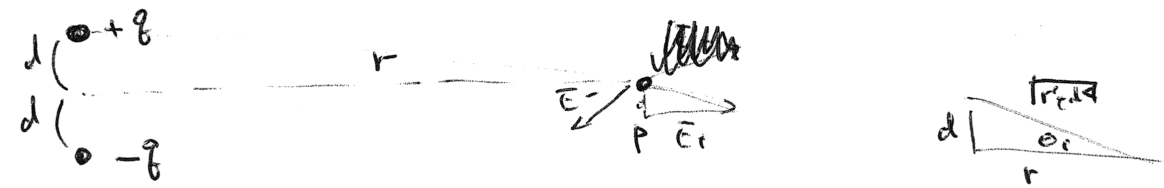
WEEK 2

ELECTRIC DIPOLE (EXAMPLE X)



$$|\vec{E}_+| = \frac{1}{4\pi\epsilon_0} \frac{q}{(\sqrt{r^2+d^2})^2}$$

∴ ONLY y COMPONENTS ADD

$$|\vec{E}_+ + \vec{E}_-| = 2|E_{+y}| = 2\frac{1}{4\pi\epsilon_0} \frac{q}{r^2+d^2} \cdot \frac{d}{\sqrt{r^2+d^2}}$$

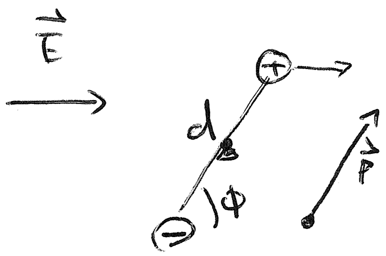
$$|E_{+y}| = |E_+| \sin\theta \qquad = \frac{1}{2\pi\epsilon_0} \frac{qd}{(r^2+d^2)^{3/2}}$$

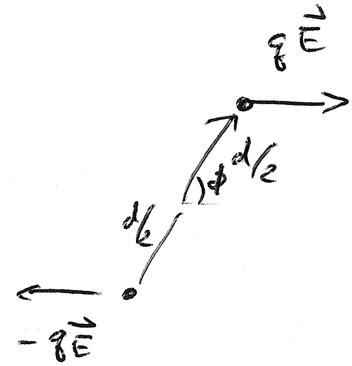
$$\sin\theta = \frac{d}{\sqrt{r^2+d^2}}$$

$$\left[\, |\vec{E}_+ + \vec{E}_-| = 2|E_+|(\sin\theta) \,\right]$$

$$\lim_{r\to\infty} |E_{TOTAL}| = \frac{1}{2\pi\epsilon_0}\frac{q\,d}{r^3}$$

$$\sim \frac{1}{r^3}$$



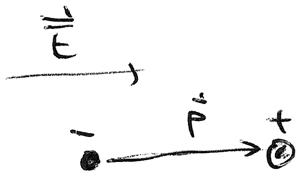


$$\vec{\tau} = (-\hat{k})\left[\,q\vec{E}\ d/2\ \sin\phi + q\vec{E}\,\frac{d}{2}\sin\phi\,\right]$$

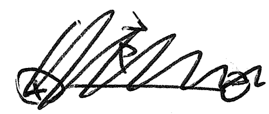
$$= -\hat{k}\ qEd\sin\phi$$

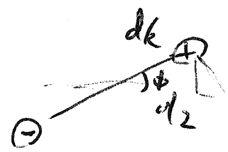
$$\underline{\vec{\tau} = \vec{p}\times\vec{E}}\ \checkmark$$

