# Fields and Waves

## Lesson 2.4

## ELECTROSTATICS - MATERIALS

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# CONDUCTORS and DIELECTRICS

## Conductors

High conductivities;
σ (for Copper) ~ $5.8 \times 10^{7}$ S/m

## Dielectrics

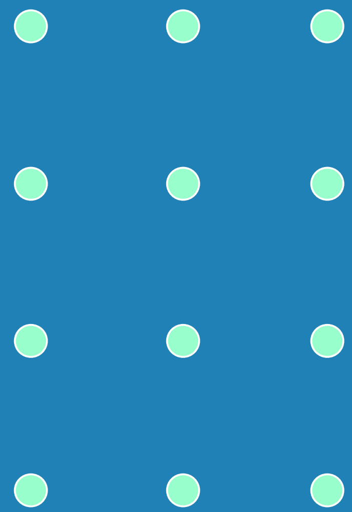
Low conductivities;
σ (for Rubber) ~ $1 \times 10^{-15}$ S/m or 1/Ω-m

Semiconductors (mid σ's)

Permittivities, $\varepsilon = 1\text{-}100\varepsilon_0$

*Note: $\varepsilon_0$ is the permittivity of free space/vacuum = $8.854 \times 10^{-12}$ F/m*

# CONDUCTORS



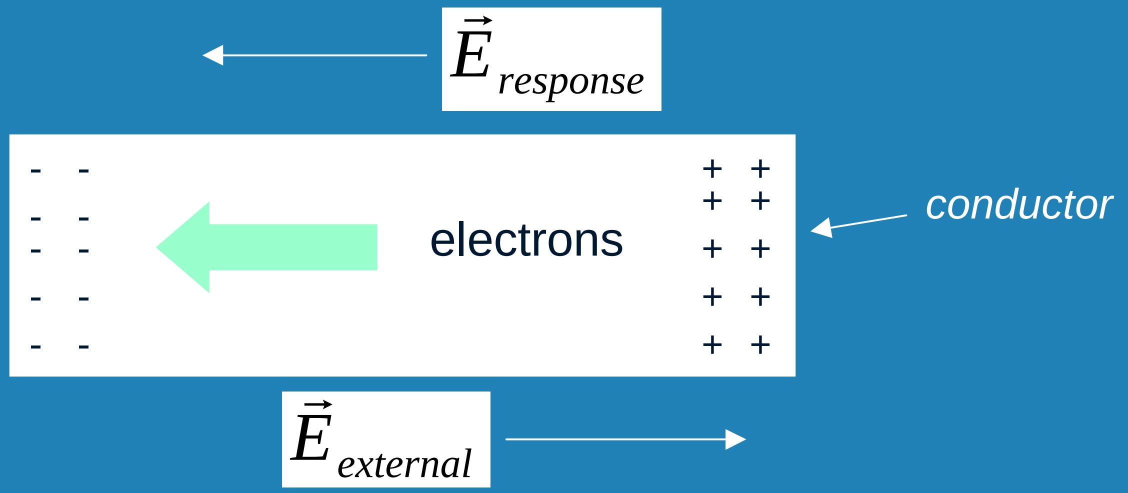
*Lattice of Nuclei*

Most electrons are stuck to the nucleus

But, 1 or 2 electrons per atom are free to move

This means that if you apply an external E-field, the free electrons will move

# CONDUCTORS




Apply external E-field,

- Force on electrons causes free electrons to move
- Charge displacement causes response E-field (opposite to applied external E-field)

