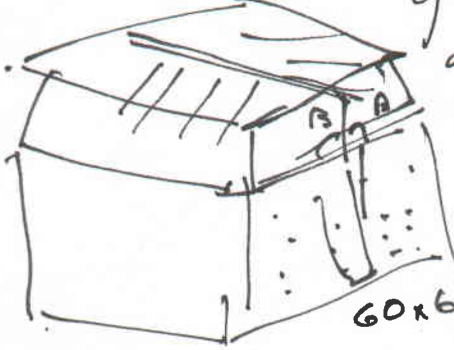
By letting the charge distribution be a series of point charges, we can represent it as a sum of points times delta functions and take an integral around them, to find an expression for total charge



60x60 lattice

Take a volume integral around a vertical line of delta charges, right below wire. Symmetric across half plane

$$\nabla\cdot\vec{F} = \alpha\rho \qquad \rho = \sum_{ij}\sigma_{ij}\,\delta(\vec{r}-\vec{r}_{ij})$$

$$\alpha := -\frac{e^2}{\epsilon_0\epsilon_R}$$

$$\sigma_{ij} = \sum_{i'j'}\lambda_{ij}\,\delta(\vec{r}-\vec{r}_{i'j'})$$

$$\oint_c \nabla\cdot\vec{F}\,\partial r = \oint_c \alpha\sum_{ij}\sigma_{ij}\,\delta(\vec{r}-\vec{r}_{ij})\,\partial r$$

~~Loop~~ integral (closed) → Select single sheet $\lambda_{ij} = \sum_{kl} q_{kl}\,\delta(\vec{r}-\vec{r}_{kl})$

$\nabla\cdot\vec{F} = F_x + F_y + F_z$ (By definition)

$F_z = 0$ (translational symmetry)

$$\oint_c F_x + F_y\;\partial r = \int_{-B}^{B} F_x + F_y\;\partial x \qquad \text{Along top axis cause edges cancel (reflectional symmetry)}$$

$$= \int_{-B}^{B} F_x\,\partial x \qquad \Rightarrow F_y \text{ also cancels}$$

$$\alpha\oint_c \sum_{ij}\sigma_{ij}\,\delta(\vec{r}-\vec{r}_{ij})\,\partial r \Longrightarrow \alpha\oint_c\sum_{ij}\lambda_{ij}\,\delta(\vec{r}-\vec{r}_{ij})\,\partial r$$

$$= \alpha\,\lambda_{ij} = \alpha\cdot\text{Total charge in that line}$$

$$\int_{-B}^{B} F_x\,\partial x = -\frac{e^2}{\epsilon_0\epsilon_R}\lambda_B$$

Increasing/Decreasing B without encompassing more point charges wont change RHS) so we can treat LHS as point forces above each line → b/c line is centered btw unit cells, $\lambda_B \mapsto 2\lambda_B$ and same reasoning applies

Let $\gamma > \beta$ by one unit cell

$$\int_{-\gamma}^{\gamma} F_x\,\partial x = \int_{-B}^{B} F_x\,\partial x + 2F_\gamma = -\frac{e^2}{\epsilon_0\epsilon_R}(\lambda_B + 2\lambda_\gamma) \Rightarrow \boxed{F_\gamma = -\frac{e^2}{\epsilon_0\epsilon_R}\lambda_\gamma}$$

Summing gives $\int F_x\,\partial x = -\frac{e^2}{\epsilon_0\epsilon_R}2\lambda_\gamma$

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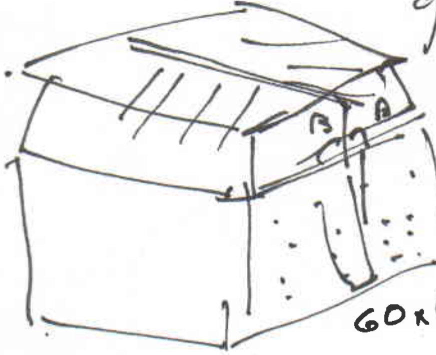

