Chapter 14: Electric Fields and Matter

- We extend the concepts of charge and electric fields due to point particles (and dipoles) to macroscopic objects

- In terms of their response to electric fields, we can classify materials to (at least) four categories

  - *Conductors:* contain mobile charged particles (electrons or ions) that can easily move through the material. Their (valence) electrons are not bound to a particular atom
    - most *metals* (mobile electrons) and *aqueous solutions* (ions in salt water)

- *<u>Insulators:</u>* materials in which the electrons are tightly bound to the atoms. Electrons are not free to move. Examples: rubber, plastic, wood, paper, glass, …
- A good thermal conductor (insulator) is a good electric conductor (insulator)
- There is no perfect conductor or insulator
- *<u>Semiconductors:</u>* intermediate between insulators and conductors. Usually, engineered materials designed for certain insulator/conductor properties or to be variable.
- *<u>Superconductors</u>*: materials in which the resistance to electron mobility goes to zero under certain conditions

Charging of Objects

- Ordinary objects are usually *neutral*
- Remove or add electrons by *contact*
- Break chemical bounds, removing ionized fragments by *contact*
- *Induction* - *polarize* object, remove excess charge via contact
- *Collisions* via photons or heavy particles

Polarization of Atoms

- In a neutral atom, its electron cloud is spherically symmetric and centered on the nucleus
- Electric field produced by N protons exactly cancels the electric field due to N electrons for observation points outside the atom ($r > R$)
- If a charge Q is brought near a neutral atom, is their attraction, repulsive, or no response?
- Nucleus and electrons “experience” the electric field of the charge. What is their response?

- Electron cloud is distorted and moves closer to the charge; nucleus is repulsed
- Results in a separation of charge centers by a distance *s*
- The atom is said to be “polarized”
- An “induced dipole moment” is created, proportional to the applied *E* field (most materials)

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

- Polarizability (α) of a material, atom, or molecule (usually neutral)
- Polarizability typically measured or calculated - available in tables
- Units: C m / (N/C) = (constant) m^3

- Charge creates induced dipole moment on neutral atom

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

Problem P33

- If the distance between a neutral atom and a point charge is tripled, by what factor does the force on the atom by the point charge change? Express your answer as a ratio: new force / original force.
- Use a proton (charge q_1 = +e) and a hydrogen atom
- Electric field on H atom due to proton is:

$$\vec{E}_1 = \frac{k_e q_1}{r^2}\hat{r}$$

Polarization of Insulators

- Summary of results:

	Insulator	Conductor
Mobile Charges	No	Yes
Polarization	Individual atoms polarize	Shift of mobile charges
Steady-State	E_{net} nonzero inside	$E_{net} = 0$ inside
Excess Charge	In random patches	Uniformly spread over surface

- Matter composed of positive (protons/nucleus) and negative charges - sum to zero charge
- In *insulators*, electrons are attached to atoms/molecules
- Permanent (or induced) dipoles rotate to align with electric field
- If charge is added to the insulator, surface or interior, it does not move or spread out
- A non-zero *E* field can be created in the interior

Polarization of Conductors

- **Ionic solutions** - in equilibrium have random distribution of positive and negative ions
- *E* field is zero in the solution
- Apply an external *E* field, ions accelerate and then drift
- Due to collisions with liquid molecules, ions acquire an average drift velocity

$$\bar{v} = uE_{\mathrm{net}}$$

- *u* is the ion mobility in certain fluid with units m/s/(N/C). Also tabulated.
- Concentration of charge builds up on either side of vessel holding the solution

- A giant dipole is produced in the solution giving an opposing *E* field due to polarization

$$\vec{E}_{\text{net}} = \vec{E}_{\text{applied}} + \vec{E}_{\text{pol}}$$

- Quickly, $\vec{E}_{\text{pol}} \to -\vec{E}_{\text{applied}}$
- resulting in $\vec{E}_{\text{net}} = \vec{0}$
- Ions stop flowing, *E* field in solution becomes zero, reaching *steady-state*
- Applied *E* field outside, still finite

Problem P44

- An electric field is applied to a solution containing bromide ions. As a result the ions move through the solution with an average drift speed of 3.7×10^{-7} m/s. The mobility of bromide ions in the solution is 8.1×10^{-8} m/s/(N/C). What is the magnitude of the net electric field inside the solution?
- Solution: apply $\bar{v} = uE_{\mathrm{net}}$

- **Metals** - positive charged ions (nucleus plus *N*-1 electrons) are fixed in place in a lattice
- Valence electrons are free to roam, but uniformly fill the space of the metals - "*electron sea*"
- Total charge is zero, i.e., neutral, and metal is in equilibrium
- Total *E* field is zero
- Now, apply an external *E* field, electrons drift along field lines
- As for ionic solution, charge concentrations build up on edges, creating a giant dipole moment, and resulting in polarization *E* field

- Net electric field: $$\vec{E}_{\text{net}} = \vec{E}_{\text{applied}} + \vec{E}_{\text{pol}}$$
- When $$\vec{E}_{\text{pol}} \to -\vec{E}_{\text{applied}}$$

$$\vec{E}_{\text{net}} = \vec{0}$$

- But prior, electrons have drift speed

$$\bar{v} = uE_{\text{net}}$$

- with *u*, the electron mobility in the metal
- Metal reaches steady-state
- While conductor is being polarized, E_{net} is *<u>not zero (non steady-state)</u>*

Polarization without Charge

❑ Can an electric force exist between two neutral particles?

Problem P39

❑ In Fig. 14.84 there is a permanent dipole on the left with a dipole moment of Qs_1 and a neutral atom on the right with polarizability α, so that it becomes an induced dipole with dipole moment $qs_2 = \alpha E_1$, where E_1 is the magnitude of the electric field produced by the permanent dipole. Find the force (if it exists) that the permanent dipole exerts on the neutral atom.

❑ Can an electric force exist between two neutral atoms?