UNM Physics 405 : Lecture 11

Conductors

So far, we have discussed charge distributions in the "abstract". We now want to begin the discussion of the electrostatic properties of materials.

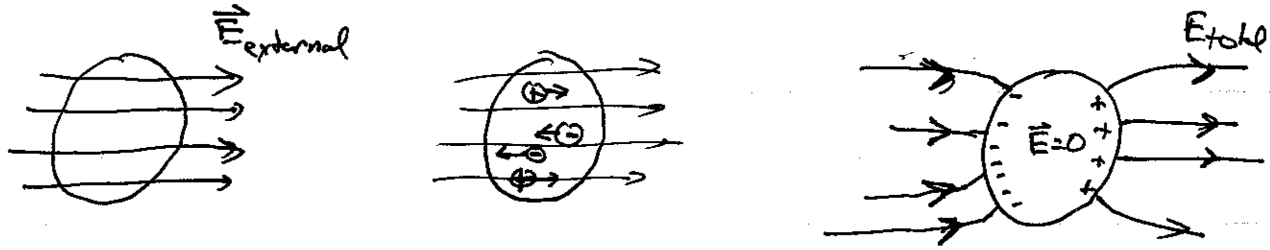
We can crudely divide materials into two classes: conductors and insulators (also known as dielectrics). In conductors, electrons are mobile, able to freely move in response to applied electric fields. In dielectrics, electrons are bound to the nuclei and cannot flow. As a first approximation many materials (metals) can be treated as ideal conductors with infinite mobility (conductivity), and insulators with zero conductivity.

Ex: Au, Ag, Cu conductivity $\sim 10^{8} \frac{1}{\text{ohm-meter}}$

Wood, Glass, Rubber conductivity $\sim 10^{-10}-10^{-16} \frac{1}{\text{ohm-meter}}$

Over 20 orders of magnitude separate good conductors from good insulators, so we can treat them as "ideal".

Conductor in an external electric field



If there are no other forces on mobile charge carriers (electrons, ions), they move until there is no longer any force on them; ie the total electric field $\vec{E}_{total} = \vec{E}_{external} + \vec{E}_{internal}$

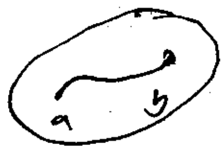
must go to <u>zero</u> inside the conductor.

- The mobile charge builds up at surface in order to cancel the external field (self organizing).
- In charges are not mobile to escape material (for reasonable strength external field). The charges are free to move along the surface $\Rightarrow$ In steady state charges arrange themselve to cancel the tangential force along the surface

$\Rightarrow$ In electrostatics, the total electric field in $\perp$ to the surface

$\Rightarrow$ Surface of conductor is an <u>equipotential surface</u>

- The potential V is constant throughout the conductor



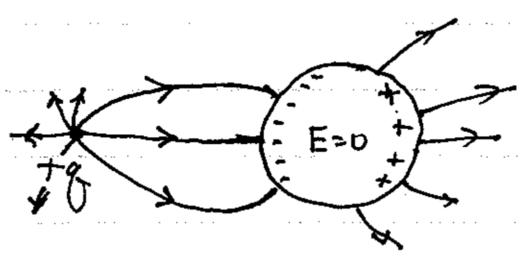
$$V(a) - V(b) = -\int_b^a \vec{E} \cdot d\vec{l} = 0$$

In summary

- $\vec{E}$ inside the material of a conductor is zero in electro statics
    - $\vec{\nabla} \cdot \vec{E} = \rho/\epsilon_0 \Rightarrow \rho$ is zero in the material
    - All residual charge resides @ surface
- $\vec{E}_{total} \perp$ to surface of conductor
    - Surface of conductor is an equipotential

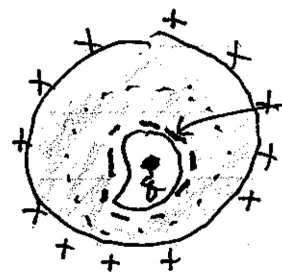
Possible Situations to Consider

(1) External field created by charges



Note: q and conductor will attract each other

(2) A fixed charge placed inside the "cavity" of a conductor (q, say > 0)

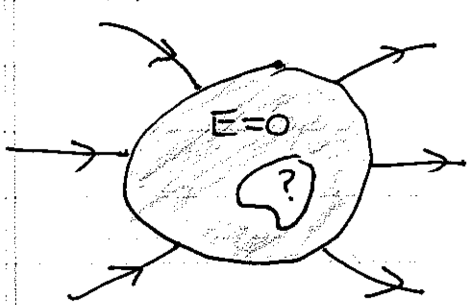


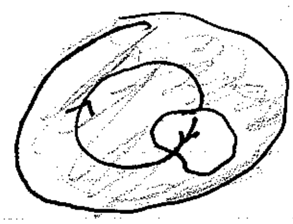
negative charge builds up to cancel field in bulk

remaining positive charge set to outter surface

Outer surface is equipotential.

