

PHYS11 CH18: Electrostatics

Charges, Fields, Potential, and Capacitors

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Presentation Outline

- 1 Introduction
- 2 Electrical Charges
- 3 Coulomb's Law
- 4 Electric Field
- 5 Electric Potential
- 6 Capacitors and Dielectrics
- 7 Key Equations
- 8 Examples
- 9 Summary

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Learning Objectives

By the end of this presentation, you will be able to:

- Describe the nature of electric charge and its conservation
- Apply Coulomb's law to calculate forces between charges
- Define and calculate electric fields around charge distributions
- Understand electric potential and potential energy concepts
- Explain how capacitors work and calculate their capacitance
- Solve problems involving electric forces, fields, potential, and capacitors

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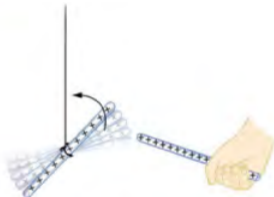
Electrical Charges

Key Concepts

- Two varieties: **positive** and **negative**
- Like charges **repel**, opposite charges **attract**



(a)



(b)



(c)

Conductors vs. Insulators

- **Conductors:** Charges move easily **Insulators:** Charges cannot move easily

Transfer of Charge

Three ways to charge objects:

① Charging by contact

- Direct physical contact between objects
- Charges transfer from one object to another

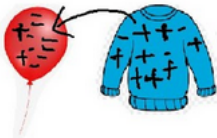
② Charging by conduction

- Charges flow through conducting path

③ Charging by induction

- No contact required
- Charge separation due to electric field

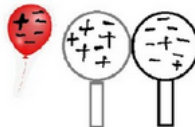
Friction



Conduction



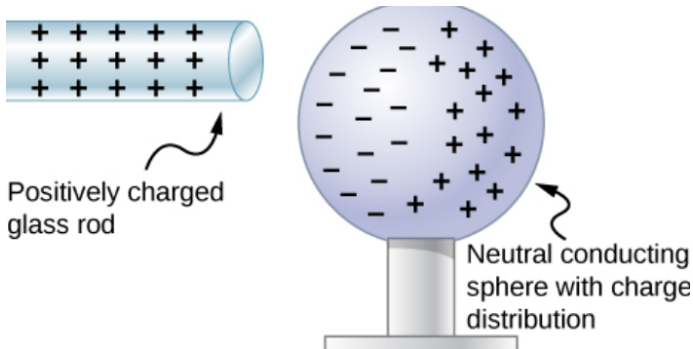
Induction



Polarization

Polarized Objects

- A polarized object may be electrically neutral overall
- But its charge is **unbalanced**:
 - One side has excess **negative** charge
 - The other side has equal magnitude of excess **positive** charge



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Coulomb's Law

Definition

Coulomb's law describes the electrostatic force between charged particles:

$$\vec{F} = \frac{kq_1q_2}{r^2}\hat{r} \quad (1)$$

where:

- $k = 9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$ (Coulomb constant)
- q_1, q_2 are the charges
- r is the distance between charges
- \hat{r} is the unit vector pointing from q_1 to q_2

Properties of Coulomb's Law

- **Inverse square law:** Force $\propto \frac{1}{r^2}$
- Force is **proportional** to the product of charges
- Force interpretation:
 - $F < 0 \rightarrow$ **attractive** force
 - $F > 0 \rightarrow$ **repulsive** force
- Vector nature: Forces act along the line joining the charges



Repulsive force

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Electric Field Concept

Definition

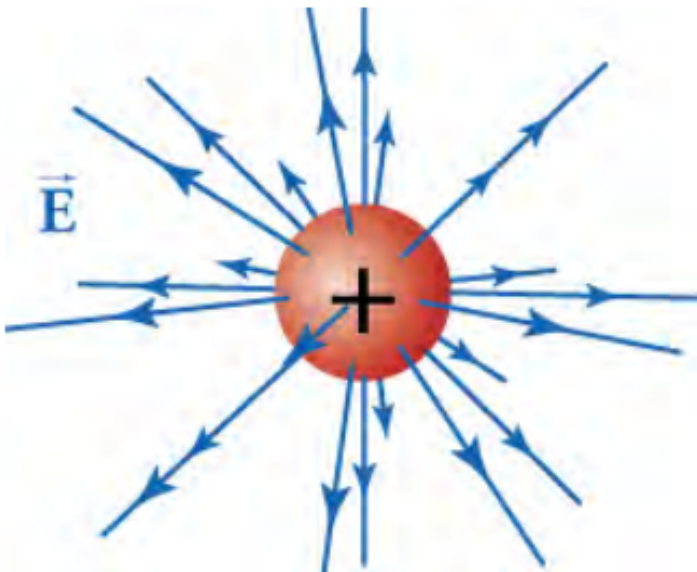
The electric field defines the force per unit charge in the space around a charge distribution:

$$\vec{E} = \frac{\vec{F}}{q_{\text{test}}} \quad (2)$$

Point Charge Electric Field

For a point charge or sphere of uniform charge:

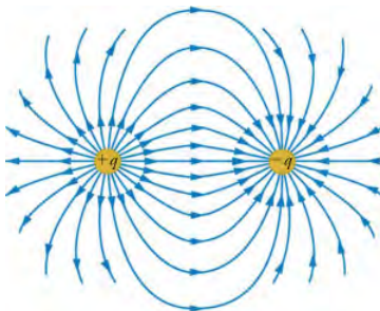
$$E = \frac{kq}{r^2} \quad (3)$$



Electric Field Lines

Properties of electric field lines:

- Electric field lines **never cross** each other
- More field lines indicate a **stronger field**
- Lines **start at positive charges** and point away
- Lines **end at negative charges** and point toward them
- In free space, field lines extend to infinity



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Electric Potential Energy

Definition

Electric potential energy is the potential that charges have to do work by virtue of their positions relative to each other.

Mathematical Expression

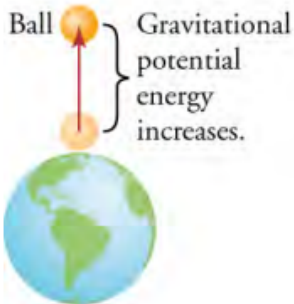
For a charge q in the presence of a point charge Q :

$$U_E = \frac{kqQ}{r} \quad (4)$$

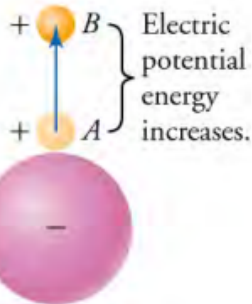
Change in potential energy in constant field:

$$\Delta U_E = -qE(r_f - r_i) \quad (5)$$

Gravitational Potential Energy



Electric Potential Energy



Electric Potential

Definition

Electric potential is the electric potential energy per unit charge:

$$V = \frac{U_E}{q} \quad (6)$$

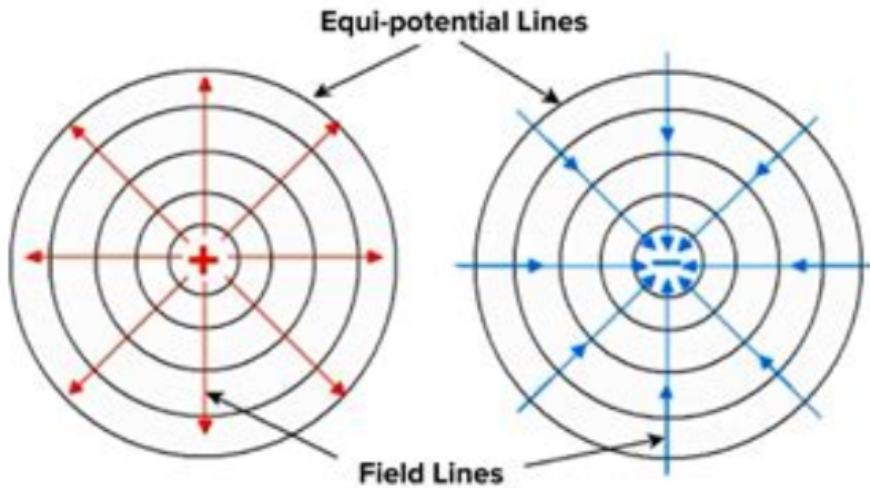
Mathematical Expression

For a point charge Q :

$$V = \frac{kQ}{r} \quad (7)$$

Change in potential in constant field:

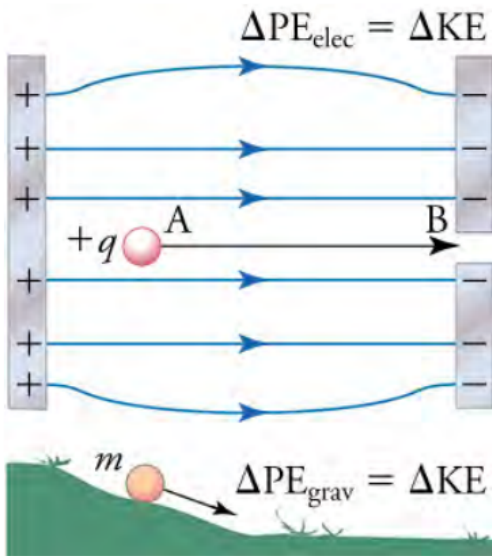
$$\Delta V = -E(r_f - r_i) \quad (8)$$



Movement of Charges in Potential

Key Principles

- Potential is always measured between two points
- One reference point may be at infinity ($V = 0$)
- Charges move spontaneously to minimize potential energy:
 - **Positive charges** move from **high** to **low** potential
 - **Negative charges** move from **low** to **high** potential



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Capacitors

Definition

A capacitor is a device that stores electric charge and energy in the electric field between its plates.

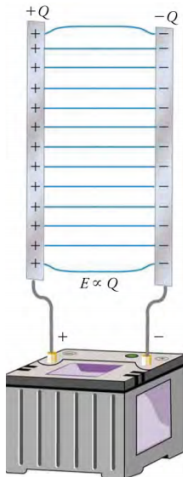
Capacitance

Capacitance is the ratio of charge to potential difference:

$$C = \frac{Q}{V} \quad (9)$$

Capacitance depends only on:

- Geometry of the capacitor
- Materials from which it is made
- **Does not** depend on the voltage



Parallel-Plate Capacitor

Capacitance Formula

For a parallel-plate capacitor:

$$C = \epsilon_0 \frac{A}{d} \quad (10)$$

where:

- $\epsilon_0 = 8.85 \times 10^{-12} \text{ F/m}$ (permittivity of free space)
- A is the area of each plate
- d is the separation distance between plates

Energy Storage

Energy stored in a capacitor:

$$U_E = \frac{1}{2} CV^2 \quad (11)$$

Dielectrics

Definition

A dielectric material is an insulator that becomes polarized in an electric field.

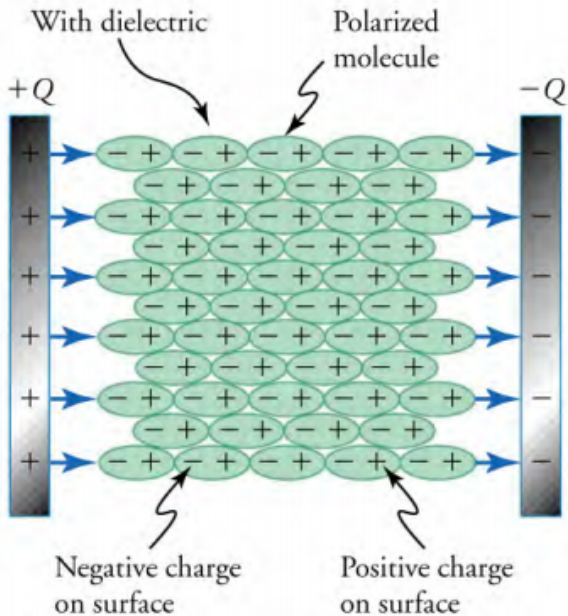
Effects of Dielectrics

Inserting a dielectric between capacitor plates:

- Increases the capacitance by a factor κ (dielectric constant)

$$C = \kappa \epsilon_0 \frac{A}{d} \quad (12)$$

- Reduces the electric field inside the capacitor
- Allows for higher voltage before breakdown



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Key Equations Summary

Electric Potential:

Coulomb's Law:

$$F = \frac{kq_1q_2}{r^2}$$

(13) **Capacitance:**

$$V = \frac{kQ}{r} \quad (16)$$

Electric Field:

$$E = \frac{F}{q_{\text{test}}}$$

(14) **Parallel-Plate Capacitor:**

$$C = \frac{Q}{V} \quad (17)$$

Point Charge Field:

$$E = \frac{kq}{r^2}$$

(15) **Energy Storage:**

$$C = \epsilon_0 \frac{A}{d} \quad (18)$$

$$U_E = \frac{1}{2} CV^2 \quad (19)$$

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"I do" Example: Coulomb's Law

Problem

Two point charges $q_1 = +2.0 \mu\text{C}$ and $q_2 = -3.0 \mu\text{C}$ are separated by a distance of 0.15 m. Find the magnitude and direction of the electric force between them.

