Electricity and Magnetism - Lecture 4 Notes

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Van der Waals Forces

- **Induced dipoles** cause weak attractive forces between atoms and molecules.
- **Electron clouds** fluctuate, creating **temporary dipoles**.
- Molecules do not need to be polar to interact.
- Fluctuations in electron clouds can synchronize, resulting in **attractive forces**.
- Example: **Gecko feet** adhere to surfaces via van der Waals forces, allowing them to climb walls.

Insulators vs. Conductors

- **Insulators**: Electrons are bound to atoms and cannot move freely.
  - Examples: plastic, wood, glass, pure water, air.
  - Electrons can shift slightly but remain bound.
  - **Polarization** occurs quickly (less than 1 nanosecond).
- **Conductors**: Charges can move freely.
  - Examples: metals, ionic solutions (e.g., NaCl in water).
  - **Electric Field Inside a Conductor**: $E = 0$ in equilibrium.
  - Charges flow like a liquid; **mobile charges** can be electrons or ions.

Polarization in Conductors and Insulators

- **Insulators**: Atoms or molecules polarize individually when an external electric field is applied.
- **Conductors**: The entire **sea of mobile charges** shifts in response to an external field.

- **Ionic Solutions** (e.g., NaCl in water):
  - Positive and negative ions move to either side under an applied electric field (E_{app}).
  - The net electric field (E_{net}) results from the applied field and the field due to ion displacement.

Electric Field Inside a Conductor

- **In Equilibrium**: $E_{\text{net}} = 0$.
- **Proof by Contradiction**:
  - Assume $E_{\text{net}} \neq 0$. Charges would move, violating equilibrium.
  - Therefore, $E_{\text{net}} = 0$ in equilibrium.
- Excess charges in a conductor in equilibrium are always found on the **surface**.

Model of a Metal

- **Mobile electrons** in a metal behave like a liquid and can flow freely.
- Metals are good **conductors** due to this mobile electron sea.
- **Metal Lattice**:
  - Atoms form a 3D lattice structure.
  - Outer electrons are free to move, while inner electrons remain bound to the nucleus.

Charging and Discharging Conductors

- **Grounding**: Connecting a conductor to a very large object (e.g., Earth) to neutralize its charge.
- **Charging by Induction**:
  1. Bring a charged rod close to the conductor.
  2. Ground the conductor.
  3. Break the connection to ground while keeping the rod in place.
  4. Remove the rod, and the conductor retains the induced charge.

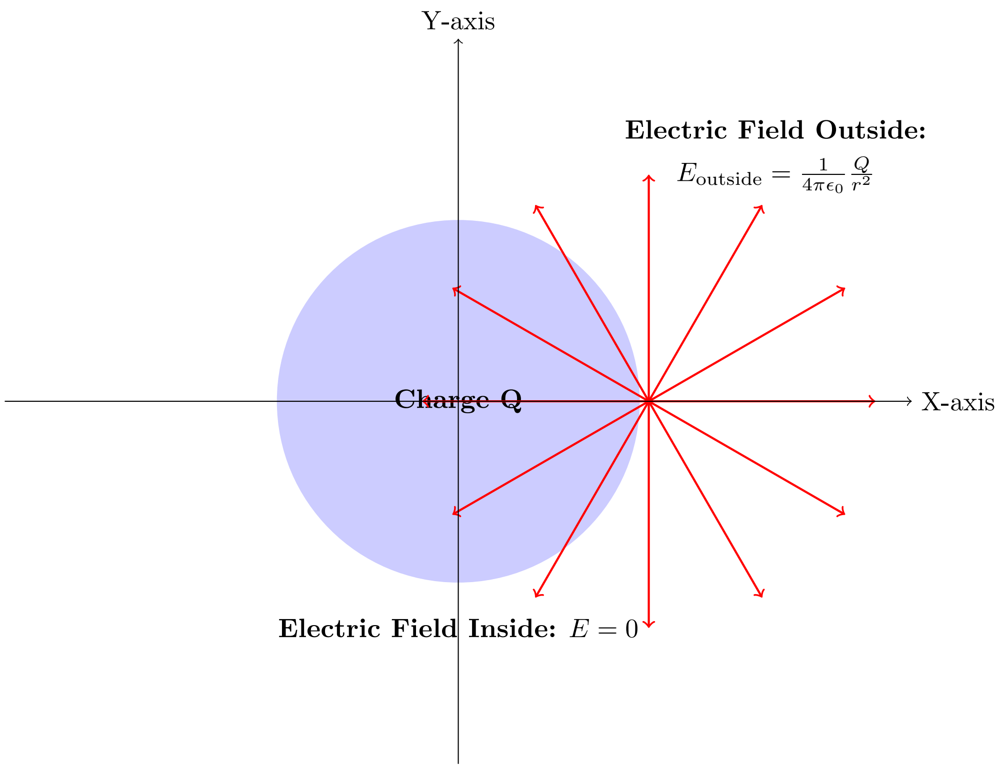

Figure 1: Electric field of a solid metal sphere with charge Q in equilibrium. The electric field inside the sphere is $E = 0$, while the electric field outside follows the inverse square law.

Summary of Conductors vs. Insulators

- **Conductors**:
  - **Mobile charges** are present.
  - Entire sea of charges polarizes in an electric field.
  - In equilibrium: $E_{\text{net}} = 0$ inside.
  - Excess charges are only found on the **surface**.
- **Insulators**:
  - No mobile charges.
  - Individual atoms/molecules polarize.
  - Inside field: $E_{\text{net}} \approx E_{\text{app}}$ for low density.
  - Excess charges can be anywhere in the material.

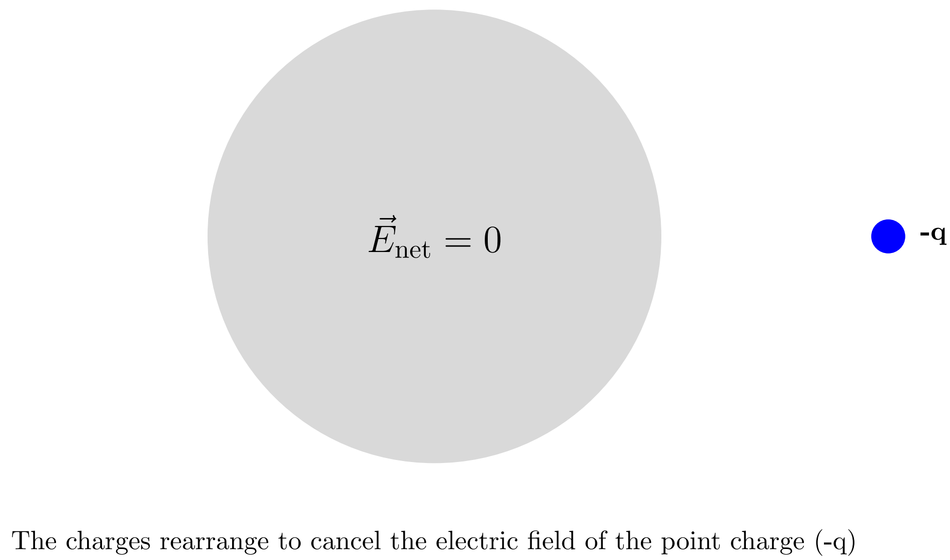

Figure 2: Conducting sphere with charge +Q near a point charge -q. The charges on the sphere rearrange to screen the field from the point charge.