(3) External field w/ cavity (empty space) inside





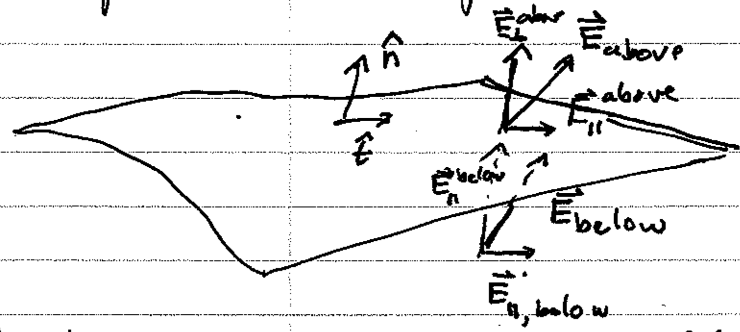
$$\oint \vec{E} \cdot d\vec{\ell} = 0$$

$\Longrightarrow$ $\vec{E} = 0$ inside Cavity

"Farady Cage": We can shield ourselves from (electrostatic) electric fields by surrounding ourselfs ~~by~~ with a conducting "cage".

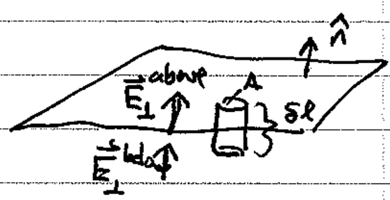
Boundary conditions

We see that at the surface of a conductor the electric field can be discontinuous. This is an example of the general boundary condition in electrostatics



At the boundary, break up the field into a component normal to and tangental (parallel) to ~~to~~ the surface

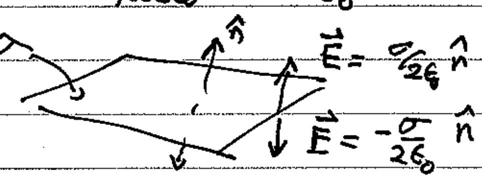
B.C. on normal component



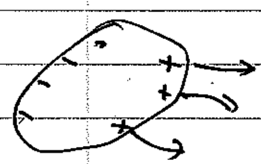
$$\lim_{\delta l \to 0} \oint \vec{E}\cdot d\vec{A} = (E_{\perp,above} - E_{\perp,below})A$$
$$= \frac{Q_{enc}}{\epsilon_0}$$

$$\Rightarrow \Delta E_\perp = E_{\perp above} - E_{\perp, below} = \sigma/\epsilon_0$$

Eg. Sheet of charge

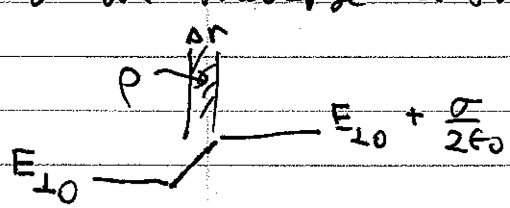


Conductor



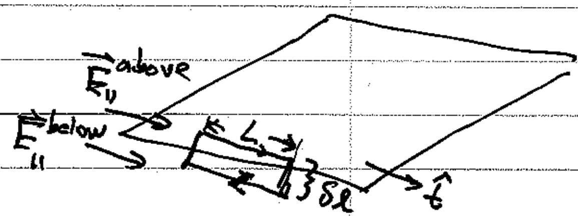
$$E_{surface} = \sigma/\epsilon_0$$

In reality the "discontinuity" represents the rapid change in $\vec{E}$ as we traverse a thin layer of charge (see P.S. #3.4)



$\sigma = \rho \Delta r$

Boundary conditions ~~of~~ on tangential component



$$\oint \vec{E}\cdot d\vec{l} = E_{\parallel}^{above} L - E_{\parallel}^{below} L + (\ \ )\delta l = 0$$

$$\lim_{\delta \to 0} \Rightarrow \boxed{\Delta E_{\parallel} = 0}$$

Tangential component of $\vec{E}$ continuous across boundaries