Last Time

- Charge is conserved:
  - You can move charge around
  - It can be destroyed/created in (+/-) pairs
- Fun with Scotch Tape (NOT! – better luck with Lab 3)
- Atoms can polarize ("induced dipole")
- Neutral Atoms are attracted by Point Charges

Today

- Insulators: Electrons stay close to their own atoms

- Conductors: Charges are free to move
  - E = 0 inside conductor in equilibrium
  - Ionic solutions
  - Metals

- Charging and Discharging Objects
  - Why humidity matters!

Insulators and Conductors

Insulator: Charges are bound to the atoms or molecules.

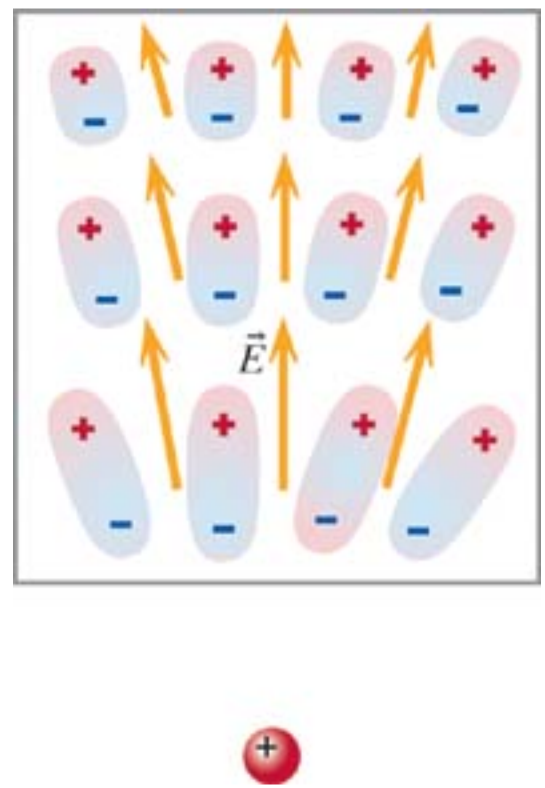
Conductor: Charges can move throughout the material

Polarization of Insulators

Insulator: Electrons are bound to the atoms or molecules.

Each electron shifts slightly (<1 Å)

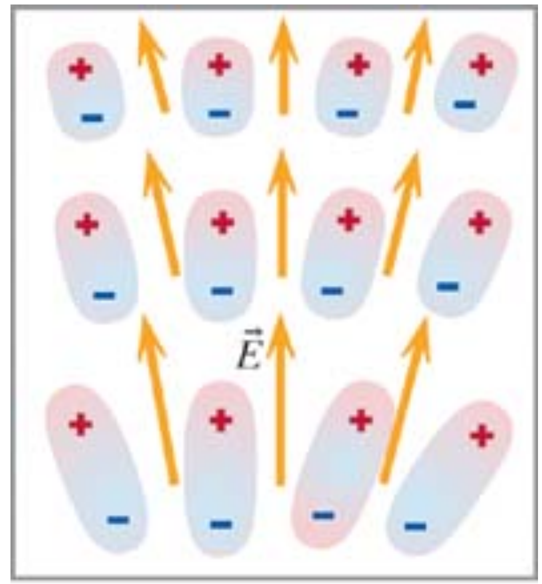
NET effect can be large



Reality Physics: E_{tot} *vs.* $E_{applied}$

We defined Polarizability as:

$$\vec{p} = \alpha \vec{E}$$



Inside the material, this means:

$$\vec{p} = \alpha(\vec{E}_{\text{applied}} + \vec{E}_{\text{dipoles}})$$

We will assume:

$$\vec{E}_{\text{applied}} \gg \vec{E}_{\text{dipoles}} \quad \Rightarrow \quad \vec{p} \approx \alpha \vec{E}_{\text{applied}}$$

