Gauss's Law

We see with Coulomb's Law
- relation between electric force (& field) & charge

Calculations are difficult in many charge distributions

Gauss's Law a more general law
- simplifies some specific calculations
- considered now to be more fundamental than Coulomb's
- provides more insight into underlying physics

For any closed surface:

$$\boxed{\Phi_E = \oint \vec{E} \cdot d\vec{A} = q_{in}/\epsilon_0}$$

q_{in} → net charge enclosed by A
- if no charge ⇒ no flux & no field

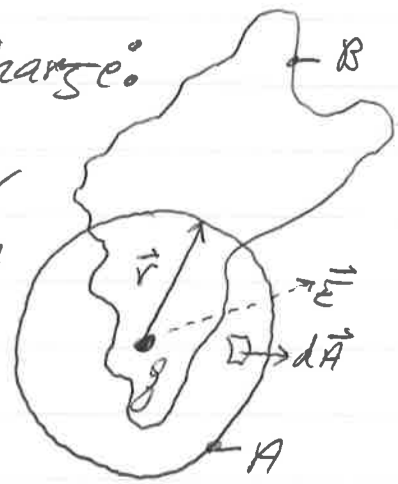
external charge ⇒ no contribution to flux

Gauss's Law & Coulomb's Law

So the net flux thru any closed surface surrounding a point charge, q, $= q/\epsilon_0$
- independent of shape of surface

Used to evaluate $\vec{E}$ most effectively when charge distribution exhibits some symmetry.

Consider point charge:



- spherical symmetry
  - → $|E|$ constant for a given $|r|$
  - → $d\vec{A} \parallel d\vec{E}$

$$\Phi_E = \oint \vec{E} \cdot d\vec{A}$$
$$= \oint E\,dA = q_{in}/\epsilon_0$$

Assume we don't know E, & solving

$$E \oint dA = q_{in}/\epsilon_0 = E(4\pi r^2)$$

$$\boxed{E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2} = k\frac{q}{r^2}}$$

Coulomb's Law!!! for E field

Choice of Surface

We could have ignored symmetry and chosen surface B

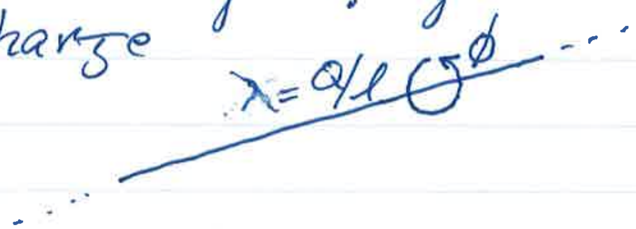
→ same # of crossing field lines
∴ same flux as with sphere
- since same q_{in}

But integral $\oint_B \vec{E} \cdot d\vec{A}$ very difficult!!

Often we are attempting to understand E-field
- surface B does not help us here

Example

1) For a uniform, infinite line of charge

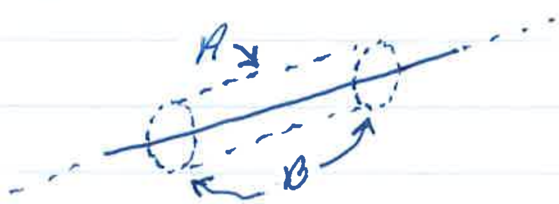


a) what is symmetry?

- same E in all ϕ directions

$\therefore$ cylindrical

b) How draw Gaussian surface?



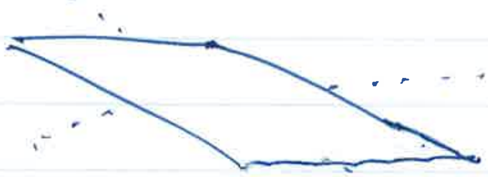
Surface A: $\vec{E} \cdot d\vec{A} = E\,dA \neq 0$

Surfaces B: $\vec{E} \cdot d\vec{A} = 0$

since $\vec{E} \perp d\vec{A}$

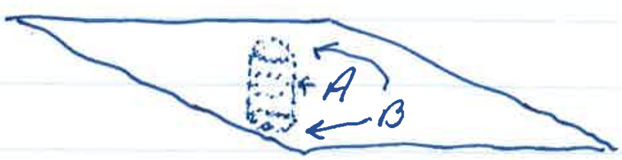
Example (cont.)

2) For an infinite sheet with uniform charge density



a) what is symmetry?
- same E for all (x, y): planar

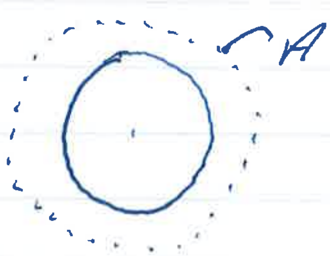
b) what is the Gaussian surface?