POTENTIAL ENERGY OF DIPOLE



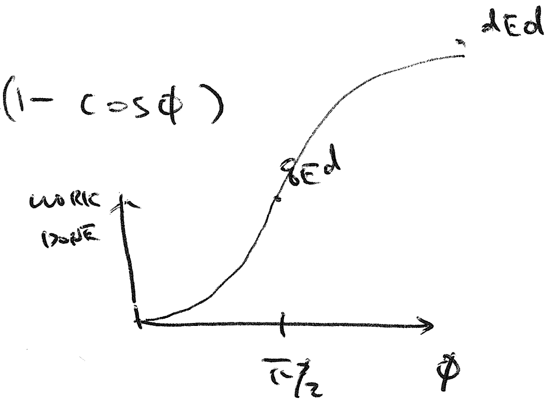
LOWEST



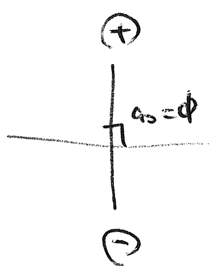


$$qE\,\tfrac{d}{2}(1-\cos\phi) + qE\,\tfrac{d}{2}(1-\cos\phi)$$

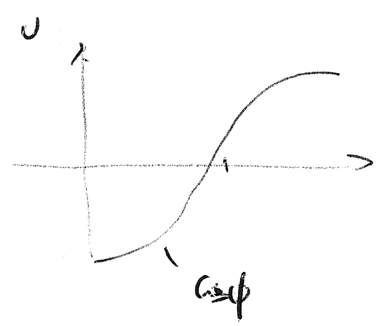
WORK $=$ $qEd(1-\cos\phi)$



DEFINE

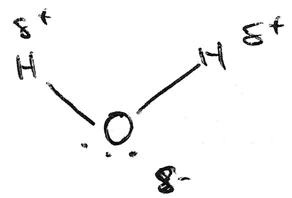


$U=0$



~~WORK~~ $U = -\vec{p}\cdot\vec{E}$

EXAMPLE WATER

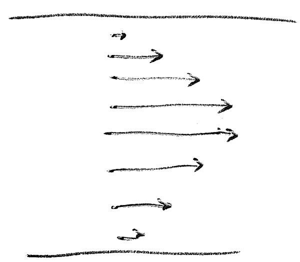


$\uparrow \vec{p}$

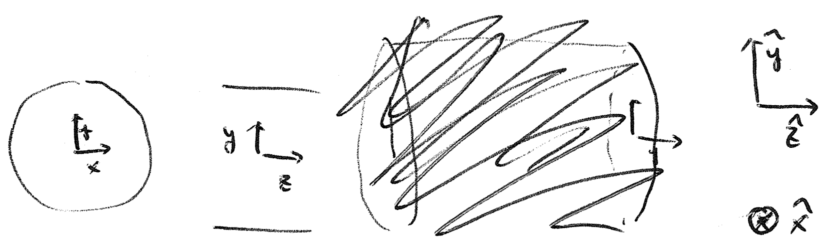
GAUSS'S LAW

CONSIDER A PIPE WITH WATER FLOWING INSIDE OF IT

CROSS SECTION



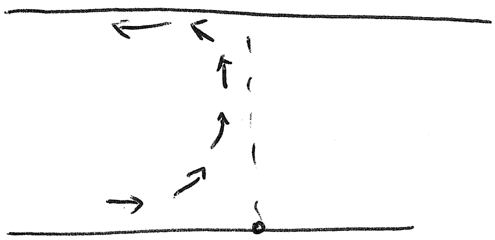
VELOCITY DISTRIBUTION



$V_z(x,y)$: VELOCITY OF FLUID IN Z DIRECTION

(~~AVERAGE VELOCITY~~)

FLOW = $\int V_z(x,y)\,dx\,dy$

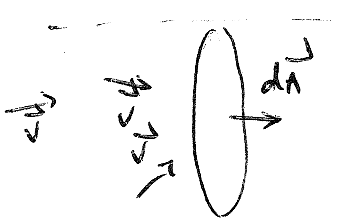


FLOW HERE IS 0

SINCE $\int V_z \, dx \, dy = 0$

IN VECTOR FORM

$$V_z = \vec{v} \cdot d\vec{A}$$

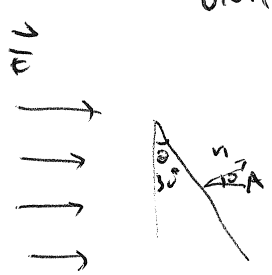


FLOW = "FLUX" = $\int_{SURFACE} \vec{v} \cdot d\vec{A}$

$$\text{ELECTRIC FLUX} = \int_{SURFACE} \vec{E} \cdot d\vec{A} = \oint \vec{E} \cdot \hat{n} \cdot ds = \Phi$$

