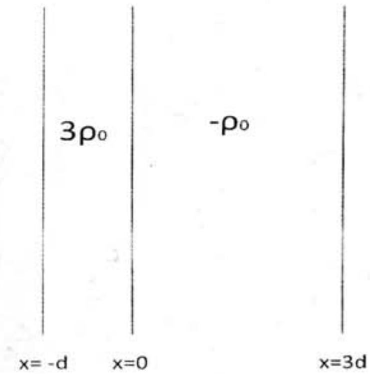
where $(r_0, 0, 0)$ has been chosen as the reference.

Can choose $r_0 = 1$, for convience.

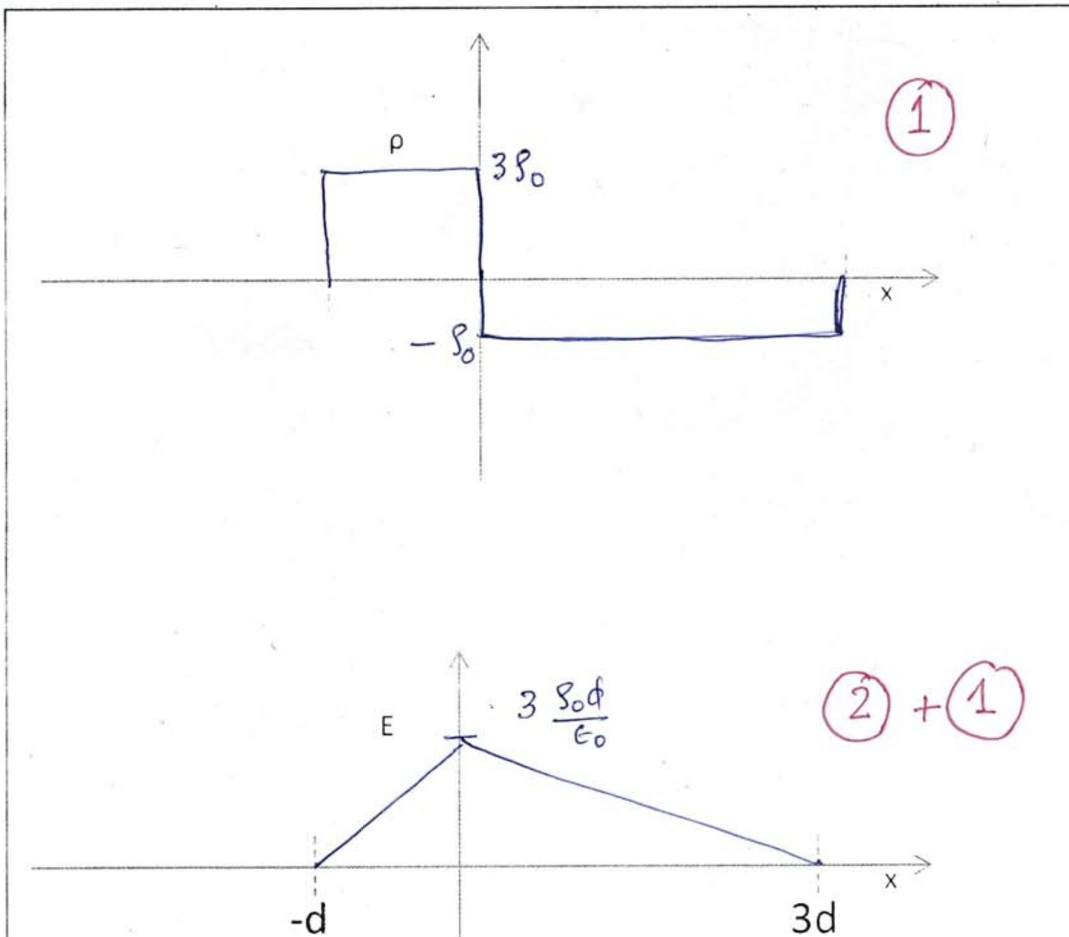
c) A large slab of thickness *4d* with its plane faces parallel to y-z plane carries volume charge (as indicated in the Figure)

$$\rho = \begin{cases} 3\rho_0, & -d \le x < 0 \\ -\rho_0, & 0 \le x \le 3d \end{cases}$$

and zero elsewhere such that net charge is zero.



i) Find the location and magnitude of maximum electric field.
ii) Sketch below in the box given charge density, and the electric field E neatly marking the axes to indicate values.
iii) Find the total voltage drop across the charge system. (6)



Field zero outside.

