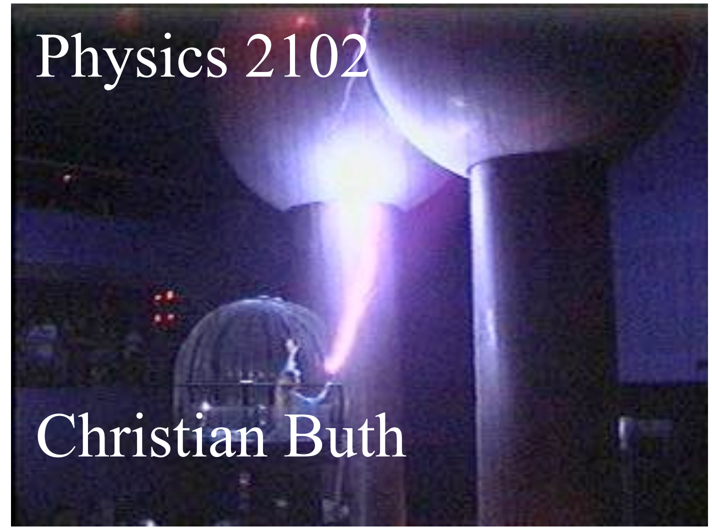
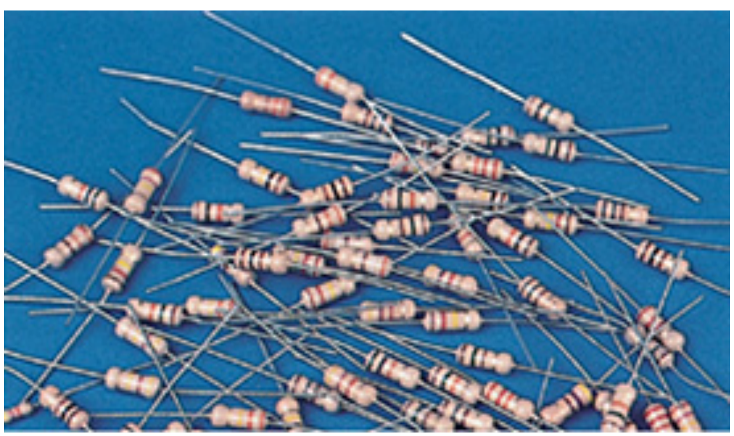
Resistance
Is
Futile!



Physics 2102
Lecture 13
Current and Resistance 1

Georg Simon Ohm
(1789-1854)

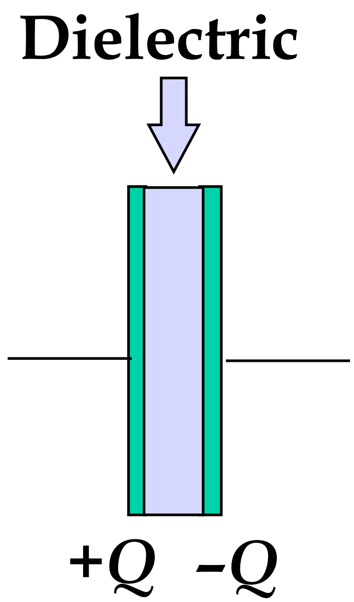


Version: 02/11/2009

Review

- **Capacitors in series**: same charge, not necessarily equal potential; equivalent capacitance $1/C_{eq}=1/C_1+1/C_2+\ldots$
- **Capacitors in parallel**: same potential; not necessarily same charge; equivalent capacitance $C_{eq}=C_1+C_2+\ldots$
- **Energy in a capacitor**: $U=Q^2/2C=CV^2/2$
- **Energy density**: $u=\varepsilon_0 E^2/2$