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$$\oint_c \nabla \cdot \vec{F} \, \partial r = \oint_c \alpha \sum_{ij} \sigma_{ij} \delta(\vec{r} - \vec{r}_{ij}) \, \partial r \qquad \sigma_{ij} := \sum_{i'j'} \lambda_{ij} \delta(\vec{r} - \vec{r}_{i'j'})$$

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$$\alpha \oint_c \sum_{ij} \sigma_{ij} \delta(\vec{r} - \vec{r}_{ij}) \, \partial r \Rightarrow \alpha \oint_c \sum_{ij} \lambda_{ij} \delta(\vec{r} - \vec{r}_{ij}) \, \partial r$$

$$\int_{-B}^{B} F_x \, \partial x = -\frac{e^2}{\epsilon_0 \epsilon_R} \lambda_{B} \qquad = \alpha \lambda_{ij} = \alpha \cdot \text{Total charge in that line}$$

Let $\gamma > B$ by one unit cell

Increasing/decreasing B without encompassing more point charges wont change RHS) so we can treat LHS as point forces above each line → if line is centered btw unit cells, $\lambda_B \mapsto 2\lambda_B$ and same reasoning applies

$$\int_{-\gamma}^{\gamma} F_x \, \partial x = \int_{-B}^{B} F_x \, \partial x + 2F_\gamma = -\frac{e^2}{\epsilon_0 \epsilon_R} (\lambda_B + 2\lambda_\gamma) \Rightarrow \boxed{F_\gamma = -\frac{e^2}{\epsilon_0 \epsilon_R} \lambda_\gamma}$$

Summing gives $\int F_x \, \partial x = -\frac{e^2}{\epsilon_0 \epsilon_R} 2\lambda_\gamma$

$$\frac{\lambda}{2\pi\epsilon_1\epsilon_0 r}\cdot\frac{H}{r}$$

$$\int_{-\alpha}^{\alpha}\mathcal{E}_N\,\partial y = \frac{\lambda}{\cancel{2}\pi\epsilon_1\epsilon_0}\arctan\left(\frac{\alpha}{H}\right)$$

ρ

$$\oint_{\partial\Omega}\nabla\cdot\vec{\mathcal{E}}\,\partial r = \int\frac{\sum\rho_{ij}\delta(\vec{r}-\vec{r}_{ij})}{\epsilon_2\epsilon_0} = \frac{e\tilde{\rho}_\Sigma}{\epsilon_2\epsilon_0}$$

treat it as $[\tilde{\rho}_\Sigma] = \frac{1}{m}\delta$ cause integrating cancels

$\tilde{\rho}_\Sigma$ is a scalar multiple

electron charge

$$= \int_{-\alpha}^{\alpha}\mathcal{E}_N\,\partial y = \frac{\lambda}{\pi\epsilon_1\epsilon_0}\arctan\left(\frac{\alpha}{H}\right)$$

Both sides in volts

$$\tilde{\rho}_\Sigma = \left(\frac{\epsilon_2}{\epsilon_1}\right)\left(\frac{\lambda}{e\pi}\right)\arctan\left(\frac{\alpha}{H}\right)$$

~~Let $\frac{\lambda}{e}$ be~~

Let $\tilde{\lambda} = \frac{\lambda}{e}$ be a multiple of electron charge

re $\tilde{\lambda} = 10^6$ electrons/meter

$$\tilde{\rho}_\Sigma = \left(\frac{\epsilon_2}{\epsilon_1}\right)\left(\frac{1}{\pi}\right)\arctan\left(\frac{N}{2H}\right)\tilde{\lambda}$$

sheet line point

$$\nabla\cdot\nabla V = \nabla^2 V = \frac{\rho}{\epsilon_2\epsilon_0} = \frac{\sum\rho_{ij}\delta(\vec{r}-\vec{r}_{ij})\delta_2\delta_3}{\epsilon_2\epsilon_0} = \frac{e}{\epsilon_2\epsilon_0}\sum_{ijxyz}\tilde{\rho}_{ij}\,\delta(\vec{r}-\vec{r}_{ij})\delta(\vec{r}-\vec{r}_{xy})\delta(\vec{r}-\vec{r}$$