Since the field E must be perpendicular to the planes parallel to the charge distribution, and be uniform over any particular plane.

$\frac{dE}{dx} = \frac{\rho}{\epsilon_0}$, $\Rightarrow$ E will linearly increase with + slope $\frac{\rho}{\epsilon_0}$ from $-d$ to 0

yen

and E will linearly decrease (negative slope $-\frac{\rho_0}{\epsilon_0}$) from a maximum at $x=0$.

$$E_{max}(x=0) = \frac{3\rho_0 d}{\epsilon_0}.$$

Voltage dropped across the distribution

$$V = -\int_{-d}^{3d} \vec{E}\cdot\vec{dl} = \text{Area under the curve of } E(x)$$

$$|V| = \frac{1}{2}(4d)\cdot\frac{3\rho_0 d}{\epsilon_0} = \frac{6\rho_0 d^2}{\epsilon_0}$$

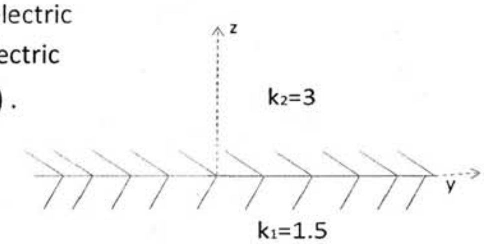
2

Alternatively, Realizing symmetry of E, choose appropriate Gaussian surfaces to show $E=0$, $x<-d$, & $x>3d$ and then solve for E between $-d$ and 0, and 0 and $3d$.

d) Consider that the space below z=0 plane is filled with a material of dielectric constant k_1=1.5, and the space above with another material with dielectric constant k_2=3, in which the electric field is $\vec{E}_2 = 3\hat{\imath} + 4\hat{\jmath} - 12\hat{k}$ (V/m) .

i) Determine $\vec{D}$ in the lower half i.e. z<0. ,

ii) Find potential difference between two points (0,0,-2) and (0,0,0).



(6)

Boundary conditions: $\vec{E}_{1t} = \vec{E}_{2t}$

$$D_{1n} = D_{2n}$$

$$\Rightarrow k_1 E_{1n} = k_2 E_{2n}, \text{ and } E_{2n} = -12 \text{ V/m}$$

3

$$\therefore E_{1n} = \left(\frac{k_2}{k_1}\right)(-12) = 2(-12) = -24 \text{ V/m}$$

$$\Rightarrow D_{2n} = k_2 \epsilon_0 \vec{E}_2 \cdot \hat{n} = -36\epsilon_0 = \vec{D}_1 \cdot \hat{n}$$

$$\therefore \vec{E}_1 = (3\hat{\imath} + 4\hat{\jmath} - 24\hat{k}) \text{ V/m}$$

2

$$\vec{D}_1 = k_1 \epsilon_0 \vec{E}_1 = \left(\frac{9}{2}\hat{\imath} + 6\hat{\jmath} - 36\hat{k}\right)\epsilon_0 \ \frac{C}{m^2}$$

ii) $$V(P) - V(0) = -\int_0^P \vec{E}\cdot d\vec{l}$$

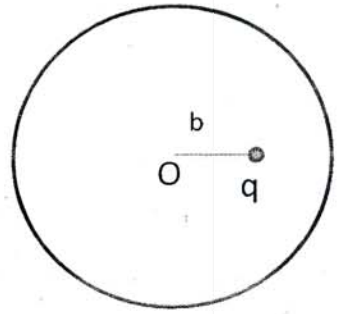
1

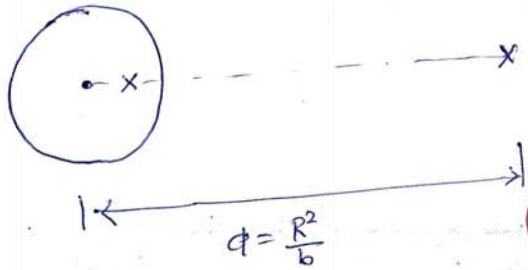
$$= -24 \times 2$$

$$= -48 \text{ V}$$

2. a) A charge q is placed at a distance b from the centre of a grounded conducting sphere of radius R. Find the force on the charge, and specifically find it when $b=R/2$.