Dielectric Constant

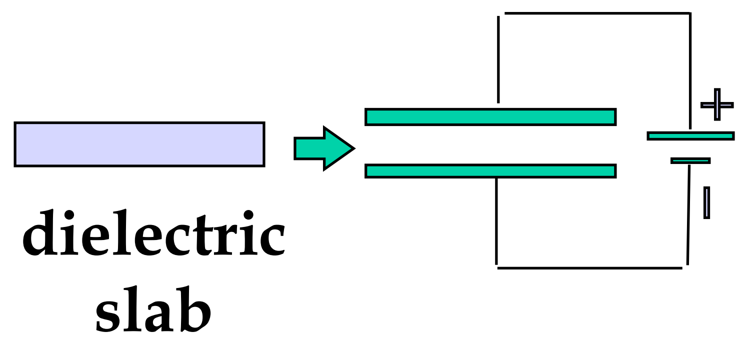


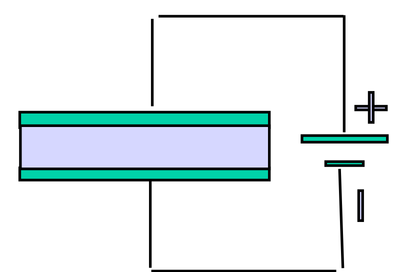
$$C = \kappa \varepsilon_0 A/d$$

- **Dielectric** is an insulating material
- **Space between** capacitor plates is filled with dielectric
- Capacitance **increases** by a factor κ
- Typical values of κ are 1–300

Example

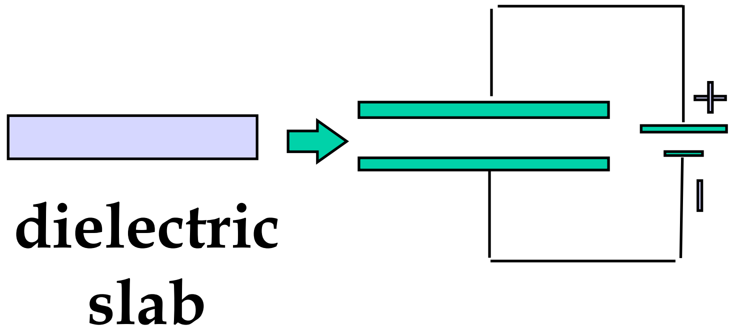
- Capacitor has charge Q, voltage V
- Battery remains connected while dielectric slab is inserted
- Do the following increase, decrease or stay the same:
  - Potential difference?
  - Capacitance?
  - Charge?
  - Electric field?

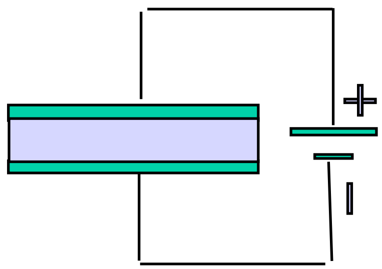




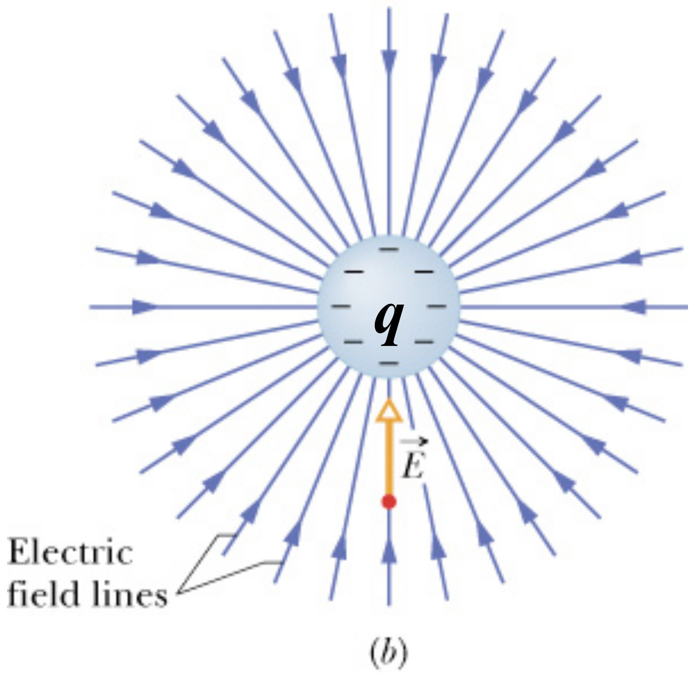
Example

- **Initial values**:
  capacitance = $\boldsymbol{C}$; charge = $\boldsymbol{Q}$;
  potential difference = $\boldsymbol{V}$;
  electric field = $\boldsymbol{E}$;
- Battery **remains** connected
- V is **fixed**; $V_{new} = V$ (**same**)
- $C_{new} = \kappa C$ (**increases**)
- $Q_{new} = (\kappa C)V = \kappa Q$ (**increases**)
- Since $V_{new} = V$, $E_{new} = E$ (**same**)