EXAMPLE #1

UNIFORM ELECTRIC FIELD TILTED PLANE

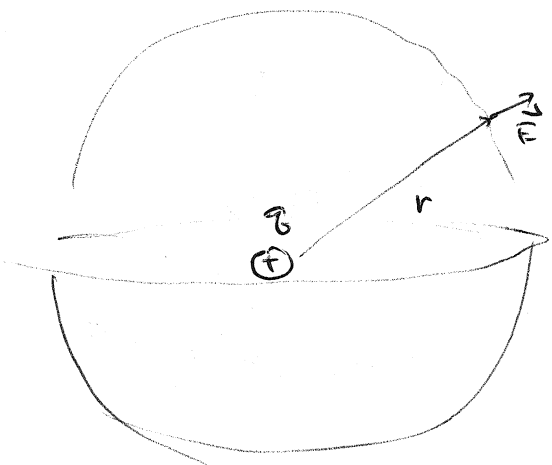


$$\vec{E} \cdot \vec{n} = |\vec{E}||\hat{n}| \cos\theta$$

$$= \frac{\sqrt{3}}{2} E$$

$$\Phi = \oint \frac{\sqrt{3}}{2} E \, d\vec{s} = \boxed{\frac{\sqrt{3}}{2} E A}$$

EXAMPLE # 1



FLUX THRU SPHERE

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\,\hat{r}$$

$$\text{FLUX} = \Phi = \int \vec{E}\cdot d\vec{A}$$

$$\left[\vec{E}\cdot d\vec{A} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\,d\vec{A}\right]$$

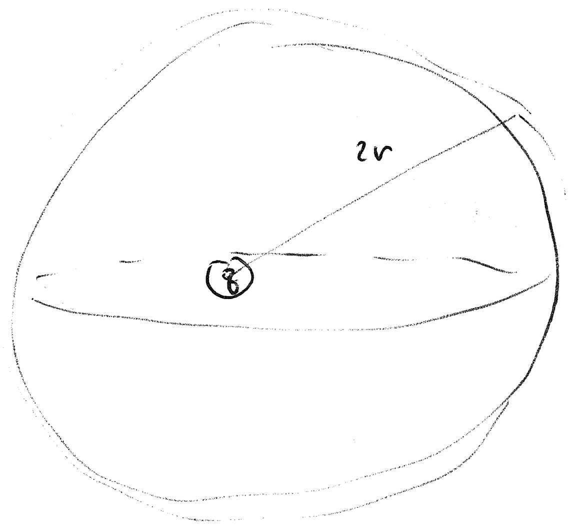
$$\Phi = \int \vec{E}\cdot d\vec{A} = |E|\int d\vec{A}$$

$$= |\vec{E}|\cdot\vec{A}$$

$$= |\vec{E}|\cdot 4\pi r^2$$

$$\Phi = \frac{q}{\varepsilon_0}$$

EXAMPLE #3



$$\Phi = |E| A \Rightarrow$$

$$|E| = \frac{1}{4\pi\varepsilon_0} \frac{q}{(2r)^2}$$

$$A = (2r)^2 4\pi$$

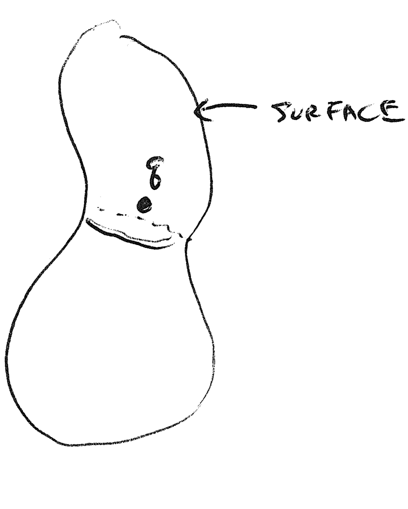
$$|E| A = \frac{1}{\cancel{4\pi\varepsilon_0}} \frac{q}{\cancel{(2r)^2}} \cancel{(2r)^2} \cancel{4\pi}$$