"I do" Example: Coulomb's Law

Problem

Two point charges $q_1 = +2.0 \mu\text{C}$ and $q_2 = -3.0 \mu\text{C}$ are separated by a distance of 0.15 m. Find the magnitude and direction of the electric force between them.

Solution

Using Coulomb's law: $F = \frac{kq_1q_2}{r^2}$

$$F = \frac{(9 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(2.0 \times 10^{-6} \text{ C})(-3.0 \times 10^{-6} \text{ C})}{(0.15 \text{ m})^2}$$
$$F = \frac{(9 \times 10^9)(-6.0 \times 10^{-12})}{0.0225}$$
$$F = -2.4 \times 10^{-3} \text{ N}$$

The negative sign indicates an attractive force. The force on q_1 is directed toward q_2 , and the force on q_2 is directed toward q_1 .

"We do" Example: Electric Field

Problem

Three point charges are arranged on the x-axis: $q_1 = +2.0 \mu\text{C}$ at $x = 0$, $q_2 = -3.0 \mu\text{C}$ at $x = 0.15 \text{ m}$, and $q_3 = +1.0 \mu\text{C}$ at $x = 0.30 \text{ m}$. Find the electric field at point P located at $x = 0.45 \text{ m}$.

"We do" Example: Electric Field

Problem

Three point charges are arranged on the x-axis: $q_1 = +2.0 \mu\text{C}$ at $x = 0$, $q_2 = -3.0 \mu\text{C}$ at $x = 0.15 \text{ m}$, and $q_3 = +1.0 \mu\text{C}$ at $x = 0.30 \text{ m}$. Find the electric field at point P located at $x = 0.45 \text{ m}$.

Solution Approach

1. Calculate the electric field due to each charge at point P

$$E_1 = \frac{kq_1}{r_1^2} = \frac{k(+2.0 \times 10^{-6})}{(0.45)^2} \text{ (pointing right)} \quad (20)$$

$$E_2 = \frac{kq_2}{r_2^2} = \frac{k(-3.0 \times 10^{-6})}{(0.30)^2} \text{ (pointing left)} \quad (21)$$

$$E_3 = \frac{kq_3}{r_3^2} = \frac{k(+1.0 \times 10^{-6})}{(0.15)^2} \text{ (pointing right)} \quad (22)$$

2. Find the total field by superposition: $\vec{E}_{\text{total}} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3$

"You do" Example: Capacitor

Problem

A parallel-plate capacitor has plates with an area of 0.0025 m^2 separated by a distance of 0.5 mm .

- (a) Calculate the capacitance of this capacitor.
- (b) If the capacitor is connected to a 12 V battery, determine the charge stored on each plate.
- (c) Calculate the energy stored in the capacitor.
- (d) If a dielectric with $\kappa = 3.0$ is inserted between the plates, find the new capacitance.

Hints

- Use $C = \epsilon_0 \frac{A}{d}$ for part (a)
- Apply $Q = CV$ for part (b)
- Use $U_E = \frac{1}{2} CV^2$ for part (c)
- Remember that with a dielectric, $C = \kappa \epsilon_0 \frac{A}{d}$

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Summary: Key Takeaways

Electrical Charges & Coulomb's Law

- Electric charge is conserved; like charges repel, unlike attract
- Coulomb's law: $F = \frac{kq_1q_2}{r^2}$

Electric Field & Potential

- Electric field: force per unit charge; $E = \frac{F}{q_{\text{test}}}$
- Electric potential: potential energy per unit charge; $V = \frac{U_E}{q}$

Capacitors & Dielectrics

- Capacitance $C = \frac{Q}{V}$; energy storage $U_E = \frac{1}{2}CV^2$
- Parallel-plate capacitor: $C = \epsilon_0 \frac{A}{d}$
- Dielectrics increase capacitance by a factor κ

Thank You!

Questions?

Practice problems: Textbook Chapter 18