I need V in volts, so U will be in eV $[\delta]=\frac{1}{m}$, $[e]=C$, $[\tilde{\rho}_{ij}]=$

$[\epsilon_0]=\frac{F}{m}$

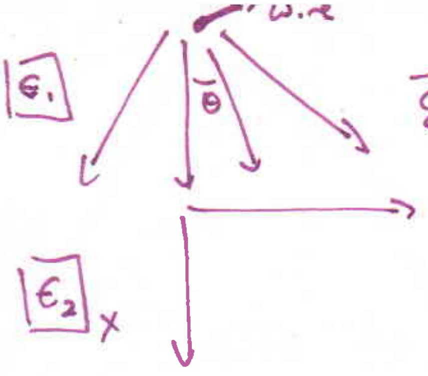
$$\nabla^2 = \frac{\partial^2}{\partial x^2} \mapsto \frac{\partial^2}{\partial\left(\frac{x}{a}\right)^2} = \frac{\tilde{\nabla}^2}{a^2}$$

$\longrightarrow$ $\frac{V}{m^2} = \frac{C}{(F/m)}\cdot\frac{1}{m^3} = \frac{V}{m^2}$

$\frac{x}{a}=1$

$a = 3\times10^{-10}\,m$ $\quad\tilde{\nabla}^2 V = a^2\cdot\frac{e}{\epsilon_2\epsilon_0}\sum\rho_{ij}\,\delta_1\delta_2\delta_3$

Just call a the base unit, convert ϵ_0, δ to a



$= \langle \mathcal{E}_N , \mathcal{E}_T \rangle$

$$\vec{\mathcal{E}} = \left\langle \frac{\lambda H}{2\pi\epsilon_1 r^2}, \frac{\lambda y}{2\pi\epsilon_1 r^2} \right\rangle$$

$\mathcal{E}_x = |\mathcal{E}|\cos\theta$ $\quad |\mathcal{E}| = \frac{\lambda}{2\pi\epsilon r}$ $\quad \mathcal{E}_y = |\mathcal{E}|\sin(\theta)$

$r = \sqrt{H^2 + y^2}$

$\cos\theta = \frac{H}{r}$

$\sin\theta = y/r$

$x = H$ is fixed

$8\pi R = \frac{e^2}{\epsilon_0 a_0}$

$a =$ Unit cell $= 3.904$ Å
$H = 12$ Å $= 3.074\, a$
$\epsilon_1 = 10$
$\epsilon_R = \epsilon_2 = 5$

$$\int_{-\alpha}^{\alpha} \vec{\mathcal{E}}\, dy = \left\langle \frac{\lambda H}{2\pi\epsilon_1\epsilon_0} \int_{-\alpha}^{\alpha} \frac{1}{H^2+y^2}\, dy , 0 \right\rangle$$

$$= \frac{\lambda}{2\pi\epsilon_1\epsilon_0}\left(\arctan\left(\frac{\alpha}{H}\right) - \arctan\left(-\alpha/H\right)\right)$$

$$= \frac{\lambda}{\pi\epsilon_1\epsilon_0}\arctan\left(\frac{\alpha}{H}\right)$$

