Lecture 17

• Charges at microscopic level
• Understand insulators, conductors...
• Quantify force: Coulomb’s law
• Concept of electric field
• Electric field due to point charge
Charge at microscopic level I

- 2 types of charges behave like positive and negative numbers, e.g. metal sphere is neutral after receiving equal amounts of 2...

- which is positive is convention (Franklin): glass rod positive, electron attracted to it electron negative

- Atomic-level/fundamental unit of charge: +e for proton, -e for electron (inherent property)

- no other sources of charge: $q = N_p e - N_e e = (N_p - N_e) e$ (charge quantization)

- acquire positive charge by losing electron (ionization); negative ion (extra electron)
Charge at microscopic level II

- charging by rubbing: molecular ions from breaking of bonds

- charge conservation (transferred by electrons/ions): $q_{wool} = -q_{plastic}$

- charge diagrams: show net charge; conserve charge in next diagram
Insulators and Conductors

- Insulators: charges immobile

- Conductors, e.g., metals: valence electrons weakly bound, respond to electric forces; salt water: ions...

Charging

- Conductors in electrostatic equilibrium: excess charge located on surface (if in interior, forces exerted causing move...)

Discharging

- human body (salt water) is (large) conductor: conductors in contact “share” charge

- grounding: object connected to earth (conductor) thru’ conductor to prevent build-up of charge

Charge polarization

- charged objects (either sign) force on neutral?

- separation of charges in neutral

Bring a positively charged glass rod close to an electroscope without touching the sphere. (a) The sea of electrons is attracted to the rod and shifts so that there is excess negative charge on the near surface.

(b) The electroscope is polarized by the charged rod. The sea of electrons shifts toward the rod.

The metal’s net charge is still zero, but it has been polarized by the charged rod. Although the net charge on the electroscope is still zero, the leaves have excess positive charge and repel each other.
Electric Dipole

- **Polarization force** attractive (both signs of charged rods)

1. The charged rod polarizes the neutral metal, causing the top surface to be negative and the bottom surface to be positive.

2. The rod exerts an upward attractive force on the excess electrons at the top surface.

3. The rod also exerts a downward repulsive force on the excess positive ion cores at the bottom surface.

4. Because electric force decreases with distance, \( F_{up} > F_{down} \). Thus there is a net upward force on the neutral metal that attracts it to the positive rod!

- charged rod picks up paper (insulator)?
- atoms polarized (electrons still bound)...net force...

**electric dipole**: two charges with separation

In an isolated atom, the electron cloud is centered on the nucleus.

The atom is polarized by the external charge, creating an electric dipole.

Electric dipoles can be created by either positive or negative charges. In both cases, there is an attractive net force toward the external charge.
Coulomb’s law

\[ F_{1\text{on}2} = F_{2\text{on}1} = \frac{K|q_1||q_2|}{r^2} \]

- equal in magnitude, opposite in direction, along line joining
- attractive for opposite, repulsive for like (vectors)
- point charges: size \( \ll \) separation between...
- static charges (\( \ll \) speed of light)

Charging by Induction

1. The charged rod polarizes the electroscope + person conductor. The leaves repel slightly, due to polarization within the electroscope, but overall the electroscope has an excess of electrons and the person has a deficit of electrons.

2. The negative charge on the electroscope is isolated when contact is broken.

3. When the rod is removed, the leaves first collapse, as the polarization vanishes, then repel as the excess negative charge spreads out. The electroscope has been negatively charged.
Using Coulomb’s law

• Units of charge (derived from current):

\[ e = 1.6 \times 10^{-19} \text{ C} \quad \rightarrow \quad K = 9 \times 10^9 \text{ N m}^2/\text{C}^2 \]

• Rewrite in terms of \( \epsilon_0 = \frac{1}{4\pi K} = 8.85 \times 10^{-12} \text{ C}^2/\text{N m}^2 \)

\[ F = \frac{1}{4\pi \epsilon_0} \frac{|q_1| |q_2|}{r^2} \]

• Superposition: multiple charges 1, 2, 3...

\[ \vec{F}_{\text{net on } j} = \vec{F}_1 \text{ on } j + \vec{F}_2 \text{ on } j + \ldots \]

• Strategy: pictorial representation (show charges, forces vectors...); graphical vector addition; x-and y-components
Example

- Two 1.0 g spheres are charged equally and placed 2.0 cm. apart. When released, they begin to accelerate at 150 meter per second squared. What is the magnitude of the charge on each sphere?
• gravity, electric forces long range (action at a distance): mechanism?

• force changes instantly?

• Faraday (and Maxwell): other masses/charges respond to field, \( f(x, y, z) \) cf. particle exits at 1 point

• alteration of space around a mass/charge: gravitational/electric field
Electric Field Model

- more complex: 2 types of charges, forces, materials...
- source charge create electric field $\vec{E}$, probe charge experiences $\vec{F}$ exerted by $\vec{E}$

$$
\vec{E}(x, y, z) = \frac{\vec{F}_{on \, q} \text{ at } (x, y, z)}{q}
$$

- field is agent exerting force ($F = qE$): vector at every point; same direction as $\vec{F}$ for $q > 0$; independent of $q$ (since $F_{on \, q} \propto q$)
**Electric Field of Point Charge**

- **Use Coulomb's law:**

  \[ \vec{E} = \frac{\vec{F}_{\text{on } q'}}{q'} = \left( \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \right), \text{ away from } q \]

- **field diagram (sample vectors): at tail of vector; does not stretch...**

(c) What is the electric field of \( q \) at this point?

(b) 1. Place \( q' \) at the point to probe the field.

   2. Measure the force on \( q' \).

(c) 3. The electric field is \( \vec{E} = \frac{\vec{F}_{\text{on } q'}}{q'} \).
   It is a vector in the direction of \( \vec{F}_{\text{on } q'} \).
Unit Vector Notation

- mathematical notation for “away from q”
- \( \hat{i}, \hat{j}, \hat{k} \): magnitude 1 (no units), purely directional information
- \( \hat{r} \): unit vector pointing from origin to point (“straight outward from point” like \( \vec{E} \))
  \[
  \vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}
  \]
  (electric field of a point charge)
- applies to \( q < 0 \) (\( -\hat{r} \) points towards charge)