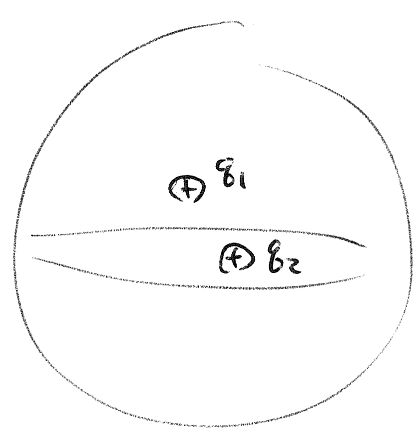
$$= \frac{q}{\varepsilon_0}$$

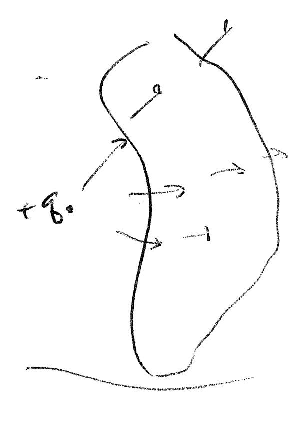
FRIDAY

GAUSS'S LAW

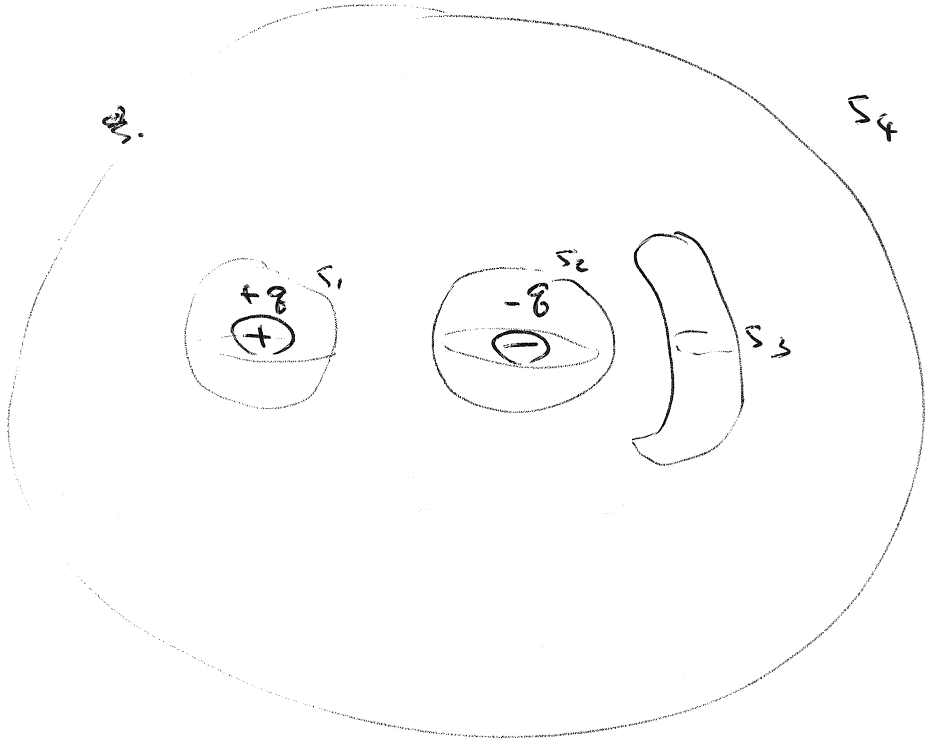
$$\Phi = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{ENCLOSED}}{\varepsilon_0}$$







$$\Phi = \frac{q_1}{\varepsilon_0} + \frac{q_2}{\varepsilon_0} = \frac{q_1 + q_2}{\varepsilon_0} = \frac{q_{TOTAL}}{\varepsilon_0}$$



$$\Phi_{S_1} = \frac{q}{\varepsilon_0} \qquad \Phi_{S_2} = -\frac{q}{\varepsilon_0} \qquad \Phi_{S_3} = \frac{0}{\varepsilon_0}$$

$$\Phi_{S_4} = 0$$

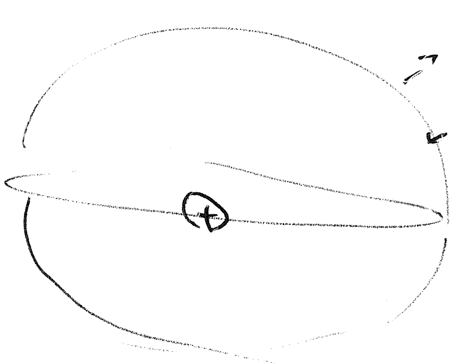
~~HOW DO WE USE IT? (TO CALCULATE $\vec{E}$?)~~

I.e. WHEN CAN WE USE IT TO CALCULATE $\vec{E}$?