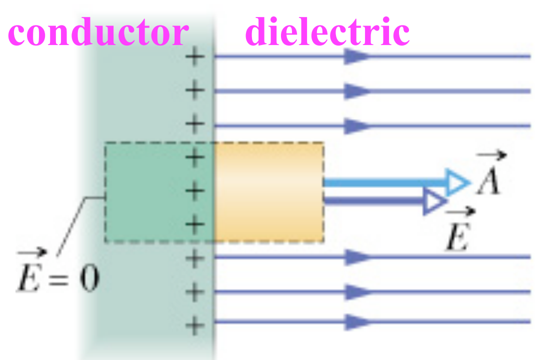
Energy stored? $u=\varepsilon_0 E^2/2 \;\Rightarrow\; u=\kappa\varepsilon_0 E^2/2 = \varepsilon E^2/2$



(b)

In a region completely filled with an insulator of dielectric constant κ, all electrostatic equations containing the constant ε_0 are to be modified by replacing ε_0 with $\kappa\varepsilon_0$.

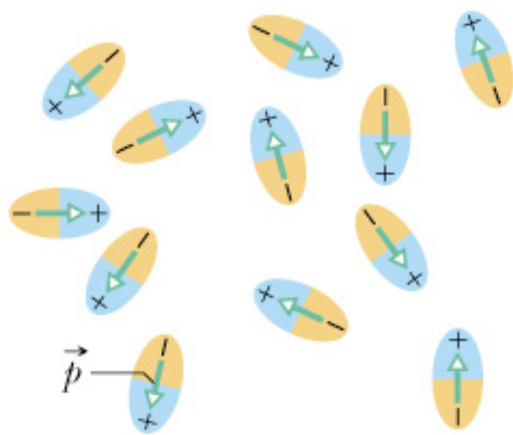
Example 1 : Electric field of a point charge inside a dielectric is: $E = \dfrac{1}{4\pi\kappa\varepsilon_0}\dfrac{q}{r^2}$.



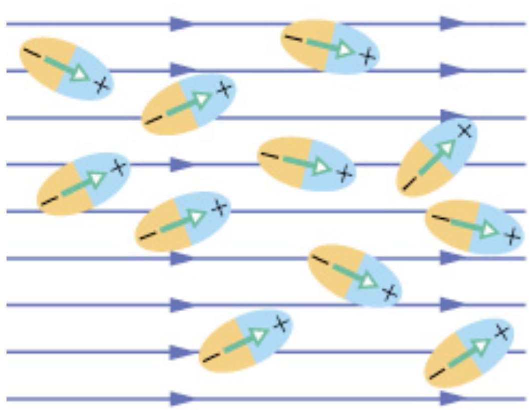
Example 2 :
The electric field outside an isolated conductor immersed in a dielectric becomes:

$$E = \frac{\sigma}{\kappa\varepsilon_0}.$$

An Atomic View on Dielectrics



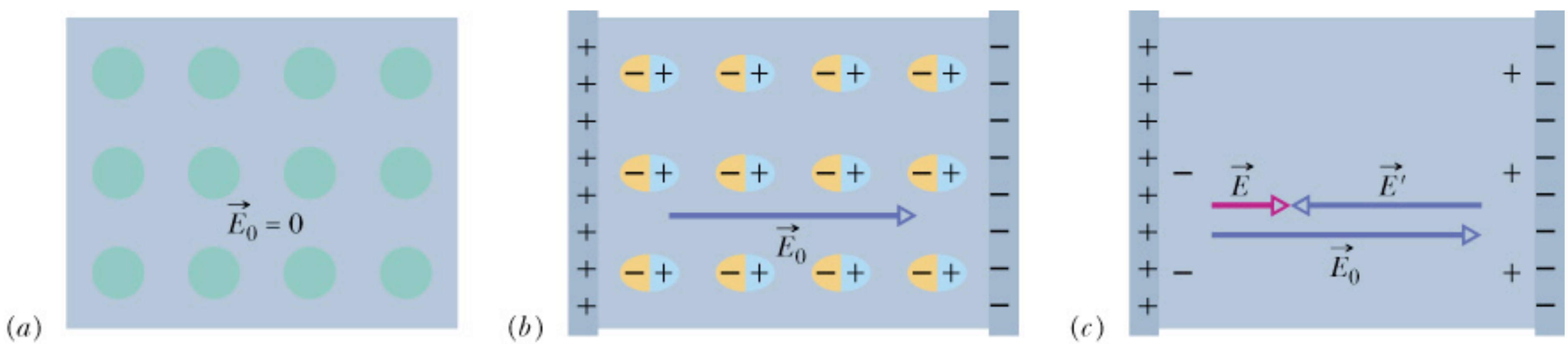
(a)


(b)

- **Polar dielectrics** consist of molecules with permanent dipole moment, e.g., H_2O
- Molecules in **nonpolar dielectrics** have no permanent dipole moment, e.g., Cl_2
- There is always **induced** dipole moments in an electric field
- In a field dipoles align (only partially due to thermal motion) and **weaken** it because their field **opposes** the external field

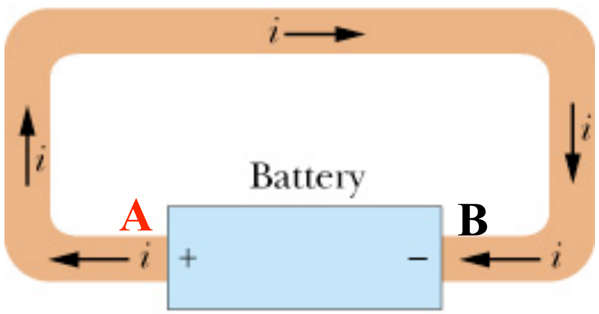
Dielectric Constant

- There is **no net charge** in the dielectric due to the alignment of the molecules
- A net charge appears at the capacitor plates from the ends of the dipoles
- These **induced surface charges** have opposite sign to the charges on the plates
- The electric field between the plates is **weakened**

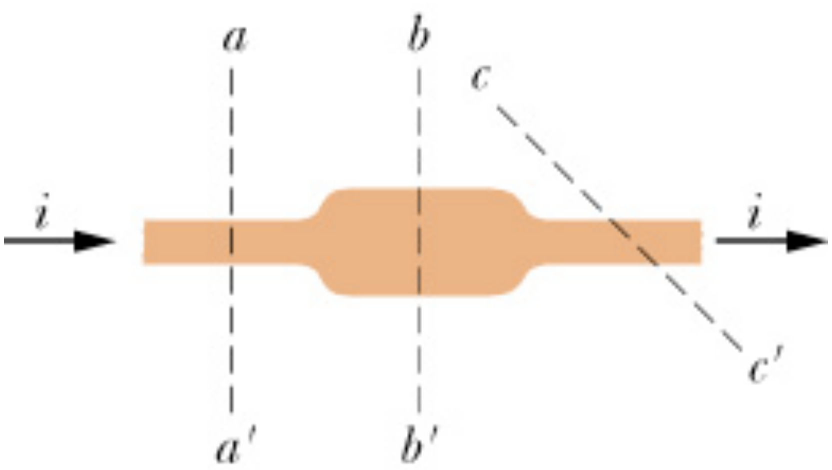


Electric Current

(a)



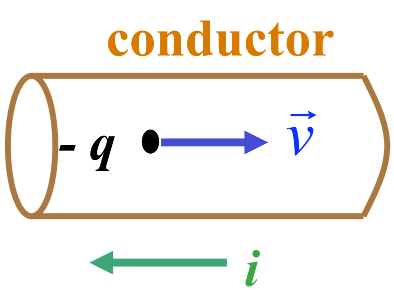
(b)