Good approximation for small $E_{applied}$ or for low density of dipoles

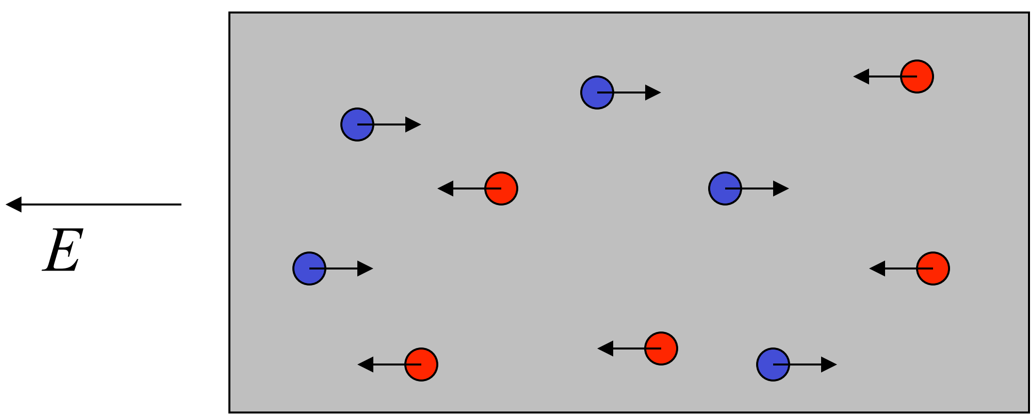
Clicker Question

Conductors

Conductor: Charges can move throughout material

Insulator: Electrons are bound to the atoms or molecules.

Inside of a Conductor



Examples of conductors: Metals, Ionic solutions

Polarization of conductors differs from that of insulators.

E = 0 Inside Conductors in Equilibrium

We want to prove: charges will move until $E_{net}=0$ in equilibrium

<u>Proof by contradiction:</u>

1) Assume the opposite is true:

   Assume $E_{net} \neq 0$ in static equilibrium

2) Show the "opposite" is self-contradictory:

   If $E_{net} \neq 0$, charges will move

   ↓

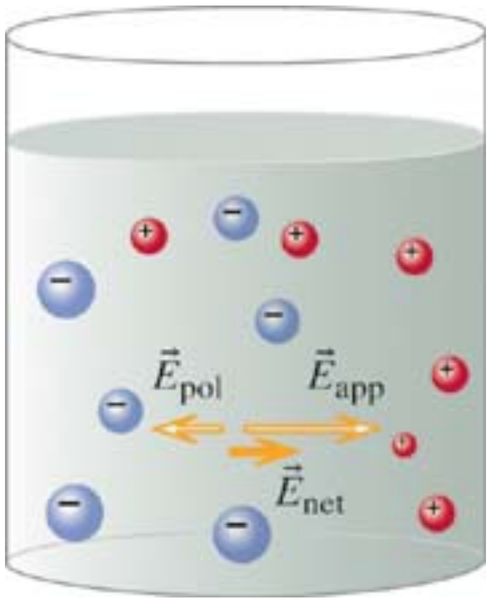
   This is not equilibrium

   ↓

   Assumption $E_{net} \neq 0$ is self-contradictory

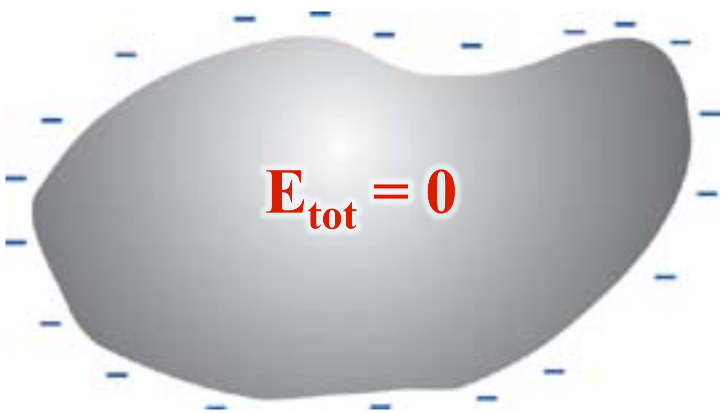
   ↓

   $E_{net}=0$ inside a conductor in equilibrium

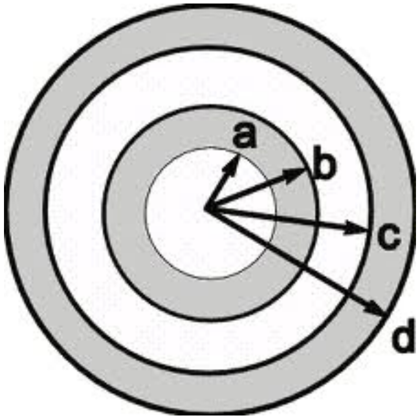


$$\vec{E}_{net} = \vec{E}_{applied} + \vec{E}_{charges}$$

Excess Charge on Conductors

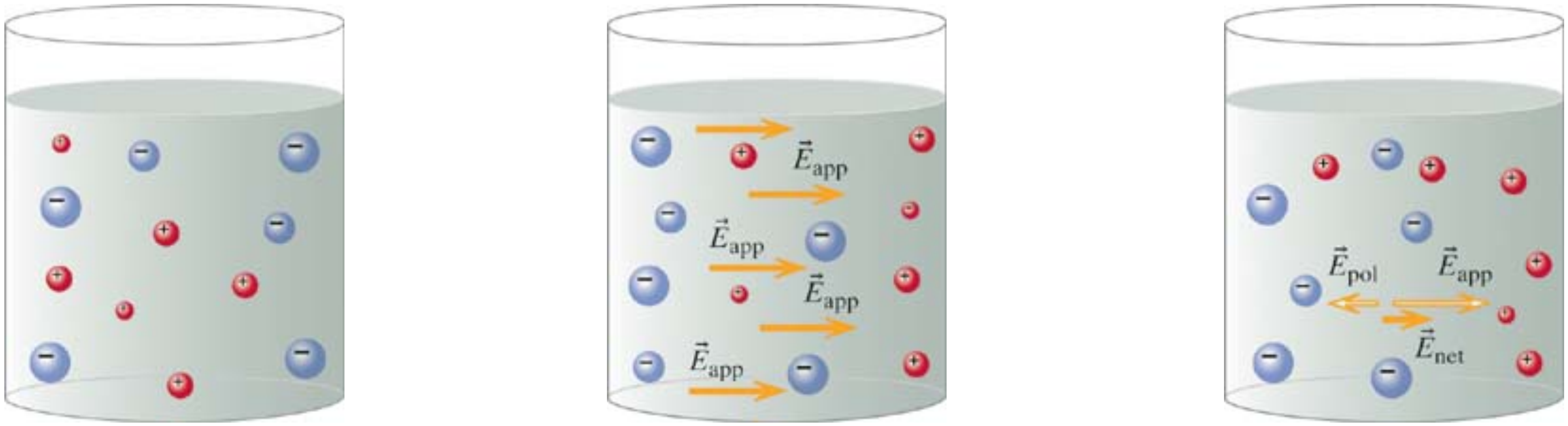


Excess charges in any conductor are always found on the surface



What about an inner surface?

Ionic Solutions are Conductors



Salt water:
Na^+ and Cl^-
H^+ and OH^-

Apply external electric field

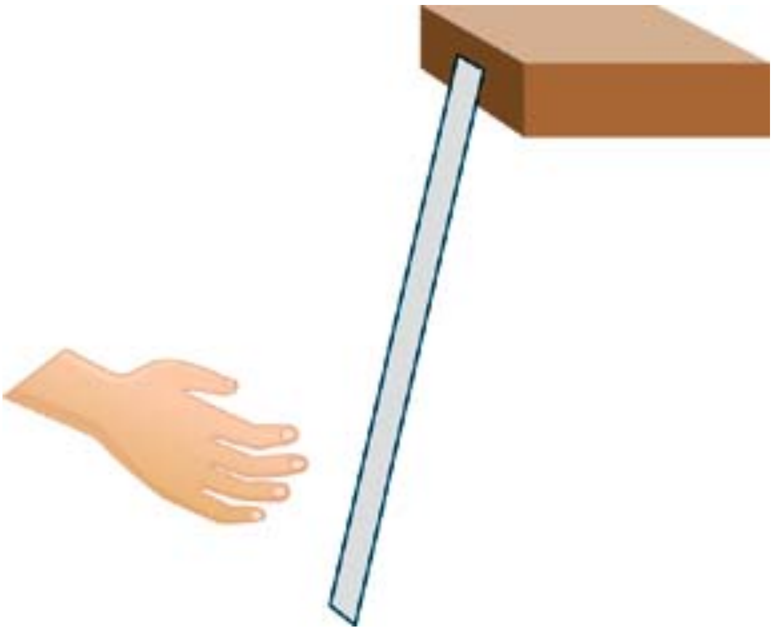
$$\vec{E}_{net} = \vec{E}_{applied} + \vec{E}_{charges}$$