# CONDUCTORS

$$\vec{E}_{total} = \vec{E}_{external} + \vec{E}_{response}$$

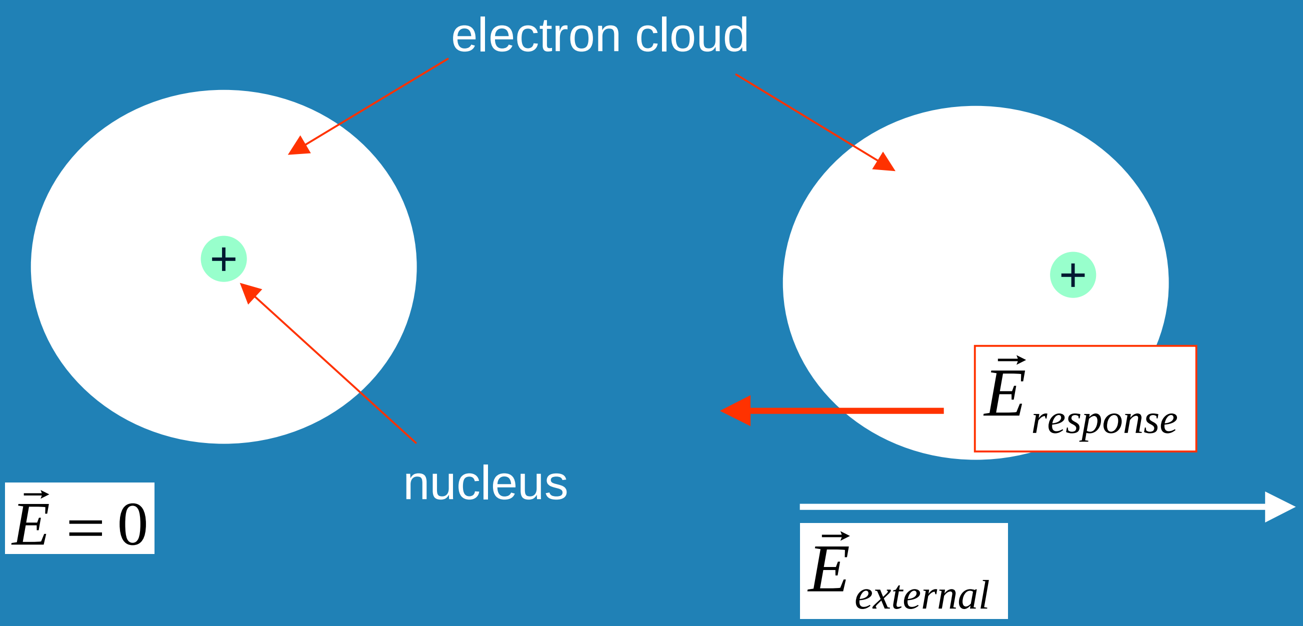
The electrons keep moving until, $\vec{E}_{total} = 0$

This means that:

- $\vec{E} = 0$ , in a conductor
- Conductor is equipotential

*Do problem 1*

# DIELECTRICS




electron cloud
centered on nucleus

Cloud shifts to setup $\vec{E}_{response}$

$$\therefore \vec{E}_{total} = \vec{E}_{external} + \vec{E}_{response} \neq 0$$

# DIELECTRICS

Define: $\vec{p} = q \cdot d =$ dipole moment

$$\vec{E}_{response} \propto -\sum \vec{p}_i = \vec{P}$$ ← Polarization

$\vec{E}_{response}$ partially cancels applied Field

# DIELECTRICS

Define: $\vec{D} \equiv \varepsilon_0 \vec{E}_{TOTAL} + \vec{P}$

subtracts out bound charge

Displacement Flux Density ( $C/m^2$ )

Electric Field (V/m)

$\vec{E}_{TOTAL}$ is due to bound/dielectric charge and free charge

$\vec{P}$ is due to bound/dielectric charge only and opposite sign

$\vec{D}$ is due to free charge only

# FREE CHARGES

Examples of free charges:

- $\rho_s$ on conductor
- electron beam
- doped region of semi-conductor

Gauss' Law uses just <u>free charge</u>

$$\oint \vec{D} \bullet d\vec{s} = \int \rho \cdot dv = Q_{enclosed}$$

*Most general form*

# DIELECTRICS

Don't need to know about bound charges to find $\vec{D}$

Many materials have $\vec{P} \propto \vec{E}$ $\quad \therefore \vec{D} \propto \vec{E}$