MM = y axis = 20
NN = λ axis = 10

$\alpha = \frac{MM}{2} \cdot a = 10\, a$

$\lambda = \frac{\pi}{.0137}$ (for convenience) $\left(\frac{\text{Coulombs}}{\text{Unit cell length}}\right)$

$$\oint \nabla \cdot \vec{F} = -\frac{e^2}{\epsilon_0 \epsilon_R}\lambda_{ij} = e\int_{-\alpha}^{\alpha} \mathcal{E}_N dy \qquad \lambda \text{ is a (integer) multiple of electron charge}$$

$$= e\int_{-\alpha}^{\alpha} \mathcal{E}\, dy = -\frac{e^2}{\epsilon_0\epsilon_R}\rho_{ij} = \frac{e\lambda}{\pi\epsilon_1\epsilon_0}\arctan\left(\frac{\alpha}{H}\right) \qquad \epsilon_R := \epsilon_2$$

$$\int \mathcal{E}\, dy = -\frac{e}{\epsilon_0\epsilon_R}\rho_\Sigma$$

$\frac{\epsilon_0}{e} = 55\ 263\ 496 \frac{F}{m \cdot C}$
$= 55 \ldots \frac{1}{V \cdot m}$
$= 55 \ldots \frac{1}{V \cdot m}\left(\frac{m}{10^{10}\text{Å}}\right)\left(\frac{3.9\ldots}{a}\right)$
$= \boxed{2.15748 \times 10^{-2} \frac{1}{V a}}$

$[\lambda] = \frac{C}{m}$

$$\rho_\Sigma = -\frac{\epsilon_0\epsilon_R}{e}\int \mathcal{E}\, dy = -\left(\frac{\epsilon_0}{e}\right)\left(\frac{\epsilon_R}{\epsilon_1}\right)\left(\frac{\lambda}{\pi}\right)\arctan\left(\frac{\alpha}{H}\right)$$

$\left[\frac{\lambda}{\epsilon_1}\right] = \frac{V}{m}$

$$\rho_\Sigma = -\frac{1}{2}\arctan\left(\frac{39.04}{12}\right)(.0215748) \cdot \left(\frac{\pi}{.0137(\pi)}\right)$$

$[$

$= 1$

$[\rho_\Sigma] = \frac{V}{a} \cdot \frac{C}{a}$

$\boxed{\frac{e}{\epsilon_0} = 46.3504 \frac{1}{a \cdot V}}$

$$\nabla \cdot \vec{\mathcal{E}} = -\frac{e}{\epsilon_0\epsilon_R}\rho_{ij} = -46.3504\left(\frac{1}{5}\right)$$

$$\sum \rho_{ij} = \rho_\Sigma = 1$$

$$\mathcal{E}_N = \frac{\pi}{(.0137)} \cdot \frac{1}{2\pi(10)} \cdot \frac{3.074}{\left(3.074^2 + \left(x - \frac{Lx}{2}\right)^2\right)}$$

1. $\epsilon_1 = 5, 10$ $\quad \epsilon_2 = 5$
2. Line source
3. Constant $\mathcal{E}$ (Capacitor)

$$\nabla^2 V = \nabla \cdot \vec{E} = \frac{\rho_{ij}'}{\epsilon_2 \epsilon_0} \qquad [\rho] = \frac{c}{m^3}$$

$$\left.\begin{aligned}[\nabla^2 V] &= \frac{V}{m^2} \\ [\epsilon_0] &= \frac{c}{Vm}\end{aligned}\right\} \cancel{[\epsilon_0 \nabla^2 V] = \frac{V}{m^2}\frac{cm}{V} = \frac{c}{m}}$$

$$Q = CV \qquad C = \frac{V}{Q} \qquad \cancel{C = FV} \qquad \boxed{F = \frac{C}{V}}$$

$$\rho_{ij} = \lambda_{ij}\, \delta(x - x_0)\, \delta(y - y_0) \qquad [\lambda_{ij}] = \frac{c}{Im}$$

$$\int \frac{\rho_{ij}}{|e|}\, dx\, dy = \frac{\lambda_{ij}}{|e|} \rightarrow \frac{1}{L} \qquad \frac{\epsilon_2 \lambda}{2\epsilon_1}$$