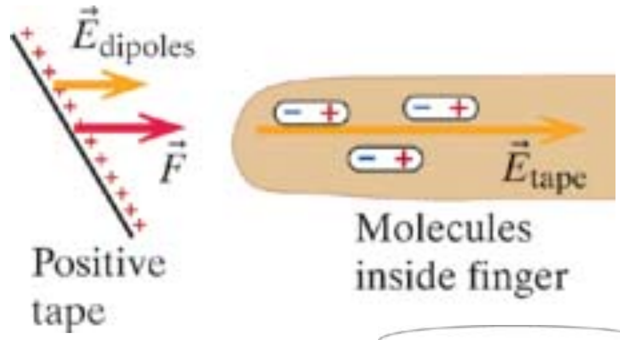
When an electric filed is applied to a conductor, the mobile charged particles begin to move in the direction of the force exerted on them by the field.

As the charges move, they begin to pile up in one location, creating a concentration of charge → creates electric field.

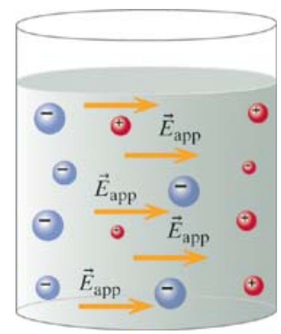
The net electric field is the superposition of the applied field and field created by the relocated charges.

Polarization of Your Hand





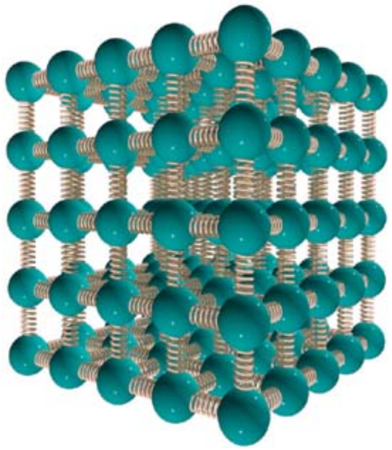
+



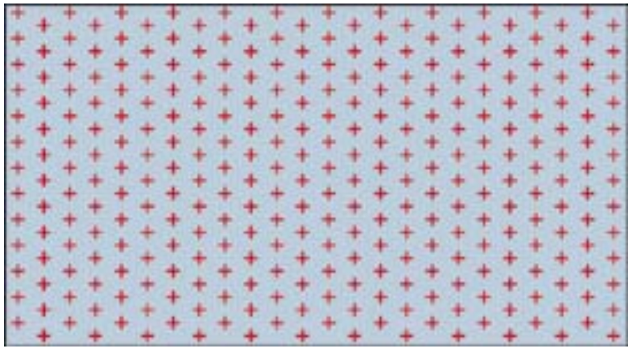
Ionic liquids in the body:

- Inside of cells
- Blood

A Model of a Metal



Metal lattice



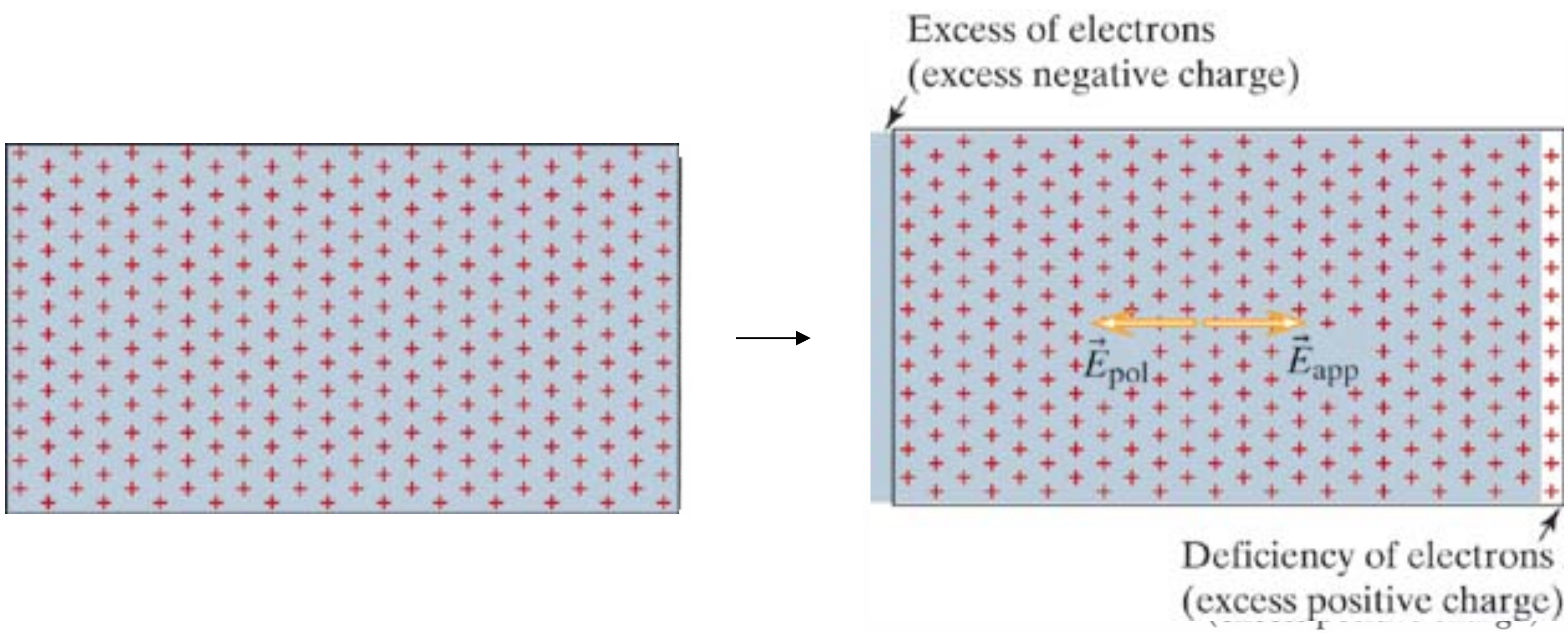
Positive atomic cores
and mobile-electron sea

Electrons are not completely free – they are bound to the metal as a whole.

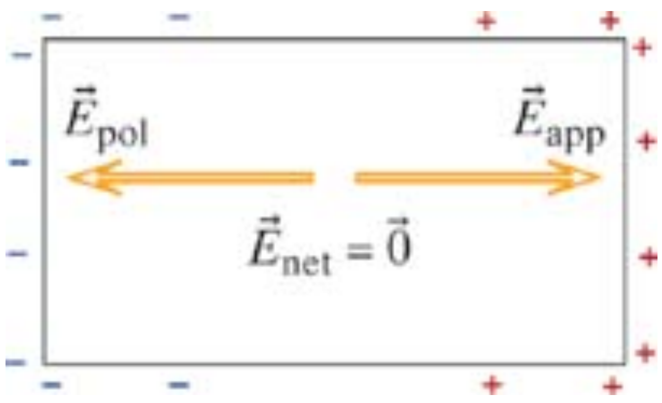
We will return to this idea when we discuss the force on a current carrying wire in a magnetic field.