- All points in Fig. (a) are on **same potential** => no net charge transport
- Battery in Fig. (b) creates **potential difference**
- Net charge flow: **electric current**
- Current has same value through all planes

Current Direction

$$\boxed{i = \frac{dq}{dt}}$$

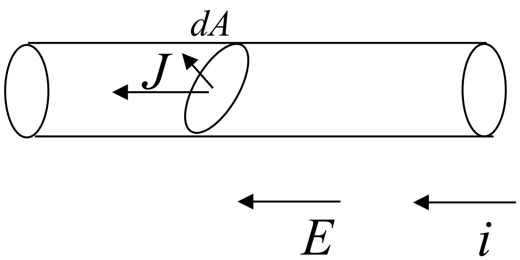


- Current = rate at which charge flows
- SI unit 1 C/s = 1 **ampere** = 1 A
- **Current arrow** is drawn in direction in which **positive** charge carriers would move
- Actual charge carriers are negative and move in **opposite** direction

Current Density

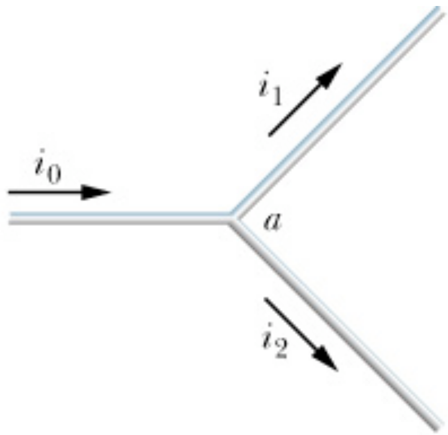
Vector: $\vec{J}$ Same direction as $\vec{E}$ such that $i = \int \vec{J} \cdot d\vec{A}$

- The current is the **flux** of the **current density**



- If surface is perpendicular to a constant electric field, then i=JA, or J=i/A

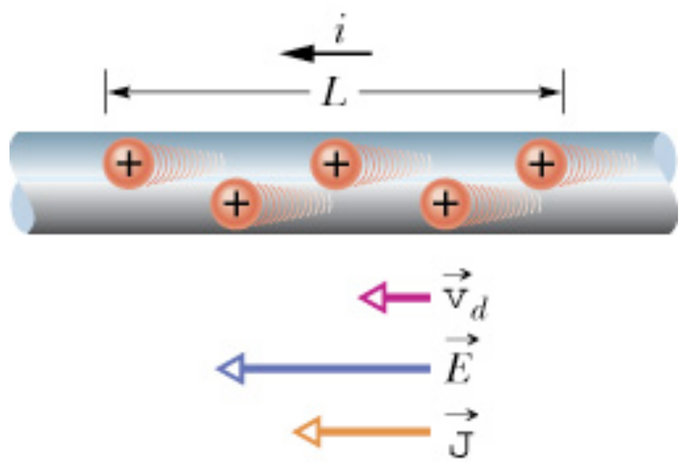
Units: $[J] = \dfrac{\text{Ampere}}{\text{m}^2}$



- Current density is a vector; current is **not** a vector

Drift Speed

- **Drift speed**: v_d speed at which electrons move to establish a current
- Drift speed **superimposed** random motion of electrons
- Charge q in the length L of conductor with area A is $q = (nAL)e$
- n = number density of electrons per unit volume, e = electric charge
- Time to **traverse** length is $t = L/v_d$
- Current is $i = \frac{q}{t} = \frac{nALe}{L/v_d} = nAev_d$



$$\boxed{v_d = \frac{i}{nAe} = \frac{J}{ne} \qquad \vec{J} = ne\vec{v}_d}$$

Summary

- Capacitor with a dielectric: **capacitance increases** $C' = \kappa C$
- Dielectric consists of molecules which **align** in field; yields **surface charges** which reduce the field between the plates
- Battery creates **potential difference** which leads to a **current** in a closed circuit
- **Current arrow** is drawn in direction in which **positive** charge carriers would move
- **Drift speed**: v_d speed at which electrons move to establish a current