$$V \rightarrow \frac{e}{L} \frac{Vm}{C}$$

$$[\nabla^2 V] = \frac{V}{L^2}$$

$$[\epsilon_0] = \frac{c}{Vm}$$

$$\Rightarrow [\epsilon_0 \nabla^2 V] = \frac{V}{L^2} \frac{c}{Vm} = \frac{c}{L^3}$$

$$\Rightarrow [\rho] = \frac{c}{L^3}$$

Define $\rho(x, y) = \sum_{ij} e \lambda_{ij}\, \delta(x - x_0)\, \delta(y - y_0)$

$$[\lambda_{ij}] = \frac{1}{L} \Longrightarrow [\rho] = \frac{e}{L^3}$$

$$(a\nabla)^2 \longrightarrow \tilde{\nabla}^2 \Longrightarrow \tilde{\nabla}^2 V = \frac{a^2 \rho(x,y)}{\epsilon_0 \epsilon_r} = \left(\frac{e}{\epsilon_0 \epsilon_r a_0}\right)\left(\frac{a_0}{a}\right) \underbrace{a^3 \rho(x,y)}$$

$$\tilde{\rho} = \frac{a^3 \rho(x,y)}{|e|} = \sum_{ij} \underbrace{a^3 \lambda\, \delta(x - x_0)\, \delta(y - y_0)}_{\tilde{\lambda}\ a\delta(x - x_0)\ a\delta(y - y_0)} \Longrightarrow \tilde{\lambda}\, \delta(\tilde{x} - \tilde{x}_0)\, \delta(\tilde{y} - \tilde{y}_0)$$

$$\oint_C \nabla \cdot \vec{F} \, \partial r$$

$$\nabla \cdot \vec{F} = -\frac{e^2 \rho}{\epsilon_0 \epsilon_R} \qquad \rho = \sum_{ij} \sigma_{ij} \cdot \delta(r - r_{ij}) = \sigma_{xy} \cdot \delta(r - r_{xy}) \quad \text{Single sheet}$$

$$\sigma_{xy} = \sum_{ij} \lambda_{ij} \, \delta(r - r_{ij})$$

$$\oint_C \nabla \cdot \vec{F} \, \partial r = \oint -\frac{e^2 \rho}{\epsilon_0 \epsilon_R} \, \partial r$$

$$\oint F_x + F_y \, \partial r$$

$$\cancel{\oint \mathcal{E}(x) \, \partial x}$$

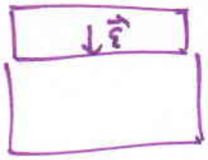
$$\int \mathcal{E}(x) \, \partial x = -\frac{e^2}{\epsilon_0 \epsilon_R} \oint \rho \, \partial r = \frac{e^2}{\epsilon_0 \epsilon_R} \int \sum \lambda_{ij} \, \delta(r - r_{ij}) \, \partial r$$

$$= \frac{e^2}{\epsilon_0 \epsilon_R} \sum \lambda_{ij} = q \cdot \text{TOTAL CHARGE}$$

(Since $F = \mathcal{E}$ except for units) x

Write ρ as a multiple of electron charge?

With a constant boundary electric field



$|\vec{\mathcal{E}}| = \gamma$, $\oint_{\partial\Omega} \nabla\cdot\vec{\mathcal{E}}\,\partial r = \int_{-\infty}^{\infty} \mathcal{E}\,\partial y = \gamma\cdot y\Big|_{-\infty}^{\infty} = 2\gamma\alpha = \gamma\cdot MM$

$\alpha_{max} = \frac{MM}{2}\cdot a$

$\rho_\Sigma = -\frac{\epsilon_0\epsilon_R}{e}\oint_{\partial\Omega}\nabla\cdot\vec{\mathcal{E}}\,\partial r = -\left(\frac{\epsilon_0}{e}\right)\epsilon_R\cdot\gamma MM$

