March 11, 2013 Physics 132 Prof. E. F. Redish

- **Theme Music:** **Bob Gramann**

  You're nothin' but a pack of neurons

- **Cartoon:** **Bill Watterson**

  Calvin & Hobbes

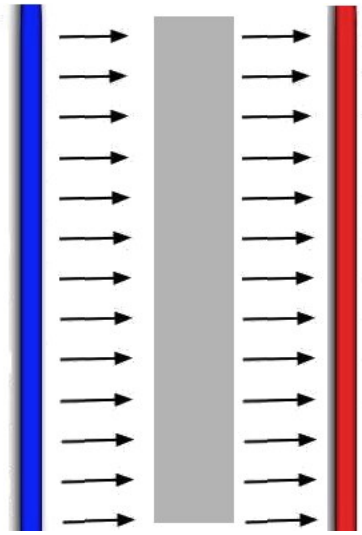
3/10/17 Physics 132 **1**

Outline

- Fields inside Matter
  - Conductors and dielectrics
- Debye length:
  Shielding charges in fluids
- The Nernst potential:
  Balancing diffusion and electric force
- Moving charges in matter: electric current

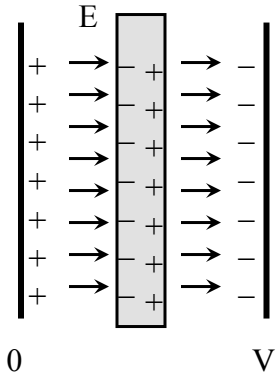
3/10/17 Physics 132 **2**

What happens
if I put
a conductor into
an electric field?

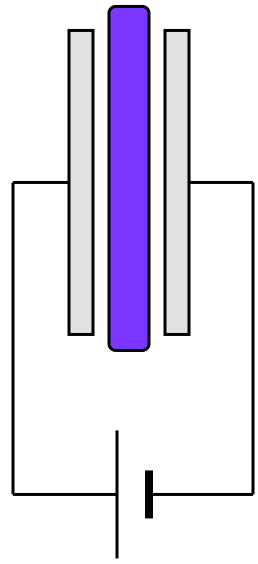


Consider what happens with a conductor

- The potential difference is produced by adding up $E\,\Delta s$.
- If we can reduce E along the path, we can reduce ΔV.
- Inside a static conductor, there can be no E field. (Why not?)
- What happens if we put a conducting sheet between the plates?



Conductors

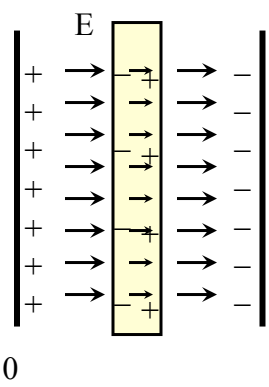


- Putting a conductor inside a capacitor eliminates the electric field inside the conductor.
- The distance, d', used to calculate the ΔV is only the place where there is an E field, so putting the conductor in reduces the ΔV for a given charge.

$$C = \frac{1}{4\pi k_C}\frac{A}{d'}$$

3/10/17 Physics 132 **5**

Consider what happens with an insulator



- We know that charges separate even with an insulator.
- This reduces the field inside the material, just not to 0.
- The field reduction factor is defined to be κ.

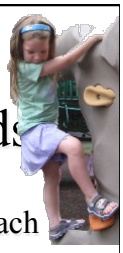
$$E_{\text{inside material}} = \frac{1}{\kappa} E_{\text{if no material were there}}$$

3/10/17 Physics 132 **6**

How a dielectric affects capacitance

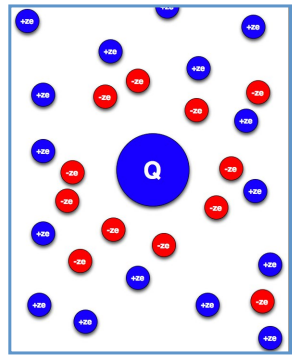
- The dielectric **decreases** the electric field (for a given charge)
- This **decreases** the potential difference across the capacitor (for a given charge)
- This **increases** the capacitance of the capacitor