(6)





$$q' = -\left(\frac{d}{R}\right)q = -\left(\frac{R^2}{b}\right)\cdot\frac{q}{R} = -\frac{R}{b}q$$ 1

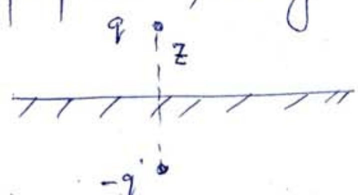
1

$$\therefore \quad F = -\frac{\left(\frac{R}{b}q\right)(q)}{4\pi\epsilon_0\left(\frac{R^2}{b}-b\right)^2} = -\frac{q^2}{4\pi\epsilon_0}\frac{Rb}{(R^2-b^2)^2}$$ 3

$$F\left(b=\frac{R}{2}\right) = -\frac{2}{9\pi\epsilon_0}\frac{q^2}{R^2}$$ 1

b) Find the work done in bringing a charge q from infinity to a height of d above a large flat grounded conductor occupying the lower half plane. (6)

Appropriate by Image method,



$$\vec{F} = -\frac{1}{4\pi\epsilon_0} \cdot \frac{q^2}{(2z)^2}\,\hat{k}$$ 1 + 1

$$W = \int_{\infty}^{d} \vec{F}\cdot\vec{dl} = \frac{q^2}{4\pi\epsilon_0}\int_{\infty}^{d}\frac{1}{4z^2}\,dz$$ 2

$$= -\frac{1}{4\pi\epsilon_0}\cdot\frac{q^2}{(4d)}$$ 2

or, Alternatively argue that
it is half of the energy stored (only in the upper)
of the two charge system q and $-q$

$$\therefore\ W = -\frac{1}{4\pi\epsilon_0}\cdot\frac{q^2}{(4d)}.$$

c) A small dipole pointing in $\vec{p} = p_0\hat{k}$ direction is placed at the centre of neutral conducting shell of inner radius a and outer radius b.

i) Describe the induced charge distribution at all surfaces.

ii) Write down the field due to the <u>induced charges alone</u>, and <u>show it in a neat diagram</u>.

iii) By taking into consideration the dipole, and the induced charges, write down the potential for the complete system.

(You are free to use any familiar equivalent systems and known results in developing your arguments.)

(8)

(i) Field <u>outside</u> the conducting shell must be <u>zero</u>.

$\sigma\big|_{r=b} = 0$, 1 $\quad \sigma\big|_{r=a} = \sigma_0 \cos\theta$ 1

Induced charges <u>alone</u>:

Outside field must be due to $-\vec{p}$ at the centre to cancel off the field of the $\vec{p}$.

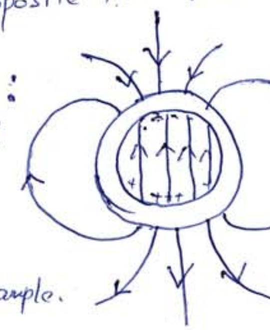
i.e. inside must be constant field opposite to $-p_0\hat{k}$.

3

Field due to induced charges alone:

$$\therefore \vec{E}\Big|_{ind.\sigma} = \frac{-p_0}{4\pi\epsilon_0 r^3}\left(2\cos\theta\,\hat{r} + \sin\theta\,\hat{\theta}\right),\ r > R$$

$$= \frac{p_0}{4\pi\epsilon_0 R^3}\hat{k},\quad r < R$$



The field and charge distribution is equivalent to uniform polarization $\vec{P}$, for example.

$$\text{where } \vec{P} = \frac{-p_0\hat{k}}{\frac{4\pi}{3}R^3}$$

2

$$\therefore \sigma_0 = \frac{3p_0}{4\pi R^3},\quad \underline{\text{or}}\quad \sigma\Big|_{r=a} = -\epsilon_0\left(E_{1,r}\right) = -\frac{3p_0\cos\theta}{4\pi R^3}$$