1. IF YOU CAN DEFINE CONSTANT $|\vec{E}|$ SURFACE OVER WICH $\vec{E} \cdot d\vec{A}$ IS KNOWN
2. $\vec{E} = 0$ AT SOME SURFACE

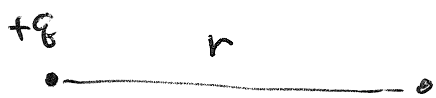
1. CAN BE KNOWN ~~AS~~ BY SYMMETRY.

I.e.



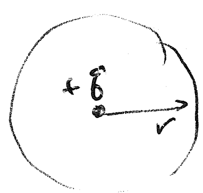
SURFACE (SPHERICAL SYMMETRY)

EXAMPLE # 1



WHAT IS $\vec{E}$ AT THIS POINT?

1. DRAW SURFACE W/ CONSTANT $\vec{E}$



2. FIND ENCLOSED CHARGE

$$+q$$

3. APPLY GAUSS'S LAW

$$\text{AREA} = 4\pi r^2$$

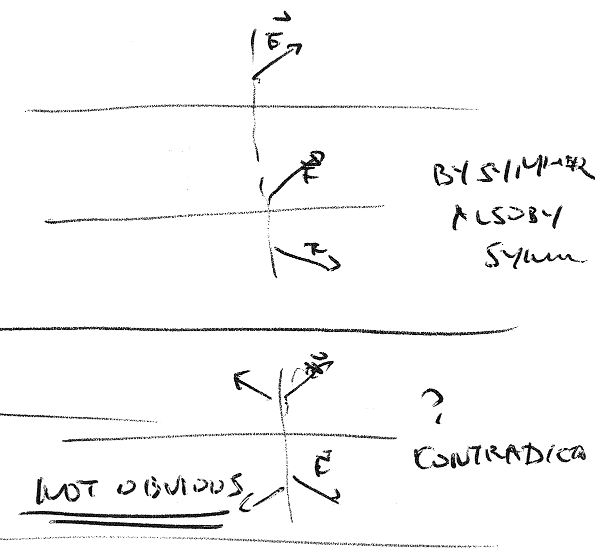
$$\Phi = E \cdot 4\pi r^2 = \frac{q}{\varepsilon_0}$$

$$\boxed{E = \frac{q}{4\pi \varepsilon_0 r^2}}$$

✓

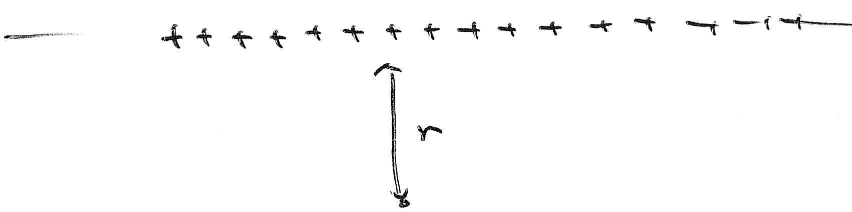
ASIDE

IF $\vec{E}$ NOT $\hat{r}$ THEN



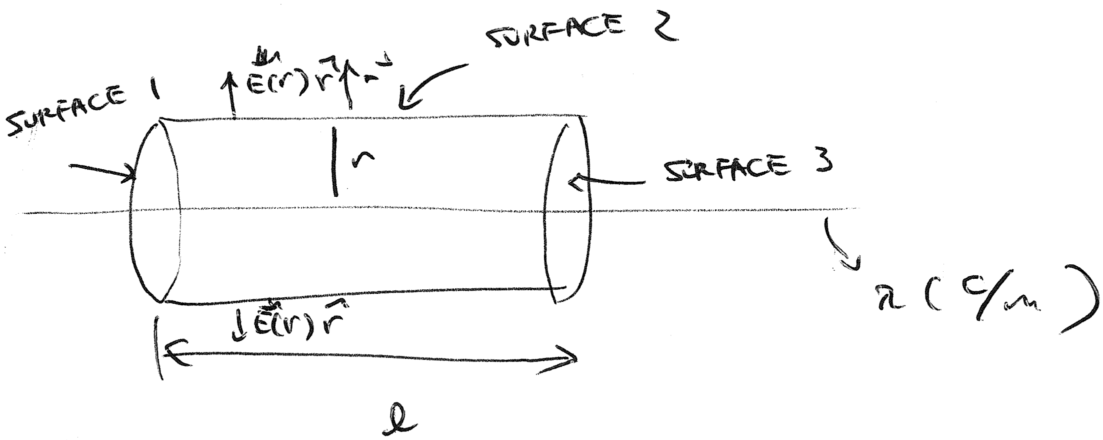
MORE COMPLEX EXAMPLE

INFINITE LINE CHARGE



CHARGE DISTRIBUTION CYLINDRICAL

SO IS THE $\vec{E}$.