Foothold ideas: Electric charges in conducting fluids



- **Electroneutrality** – opposite charges in materials attract each other strongly. Pulling them apart to create a charge unbalance costs energy.
- If a charge is placed in an ionic solution, it tends to draw up ions of the opposite type and push away ones of the same type.
- But thermal vibrations fight this. The ions have KE, which tends to keep them moving and drive them away.
- Result: the charge is **shielded**. As you get farther away from it the "apparent charge" gets less.
  - The balance between these two effects yields a scale over which this happens is called the **Debye length, λ_D.**

Debye length: equations



- Charge imbedded in an ionic solution.
  - Ion charge = ze
  - Concentration = c_0
  - Temperature = T
  - Dielectric constant = κ
- The ion cloud cuts off the potential

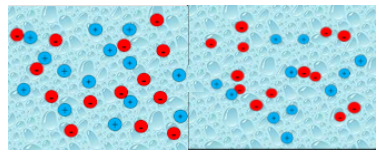
$$\lambda_D = \sqrt{\frac{k_B T}{8\pi\left(\frac{k_C z^2 e^2}{\kappa}\right)c_0}} = \sqrt{\frac{k_B T}{2\left(\frac{z^2 e^2}{\kappa\varepsilon_0}\right)c_0}}$$

$$V(r) = \frac{1}{\kappa}\left(\frac{k_C Q}{r}\right)e^{-r/\lambda_D}$$

Debye length

- It's energy vs. entropy!
- Effect of energy (forces):
  - electrical attraction pulling things together
- Effect of entropy (random motion):
  - making everything spread out
- Debye length = how far out do we have to go before the electric field goes essentially to zero (compared to the field from a point charge)?

Nernst potential equations



- Different concentrations of ions across a membrane that is more permeable to one sign of ion than the other.
- More ions of that sign diffuse across building up a (small) charge difference which sets up and E field that eventually stops the flow of excess charges.

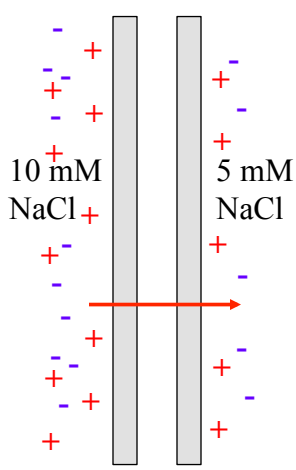
$$\frac{c_1}{c_2} = e^{-\Delta U / k_B T}$$

$$\Delta U = q \Delta V$$

$$\Delta V = \frac{k_B T}{q} \ln\left(\frac{c_1}{c_2}\right)$$

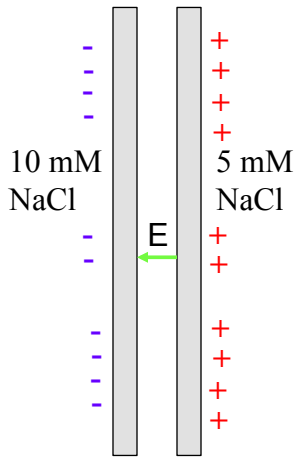
Nernst potential

- Remember diffusion
- There is a net flow from high to low concentration



Nernst potential

- Now there's a potential difference!
- And an electric field!
- The electric field opposes the flow of charge due to diffusion, so the system reaches equilibrium.



Nernst potential

- Once again, it's energy vs. entropy!
- Effect of entropy (random motion):
  - Diffusion from high to low concentration
- Effect of energy (forces):
  - Responding to electric field

Nernst potential

- We can find the Nernst potential using the Boltzmann factor.

$$\frac{c_1}{c_2} = e^{-(\Delta U / k_B T)}$$

$$-\frac{q\Delta V}{k_B T} = \ln\left(\frac{c_1}{c_2}\right)$$

$$\Delta V = \frac{k_B T}{\ln\left(\frac{c_1}{c_2}\right)}$$