$V(r)$ is a combination of that due to given dipole, say, V_1 and the induced charge distribution, say V_2.

$$V_1 = \frac{p_0\cos\theta}{4\pi\epsilon_0 r^2}\quad \text{for } 0 < r \le R$$

$$V_2 = -\frac{p_0}{4\pi\epsilon_0 R^3}\, r\cos\theta = -\frac{p_0}{4\pi\epsilon_0 R^3}\, z.$$

3

$$\therefore V = \begin{cases} \dfrac{p_0}{4\pi\epsilon_0 R^3}\left(\dfrac{R^3}{r^2} - r\right)\cos\theta, & 0 \le r \le R \\ 0; & R \le r \le b \\ 0, & r \gg b. \end{cases}$$

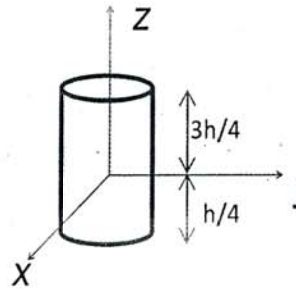
Two extra bonus marks obtainable in this question. One can score 10 out of 8!!

3\.

a) A circular cylinder (radius R and height h) is placed with its symmetry axis along z-axis, and its top and bottom faces at $z = \frac{3h}{4}$ and $z = -\frac{h}{4}$ respectively. The cylinder encloses a volume charge density given as

$$\rho = \begin{cases} \rho_0, & z > 0 \\ -\rho_0, & z < 0 \end{cases}$$

Find contributions to the potential up to dipole for a far point (r_0, φ_0, z_0). (10)



$$V_{mono} = \frac{Q}{4\pi\epsilon_0 r}, \qquad Q = \rho_0 \pi R^2 \left(\frac{3h}{4} - \frac{h}{4}\right) = \rho_0 \pi R^2 \left(\frac{h}{2}\right)$$

$$= \frac{\pi R^2 \rho_0 h}{8\pi\epsilon_0 r} = \frac{R^2 \rho_0 h}{8\epsilon_0}\left(\frac{1}{r}\right)$$

2

From symmetry $\Rightarrow$ $p_x = 0$, $p_y = 0$ 1

$$p_z = \int z\, dq, \qquad dq = (\pi R^2 dz)\rho$$

$$= \pi R^2 \rho_0 \left[\int_0^{3h/4} z\, dz - \int_{-h/4}^{0} z\, dz \right.$$

$$= \frac{5}{16} \pi R^2 \rho_0 h^2$$

$$\therefore \boxed{\vec{p} = \frac{5}{16} \pi R^2 \rho_0 h^2 \hat{k}}$$

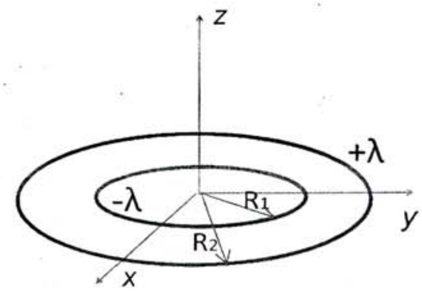
4

$$V_{dipole} = \frac{\vec{p} \cdot \hat{r}}{4\pi\epsilon_0 r^2} = \frac{5}{64} \frac{R^2 \rho_0 h^2}{\epsilon_0 r^2} \hat{k} \cdot \hat{r}$$

$$= \frac{5}{64} \frac{R^2 \rho_0 h^2}{(r_0^2 + z_0^2)} \cdot \frac{z_0}{\sqrt{r_0^2 + z_0^2}}$$

3

b) Two circular rings having a common centre at the origin are placed in the x-y plane. The linear charge densities of the inner (radius R_1) and outer rings (radius R_2) are $-\lambda$ and $+\lambda$ respectively. Obtain the monopole, dipole and quadrupole terms in the potential at a far point. Check validity of your result by finding leading order terms on the z-axis at a far point directly. (10)



- Monopolo term: $V_{mono} = \dfrac{1}{4\pi\epsilon_0} \dfrac{2\pi R_2 \lambda - 2\pi R_1 \lambda}{r}$

$$= \frac{\lambda}{2\epsilon_0} \cdot \frac{(R_2 - R_1)}{r}$$

1

- Dipole term is zero since for each ring

$$p_x = \int_0^{2\pi} (R\cos\varphi)(R\,d\varphi\,\lambda) = 0, \quad \text{and} \quad p_y = \int_0^{2\pi} (R\sin\varphi)(\lambda R\,d\varphi) = 0$$

1

$p_z = 0$.