SURFACE 1,3 : $\Phi_1 = \vec{E}_1 \cdot \vec{A}_1 = 0$

$$\Phi_3 = \vec{E}_3 \cdot \vec{A}_3 = 0$$

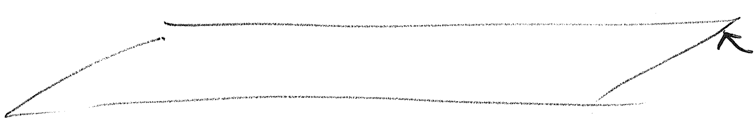
SURFACE 2 : $\Phi_2 = E \cdot A = E \cdot 2\pi r \ell = \dfrac{Q}{\varepsilon_0}$

$$Q = \lambda \cdot \ell$$

$$E\,2\pi r \ell = \frac{\lambda \ell}{\varepsilon_0}$$

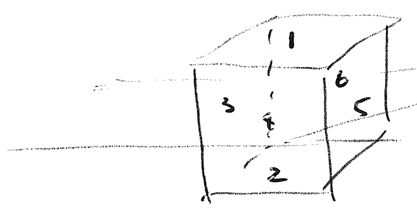
$$|\vec{E}| = \frac{\lambda}{2\pi\varepsilon_0 r} \Rightarrow \vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\,\hat{r}$$

EXAMPLE



INFINITE CHARGE PLANE ~~INFINITE~~

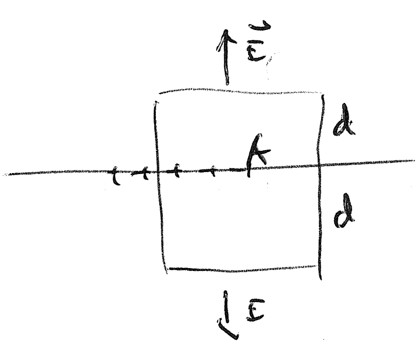
CHARGE AREA DENSITY $= \sigma$ (C/m^2)



SURFACE TO USE

SURFACE 3-6 : $\Phi = 0$ AS

$\vec{E}$ PERPENDICULAR TO SURFACE

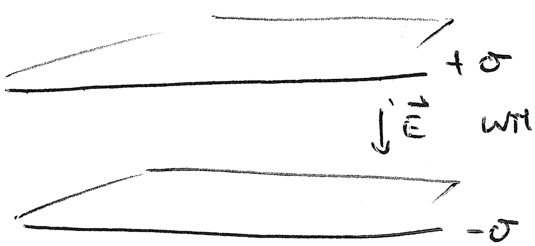


$$\Phi_1 = E(d) \cdot A$$
$$\Phi_2 = E(d) \cdot A$$

$$\Phi = 2E(d) \cdot A = \frac{Q_{\text{ENCLOSED}}}{\varepsilon_0} = \frac{\sigma A}{\varepsilon_0}$$

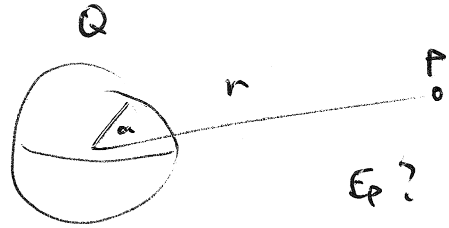
$$E(d) = \frac{\sigma}{2\varepsilon_0}$$

IN CLASS PRACTICE



WHAT'S $|\vec{E}|$?

SPHERICALLY SYMMETRIC CHARGE DISTRIBUTION



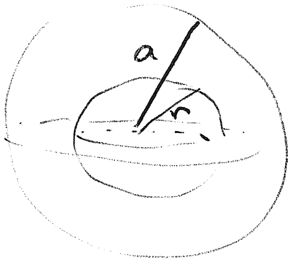
E_P ?