$\nabla\cdot\vec{\mathcal{E}} = -\frac{e}{\epsilon_0\epsilon_R}\rho_{ij}$

$|\vec{\mathcal{E}}_N| = \frac{\lambda H}{2\pi\epsilon_1\epsilon_0 r^2}$ $\quad [\epsilon_0] = \frac{F}{m}$ $\quad C = FV$

$[\mathcal{E}_N] = \frac{m}{\frac{F}{m}\cdot m^2}\cdot\frac{C}{m} = \frac{V}{m}$

$\rho = -\frac{1}{e}\left(\frac{\epsilon_2}{\epsilon_1}\right)\left(\frac{\lambda}{\pi}\right)\arctan\left(\frac{\alpha}{H}\right) = \frac{\epsilon_0\epsilon_R}{e}\int\mathcal{E}\,\partial y$

$[\rho] = \frac{C}{m}\cdot\frac{F}{m\cdot C}\cdot V = \frac{V}{m^2}$ $\qquad \frac{F}{mC}\cdot V = \frac{1}{m}$

$\int\mathcal{E}\,\partial y = \frac{\lambda}{\pi\epsilon_1\epsilon_0}\arctan\left(\frac{\alpha}{H}\right)$ for sure, units = V

$\int\mathcal{E}\,\partial y = -\frac{e}{\epsilon_2\epsilon_0}\rho_\Sigma$ $\qquad \rho_\Sigma$ is a multiple of electron charge

$\tilde{n}$ $\qquad [\tilde{n}] = \emptyset$ $\quad [\rho_\Sigma] = \emptyset$ $\quad \left[\frac{\epsilon_0}{e}\right] = V$

$V = \frac{m}{V}$

$\int\mathcal{E}\,dy = V = \int\frac{1}{\epsilon_0\epsilon_2}\sum\lambda_{ij}\delta(\vec{r}-\vec{r}_{ij})\,\partial r = \int$

$\frac{V}{m} = \frac{m}{F}\cdot\frac{C}{m^2} = \frac{V}{m}$

$25^2\cdot 9$

$\int\mathcal{E}\,\partial y = \frac{1}{\epsilon_0\epsilon_2}\sum\lambda_{ij}$

integrate to get single sheet

$\int\mathcal{E}\,\partial y = \frac{1}{\epsilon_0\epsilon_2}\cdot\rho_\Sigma = \frac{e}{\epsilon_0\epsilon_2}\tilde{\rho}$ $\qquad \tilde{\rho}\in\mathbb{Z}^+$

$= \frac{\lambda}{\pi\epsilon_1\epsilon_0}\arctan\left(\frac{\alpha}{H}\right) \Longrightarrow \tilde{\rho} = \left(\frac{\epsilon_2}{\epsilon_1}\right)\cdot\frac{1}{\pi}\left(\frac{\lambda}{e}\right)\arctan\left(\frac{\alpha}{H}\right)$

$$\mathcal{E} = \frac{\lambda}{2\pi\epsilon_1\epsilon_0}\frac{H}{r^2} = \frac{e\tilde{\lambda}}{2\pi\epsilon_1\epsilon_0\left(\frac{H}{a}\right)}\cdot\frac{1}{r^2}$$

$$= \left(\underbrace{\frac{e}{a_0\epsilon_0}}_{8\pi R}\right)\left(\frac{1}{2\pi\epsilon_1}\right)\left(\frac{a_0}{a}\right)\tilde{\lambda}\cdot\frac{H}{r^2}$$

$$\frac{8\pi R\alpha}{2\pi\epsilon_1}\cdot\tilde{\lambda}^a\cdot\boxed{\frac{H}{r^2}}$$