- For evaluating V_{quad}, find Q (either for each ring separately or together). and then calculate total V_{quad}.

For R_1 carrying $-\lambda$: $Q_{xx} = Q_{yy} = -\dfrac{1}{2}\displaystyle\int_0^{2\pi} (3R_1^2\cos^2\varphi - R_1^2)\lambda R_1\,d\varphi$

$$= -\lambda R_1^3 \cdot \frac{1}{2} \int_0^{2\pi} (3\cos^2\varphi - 1)\,d\varphi$$

$$= -\frac{\pi\lambda R_1^3}{2}$$

$$Q_{zz} = -\frac{1}{2}\int_0^{2\pi} (-R_1^2)\lambda R_1\,d\varphi = \pi\lambda R_1^3$$

Also, can be obtained from $Q_{xx} + Q_{yy} + Q_{zz} = 0$ i.e. $Q_{zz} = -2Q_{xx}$

$$V_{quad}\Big|_{-\lambda} = \frac{1}{4\pi\epsilon_0} \cdot \frac{\pi\lambda R_1^3}{r^5} (x, y, z) \begin{pmatrix} -\frac{1}{2} & 0 & 0 \\ 0 & -\frac{1}{2} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

$$= \frac{1}{4\pi\epsilon_0} \cdot \frac{\pi\lambda R_1^3}{r^5} (x, y, z) \begin{pmatrix} -x/2 \\ -y/2 \\ z \end{pmatrix}$$

$$= \frac{1}{4\pi\epsilon_0} \cdot \frac{\pi\lambda R_1^3}{r^5} \left(-\frac{x^2}{2} - \frac{y^2}{2} + z^2\right)$$

4

$$= -\frac{1}{4\pi\epsilon_0} \frac{\pi\lambda R_1^3}{2r^5} (r^2 - 3z^2)$$

$$\therefore V_{quad}\Big|_{total} = \frac{1}{4\pi\epsilon_0}\cdot\frac{\pi\lambda\,(R_2^3 - R_1^3)}{2\,r^5}\,(r^2 - 3z^2)$$

$$= \frac{\lambda}{4\epsilon_0}\,\frac{(R_2^3 - R_1^3)}{2\,r^5}\,(r^2 - 3z^2) \qquad 2$$

On the z-axis,

For $\underline{r = z}$, $$V_{quad} = -\frac{\lambda}{4\epsilon_0}\,\frac{(R_2^3 - R_1^3)}{\cancel{2}\,z^5}\cdot\cancel{2}z^2$$

$$= -\frac{1}{4\epsilon_0}\,\frac{\lambda\,(R_2^3 - R_1^3)}{z^3}$$

On the z-axis, direct calculation $V(z)$ yields.

$$V(z) = \frac{2\pi\lambda}{4\pi\epsilon_0}\left[\frac{R_2}{(z^2+R_2^2)^{1/2}} - \frac{R_1}{(z^2+R_1^2)^{1/2}}\right] \qquad 1$$

$$= \frac{\lambda}{2\epsilon_0}\left[R_2\cdot\frac{1}{z}\left(1+\frac{R_2^2}{z^2}\right)^{-1/2} - R_1\frac{1}{z}\left(1+\frac{R_1^2}{z^2}\right)^{-1/2}\right]$$

$$= \frac{\lambda}{2\epsilon_0}\left[\frac{R_2 - R_1}{z} - \frac{1}{2}\frac{(R_2^3 - R_1^3)}{z^3} + \cdots\right]$$