Define $\vec{D} = \varepsilon \cdot \vec{E}$ , where $\varepsilon = \varepsilon_r \cdot \varepsilon_0$

Typically, $1 < \varepsilon_r < 10 \to 100$

*Do Problem 2*

# DIELECTRIC BREAKDOWN - *part d of problem*

Example: Arc in Air

If E-field is too large, it will pull electrons off from atom

These electrons are accelerated by the E-field

These accelerated electrons then collide with more atoms that knock off more electrons

⇨ This is an AVALANCHE PROCESS

Damages materials - there is a Voltage limit on components, cables in air : $\vec{E}_{breakdown}$ = 30 kV/cm

BREAKDOWN OCCURS if $\overleftarrow{E}_{applied} > \vec{E}_{dielectric\_strength}$

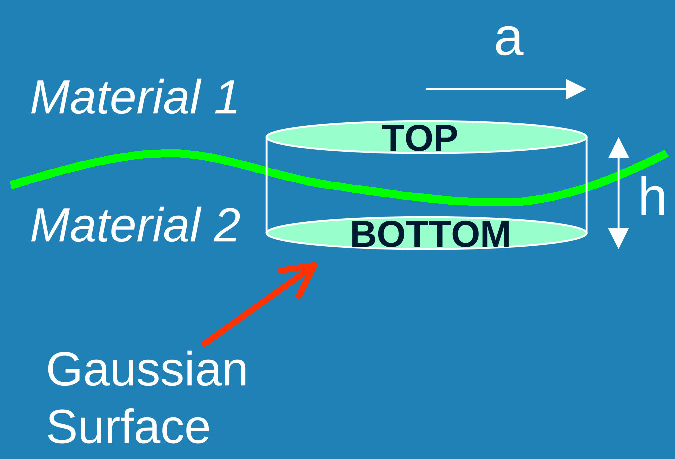
# BOUNDARY CONDITIONS - Normal Components

- all derived from Maxwell's equations

<u>NORMAL COMPONENT</u>

$$\oint \vec{D} \bullet d\vec{s} = Q_{enclosed}$$

Take h << a **(a thin disc)**




$$Q_{enclosed} = \rho_s \cdot A$$

$$\oint \vec{D} \bullet d\vec{s} = \int_{TOP} \vec{D} \bullet d\vec{s} + \int_{BOTTOM} \vec{D} \bullet d\vec{s}$$

$$= (D_{1n} - D_{2n}) \cdot A$$

$$\therefore D_{1n} - D_{2n} = \rho_s$$

# BOUNDARY CONDITIONS - Normal Components

Case 1: REGION 2 is a CONDUCTOR, $D_2 = E_2 = 0$

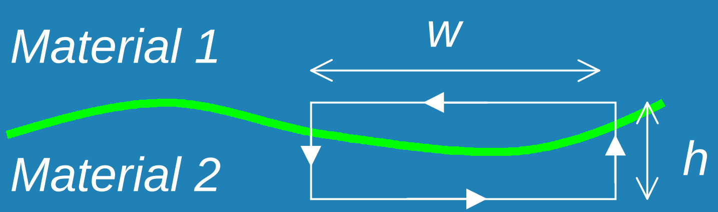
$$\therefore D_{1n} = \rho_s$$

Case 2: REGIONS 1 & 2 are DIELECTRICS with $\rho_s = 0$

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

Can only really get $\rho_s$ with conductors

# BOUNDARY CONDITIONS - Tangential Components




*h << w*

$$\oint \vec{E} \bullet d\vec{l} = 0 \quad \Rightarrow \quad \left(E_{2t} - E_{1t}\right) \cdot w = 0$$

$$\therefore E_{1t} = E_{2t}$$

*Note:* If region 2 is a conductor $E_{1t} = 0$

Outside conductor E and D are normal to the surface