$r > a \Rightarrow \vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}\hat{r}$

$r < a$?

CHARGE DENSITY $= \rho$ (C/m^3)

$$\rho\frac{4\pi a^3}{3} = Q$$



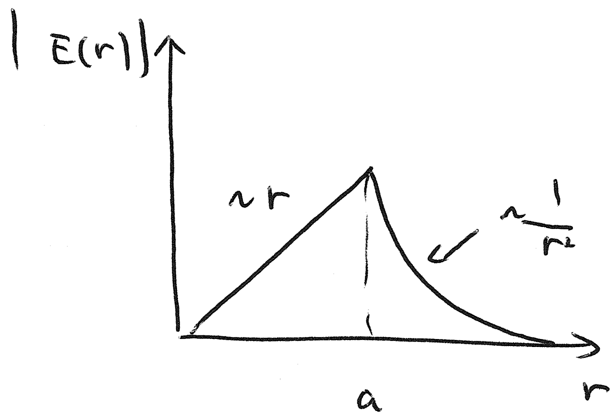
$$Q_{ENCLOSED} = \rho\frac{4\pi r^3}{3}$$

$$EA = \oint E\,\cancel{4\pi}r^2 = \frac{Q_{ENC}}{\varepsilon_0} = \frac{\cancel{4\pi}r^3}{3\varepsilon_0}\rho$$

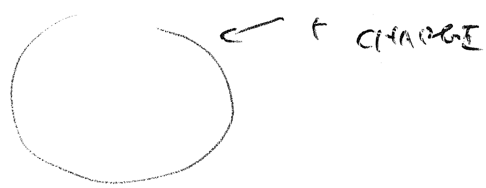
$$E = \frac{\rho r}{3\varepsilon_0}$$

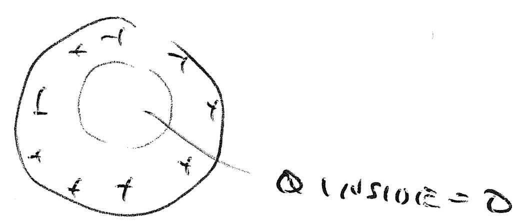
$r = a$ $\quad E = \frac{\rho a}{3\varepsilon_0}$, or $\frac{1}{4\pi\varepsilon_0}\frac{Q}{a^2} = \frac{1}{\cancel{4\pi}\varepsilon_0}\frac{\cancel{4\pi}\cancel{a^3}a\rho}{3\cancel{a^2}}$

$$= \frac{\rho a}{3\varepsilon_0} \checkmark$$



CONDUCTOR



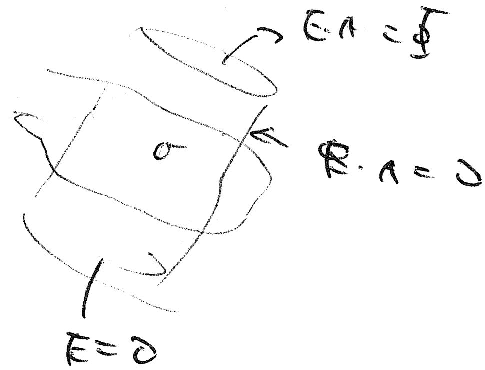


1. CHARGE IS AT SURFACE

2. $\vec{E}_{\text{INSIDE}} = 0$

3. RIGHT OUTSIDE OF CONDUCTOR, ELECTRIC FIELD IS σ/ε_0 → WE'LL PROVE NOW

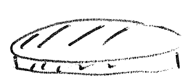
4. CHARGE DENSITY IS GREATEST WHERE THE RADIUS OF CURVATURE IS GREATEST → WE'LL PROVE LATR (NEXT WEEK)

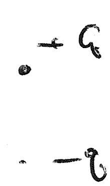


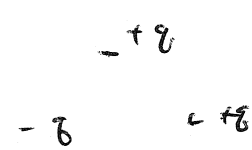
$$E \cdot A = \frac{\sigma A}{\varepsilon_0}$$

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

YOU CAN'T USE GAUSS'S LAW TO CALCULATE ELECTRIC FIELD FOR







INSUFFICIENT SYMMETRY.