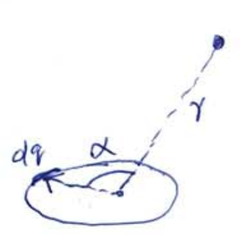
Applying Binomial expansion for $\underline{t \ll 1}$, $(1+t)^{-1/2} = 1 - \frac{1}{2}t + \frac{3}{8}t^2 + \cdots$

Hence, the first two significant terms in this expansion correspond to monopole term, and ~~dipole ter~~ quadrupole term, whereas dipole term is missing as derived more generally above. 1

Note: A direct calculation of V_{quad} of a ring using the following is problematic

$$V_{quad}\Big|_{ring} = \frac{1}{4\pi\epsilon_0}\cdot\frac{1}{r^3}\cdot\frac{1}{2}\int R^2\,(3\cos^2\alpha - 1)\,dq$$

$$= \frac{1}{4\pi\epsilon_0}\cdot\frac{1}{r^3}\cdot\frac{1}{2}\int_0^{2\pi} R^2\,(3\cos^2\alpha - 1)\,\lambda R\,d\varphi$$

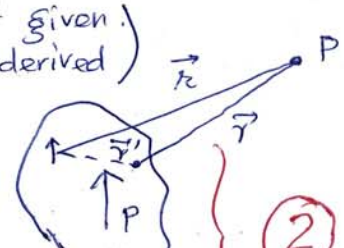


Since $\cos^2\alpha$ term is $\underline{\text{not}}$ independent of φ i.e. location of dq.

4. a) Starting from a potential of a single dipole, show that the potential at an outside far field point due an object carrying polarization $\vec{P}$ is equivalent to bound surface charge density and volume charge density, and hence find the relationship of bound charges to the given polarization vector. Specify clearly the steps and arguments.

(8)

$$V(\vec{\mathscr{r}}) = \frac{1}{4\pi\epsilon_0}\frac{\vec{p}\cdot\hat{\mathscr{r}}}{\mathscr{r}^2}$$ (Starting point given. Need not be derived)



$\vec{p} = \vec{P}\,d\tau'$ (Primed co-ordinate are source co-ordinate)

$$V(\vec{r}) = \frac{1}{4\pi\epsilon_0}\int_{\substack{\text{source}\\ \text{vol.}}} \frac{\vec{P}(\vec{r}')\cdot\hat{\mathscr{r}}}{\mathscr{r}^2}\,d\tau'$$ 2

$$= \frac{1}{4\pi\epsilon_0}\int \vec{P}\cdot\vec{\nabla}'\left(\frac{1}{\mathscr{r}}\right)d\tau'$$

Recognizing that $\vec{\nabla}'\left(\frac{1}{\mathscr{r}}\right) = \frac{\hat{\mathscr{r}}}{\mathscr{r}^2}$ 1

No negative sign if it is over source co-ordinates. 1

$$= \frac{1}{4\pi\epsilon_0}\int \vec{\nabla}'\left(\frac{\vec{P}}{\mathscr{r}}\right)d\tau' - \frac{1}{4\pi\epsilon_0}\int \frac{1}{\mathscr{r}}\left(\vec{\nabla}'\cdot\vec{P}\right)d\tau'$$

Using product rule, or integration by parts. 1

Divergence Thm. 1

$$= \frac{1}{4\pi\epsilon_0}\oint_S \frac{1}{\mathscr{r}}\vec{P}\cdot d\vec{a} - \frac{1}{4\pi\epsilon_0}\int_{\text{vol.}}\frac{(\vec{\nabla}'\cdot\vec{P})}{\mathscr{r}}\,d\tau'$$

$$= \underbrace{\frac{1}{4\pi\epsilon_0}\oint_S \frac{\vec{P}\cdot\hat{n}}{\mathscr{r}}\,da}_{\text{Potential due to an equivalent surface charge } \boxed{\sigma_b \equiv \vec{P}\cdot\hat{n}}} + \underbrace{\frac{1}{4\pi\epsilon_0}\int_{\text{vol.}}\frac{(-\vec{\nabla}'\cdot\vec{P})}{\mathscr{r}}\,d\tau'}_{\text{Potential due to a volume charge } \boxed{\rho_b \equiv -\vec{\nabla}\cdot\vec{P}}}$$ 2

b) Consider a long circular cylinder of radius R made of a homogeneous linear dielectric material of dielectric constant k with its long axis aligned along z-axis.