B: $\vec{E} \cdot d\vec{A} = E\,dA$
A: $\vec{E} \cdot d\vec{A} = 0$

3) For sphere of uniform charge density

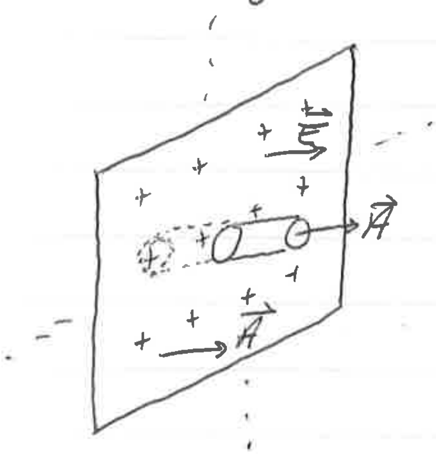
a) symmetry?
$\vec{E}$ same for all (θ, ϕ):
spherical



b) Gaussian surface? sphere A
$\vec{E} \cdot d\vec{A} = E\,dA$

Infinite Sheet of Charge 6.4

Sometimes symmetry needed is not quite so obvious



- uniform charge density
  $\sigma = Q/A$

- $\vec{E} \perp$ to surface
  - $\parallel$ components cancel by symmetry

'Gaussian surface': construct cylinder $\perp$ to sheet plane

- no flux thru cylinder sides
  only thru ends

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = q/\epsilon_0$$

$$E_{front} \cancel{A} + E_{back} \cancel{A} = \sigma \cancel{A} / \epsilon_0$$

$$\boxed{E = \sigma / 2\epsilon_0}$$

$\therefore$ - E field same for all points
- no radial dependence

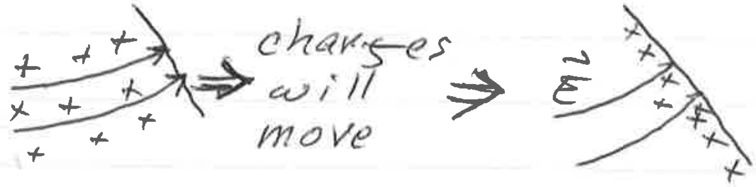
Charged Conductors in Electrostatic Equilibrium

6.5

Electrostatic equilibrium = no <u>net</u> motion of charges

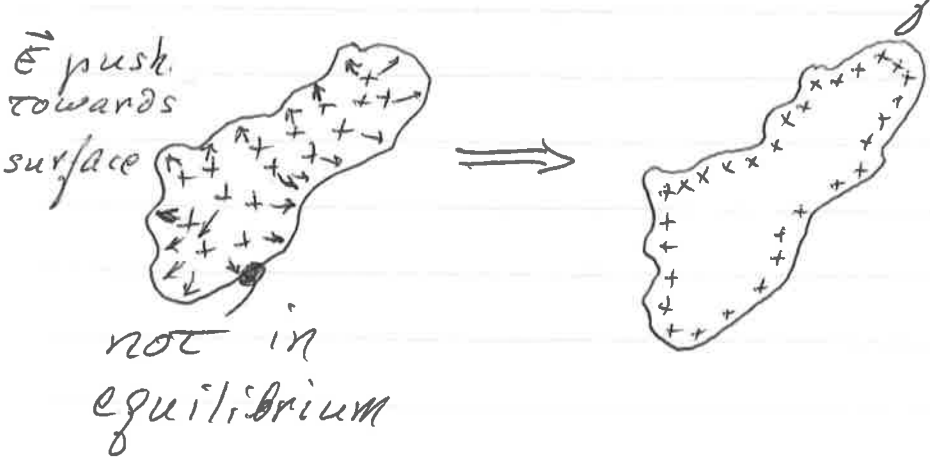
We can identify several properties of these conductors

A) $\vec{E} = 0$ at all point inside conductor



- charges move until $\vec{E} = 0$

B) for isolated conductors: all <u>net</u> charge distributed on surface



Charged Conductor (cont.)

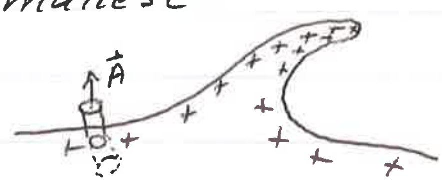
c) $\vec{E}$ is $\perp$ to surface for points close to surface

not equilibrium

- non-$\perp$ components of $\vec{E}$ will cause "surface currents" until they vanish

d) irregular shapes: charge density σ maximized where radius of curvature is smallest

What is E near surface?



Like with ∞ sheet of charge

- ~~But~~, endcap inside, $\phi = 0$

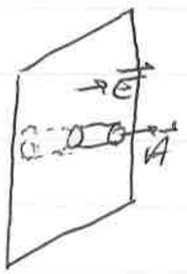
$$\therefore \phi_E = \oint \vec{E}\cdot d\vec{A} = \cancel{E_{end} A} + E_{front} A = \frac{\sigma A}{\epsilon_0}$$

$$E \cancel{A} = \frac{\sigma \cancel{A}}{\epsilon_0}$$

$$\boxed{E = \sigma/\epsilon_0}$$

Example

A nonconducting wall has $8.6\,\mu C$ distributed over $1\,m^2$. If we get 7 cm from the wall's center, what is the electric field?



Using ∞ charge sheet as an approximation,

$$E = \sigma/2\epsilon_0 = (q/A)/2\epsilon_0$$

$$= 8.6\,\mu C/m^2 / 2\epsilon_0$$

$$= \frac{8.6 \cancel{\times 10^{-6}}\, C/\cancel{m^2}}{2(8.85 \times \cancel{10^{-12}}{}^{-6}\, C^{\cancel{2}}/N\cancel{m^2})}$$

$$\sim \frac{1}{2} \times 10^6\, N/C = \boxed{5 \times 10^6\, N/C}$$

Will this be different at 5 cm?

No. ($d \ll 1m$)

What about @ 10 m?

Yes. $d \gg 1m$ & sheet will start to approximate a point charge.