Want $\left[\frac{H}{r^2}\right] = \frac{1}{m}$

$$\frac{12\mathring{A}}{(12\mathring{A}^2 + j^2a^2\mathring{A})} = \frac{1}{\mathring{A}}\frac{12}{(12^2+j^2a^2)}\cdot\frac{10^{10}\mathring{A}}{10^{-10}m} = \frac{10^{10}\cdot 12}{12^2+j^2c^2}$$

$R = 13.6$ ~~eV~~

$$k = \frac{e^2}{8\pi\epsilon_0 a_0}$$

$$\frac{e^2}{\epsilon_0 a_0} = 8\pi R \ \text{eV} \implies \frac{e}{\epsilon_0 a_0} = 8\pi R \ \text{V}$$

$$\frac{e\tilde{\lambda}}{a} = \lambda \qquad \frac{\lambda}{\pi\epsilon_0\epsilon_1}\arctan\left(\frac{L}{2H}\right) = \frac{1}{\epsilon_2}\left(\frac{e}{\epsilon_0 a_0}\right)\left(\frac{a_0}{a}\right)\sum_{ij}\int \frac{\partial x}{a}\frac{\partial y}{a}\, a^3\tilde{\rho}_{ij}$$

$$\cancel{a^3\tilde{\rho}_{ij} = \left(\frac{\epsilon_2}{\epsilon_1}\right)\left(\frac{a}{e}\right)\cdot\frac{1}{\pi}\arctan\left(\frac{L}{2H}\right)\lambda}$$

$$\boxed{a^3\tilde{\rho}_\Sigma = \left(\frac{\epsilon_2}{\epsilon_1}\right)\frac{1}{\pi}\arctan\left(\frac{L}{2H}\right)\tilde{\lambda}}$$

$\tilde{\lambda}$ is electrons per ~~unit cell~~

$$\tilde{\nabla}^2 V = \frac{1}{\epsilon_2}\underbrace{\left(\frac{e}{\epsilon_0 a_0}\right)}_{8\pi R}\underbrace{\left(\frac{a_0}{a}\right)}_{\left(\frac{.53\,\text{Å}}{3.9\,\text{Å}}\right)}\sum_{ij} a^3\tilde{\rho}_{ij}$$

$a = 3.904$ Å
$H = 12$ Å
$a_0 = .529$ Å

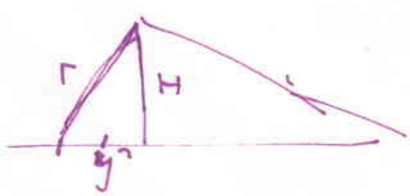
$C = FV$

$$\frac{e}{\epsilon_0 a_0} \approx \frac{1.6\times10^{-19}}{(8\times10^{-12})(.5\times10^{-10})} = .4\times10^{3}\ \text{V} \approx 400\,\text{V} = 8\pi R$$

$$\frac{e}{\epsilon_0} = \frac{1.6\times10^{-19}}{8.8\times10^{-12}} = .18\times10^{-7} = 1.8\times10^{-8}$$

$$\mathcal{E} = \frac{\lambda}{2\pi\epsilon_1\epsilon_0}\frac{H}{r^2}$$

$$= \frac{e\tilde{\lambda}}{2\pi\epsilon_1 a\epsilon_0}\cdot\frac{H}{r^2}$$



$r^2 = H^2 + y^2$

$\epsilon_0 = 8.854\times10^{-12}$
$a = 3.9\times10^{-10}$ m
$e = 1.6\times10^{-19}$ C
$H = 12\times10^{-10}$ m
$r^2 = H^2 + y^2$ m

$$= \frac{\tilde{\lambda}}{2\pi\epsilon_1}\left(\frac{e}{\epsilon_0}\right)\left(\frac{H}{a}\right)\cdot\frac{1}{r^2}$$

Let stepsize $\Rightarrow j = y$

$r^2 = \left(\frac{H}{a}\right)^2 + j^2 \quad \frac{H}{a} = 3.09$ unit cells