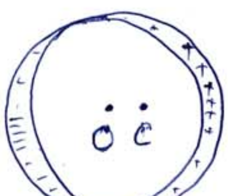
i) If it carries a frozen uniform polarization $\vec{P} = P_0\hat{\imath}$ perpendicular to the long axis, find the field inside the dielectric.

ii) If the cylinder (without any prior frozen-in polarization) is placed in an external electric field $\vec{E} = E_0\hat{\imath}$, **find the field inside the dielectric assuming that the field inside is uniform under these conditions.**

iii) Give a neat sketch of $\vec{D}$ lines in a plane containing the cross-section of the cylinder.

(12)

i)



Identifying bound charge

$\sigma_b = P_0 \cos\theta$ 1

$\rho_b = 0$

- System equivalent to two uniformly charged cylinders ρ_+ and ρ_-

$\vec{E}_+ = \frac{\rho_+}{2\epsilon_0}\vec{r}_+$, $r_+ < R$ (Gauss Law used for a long cylinder) 2

$\vec{E}_- = -\frac{\rho}{2\epsilon_0}\vec{r}_-$, $r_- < R$

$\therefore \vec{E} = \frac{\rho}{2\epsilon_0} d\,(-\hat{\imath})$, where $d = OC$ 1
A constant electric field.

Note: $\vec{P}(\pi R^2 \ell) = (\rho\,\pi R^2 \ell)(-d\,\hat{\imath})$, ℓ is any length

$\Rightarrow \rho d = P_0$ and $\boxed{\vec{E} = -\frac{\vec{P}}{2\epsilon_0}}$ for $r<R$. 1

(ii) $\vec{E}_1 = \vec{E}_0 - \frac{\vec{P}}{2\epsilon_0}$ —— 1

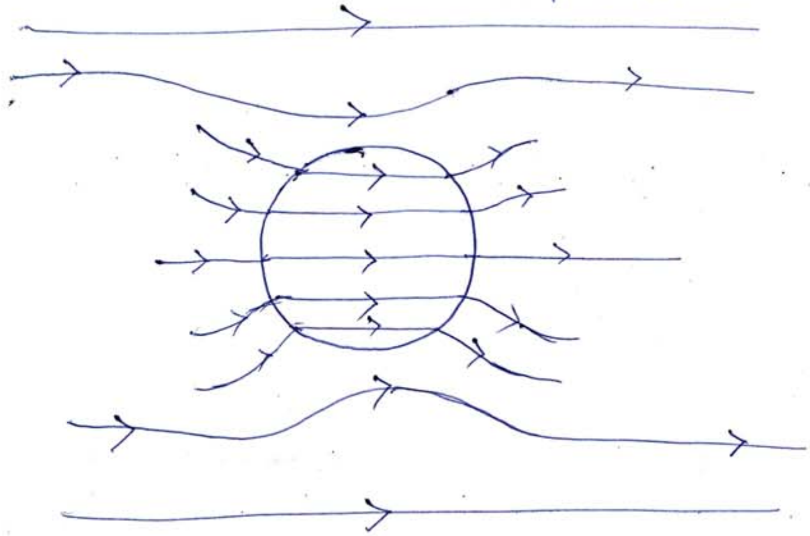
$= \vec{E}_0 - \frac{(k-1)\epsilon_0\vec{E}_1}{2\epsilon_0}$ —— 2

$\Rightarrow \vec{E}_1 + \frac{(k-1)}{2}\vec{E}_1 = \vec{E}_0$

$\Rightarrow \boxed{\vec{E}_1 = \left(\frac{2}{k+1}\right)\vec{E}_0}$ —— 1

iii) $\vec{D}$ Sketch

$\vec{D} = \epsilon_0 \vec{E} + \vec{P}$



- Inside direction and uniform (1)
- Sufficient number of lines and continuous (1)
- Outside curvature essentially as $\epsilon_0 \vec{E}$. (1)