There is negligible net interaction between mobile electrons

Metal in Electric Field



Simplified diagram of polarized metal

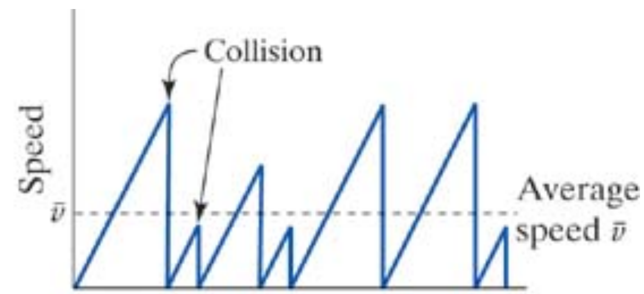


Net charge is still zero

Drude Model of Electron Motion in a Metal

$$\frac{\Delta \vec{p}}{\Delta t} = \vec{F}_{net} = (-e)\vec{E}_{net}$$

Negligible net interaction between mobile electrons
Forget previous velocity after collision



$$\Delta p = p - 0 = eE_{net}\Delta t$$

$$v = \frac{p}{m_e} = \frac{eE_{net}\Delta t}{m_e}$$

$$\bar{v} = \frac{e\overline{\Delta t}}{m_e} E_{net} \qquad \mu = \frac{e\overline{\Delta t}}{m_e}$$

(mobility)

Later we will show that
conductivity (σ) ∝ μ

Some important sources of collision:
- impurities
- thermal motion of atoms
(more motion at higher temperature T
→ shorter Δt → lower σ
[common feature of metals])

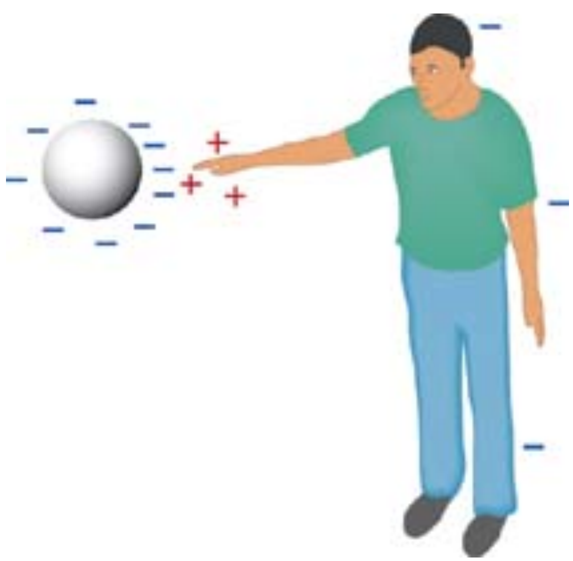
Conductors versus Insulators

	Conductor	Insulator
Mobile charges	yes	no
Polarization	entire sea of mobile charges moves	individual atoms/molecules polarize
Static equilibrium	$E_{net} = 0$ inside	E_{net} nonzero inside
Excess charges	only on surface	anywhere on or inside material
Distribution of excess charges	Spread over entire surface	located in patches

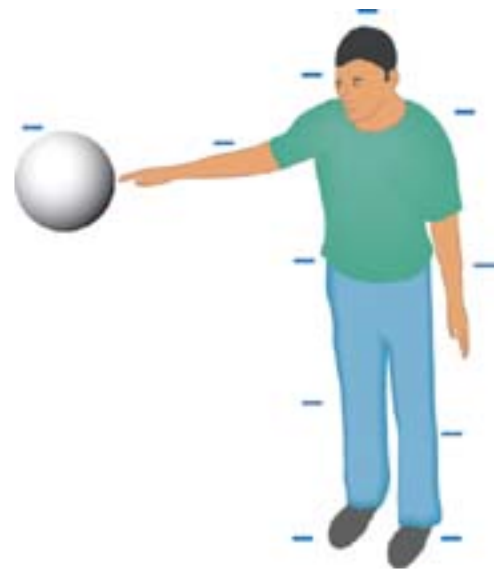
Clicker Question

Charging and Discharging

Discharging by contact:



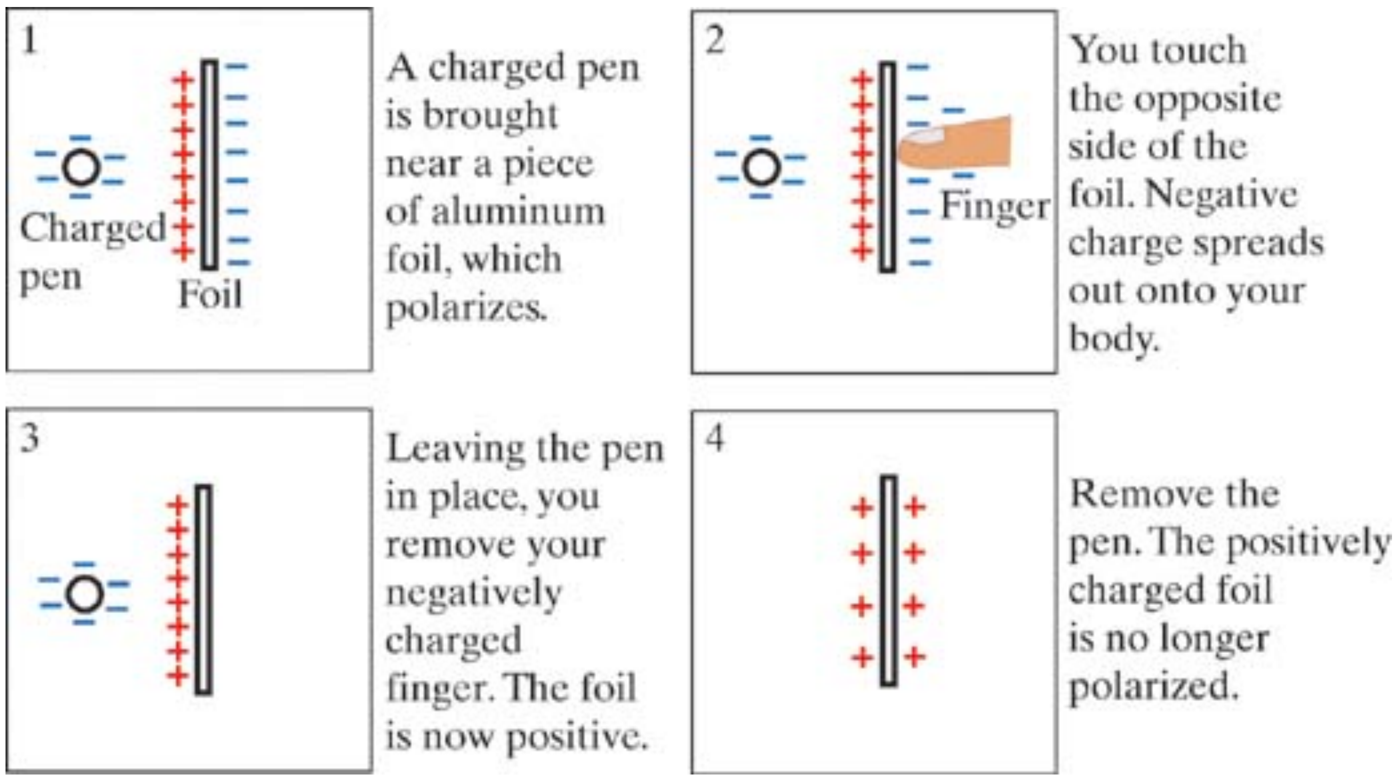
On approach:
body polarizes



On contact:
charge redistributes
over larger surface

Grounding: connection to earth (ground) – very large object

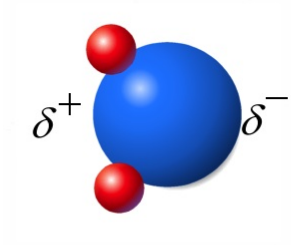
Charging by Induction



Humidity and Discharging Process

Charged tapes (and other objects) become discharged after some time.

Higher humidity – faster discharge



Water molecule - dipole

Thin film of water is formed on surfaces – conductor (poor)

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  - Why humidity matters!