

# 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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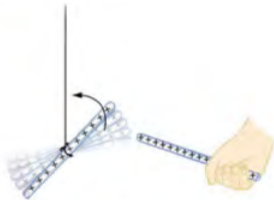
# Electrical Charges

## 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

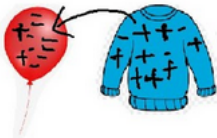
## ② Charging by conduction

- Charges flow through conducting path

## ③ Charging by induction

- No contact required
- Charge separation due to electric field

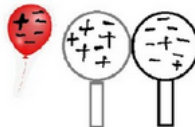
### Friction



### Conduction



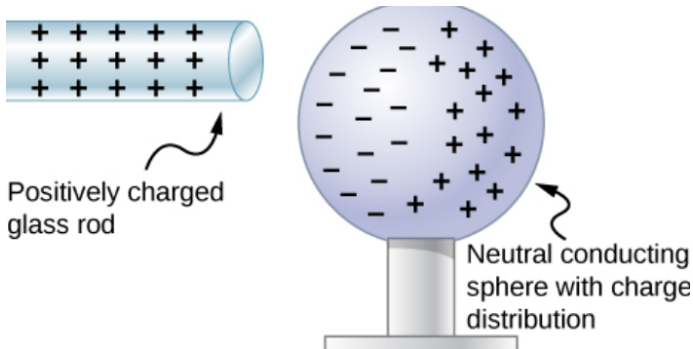
### Induction



# 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

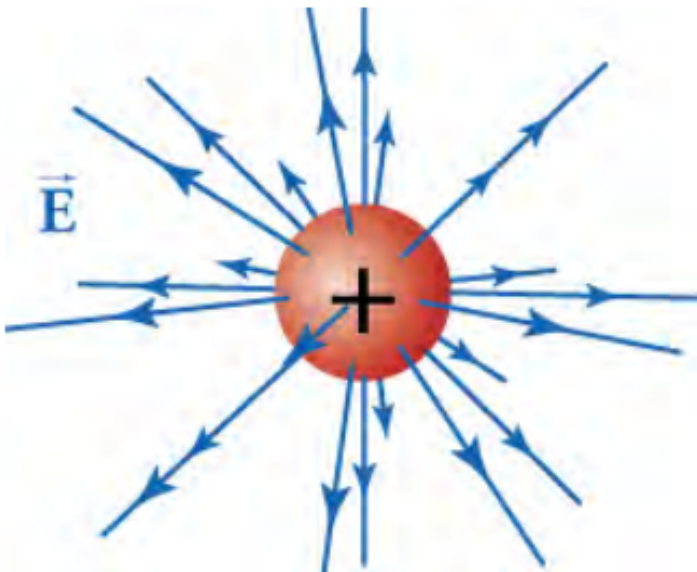
The electric field defines the force per unit charge in the space around a charge distribution:

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

## Point Charge Electric Field

For a point charge or sphere of uniform charge:

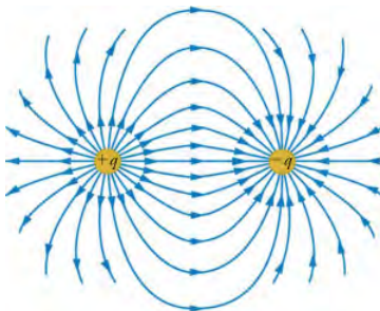
$$E = \frac{kq}{r^2} \quad (3)$$



# 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

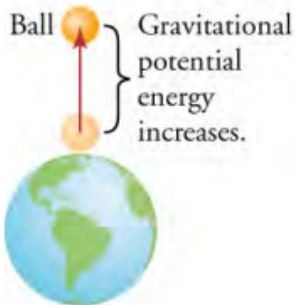
For a charge  $q$  in the presence of a point charge  $Q$ :

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

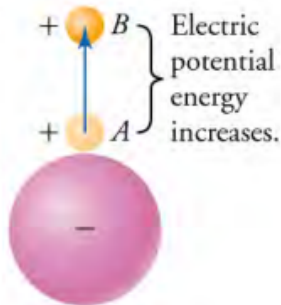
Change in potential energy in constant field:

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

## 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

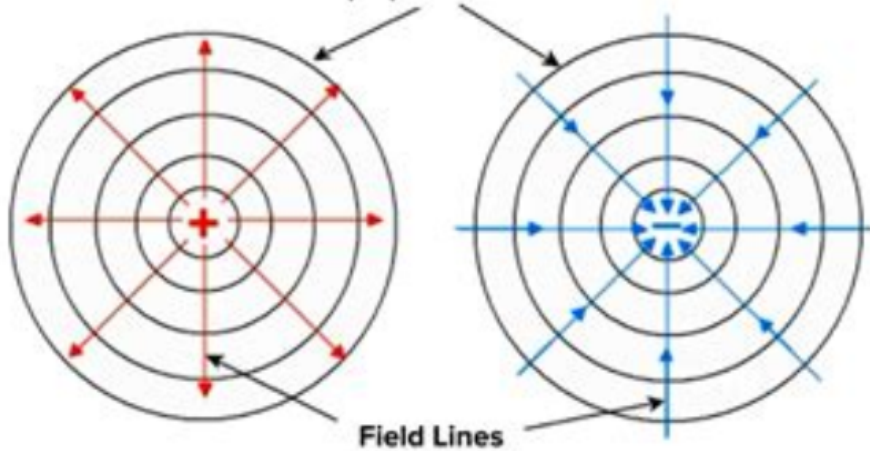
For a point charge  $Q$ :

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

Change in potential in constant field:

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

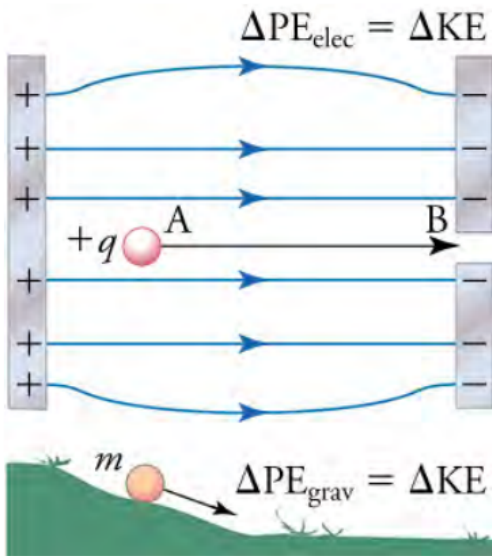
**Equi-potential Lines**



# 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

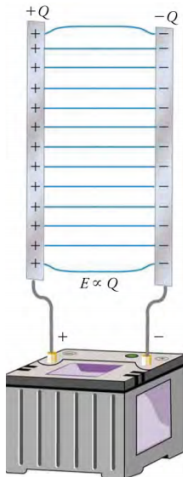
Capacitance is the ratio of charge to potential difference:

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

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.

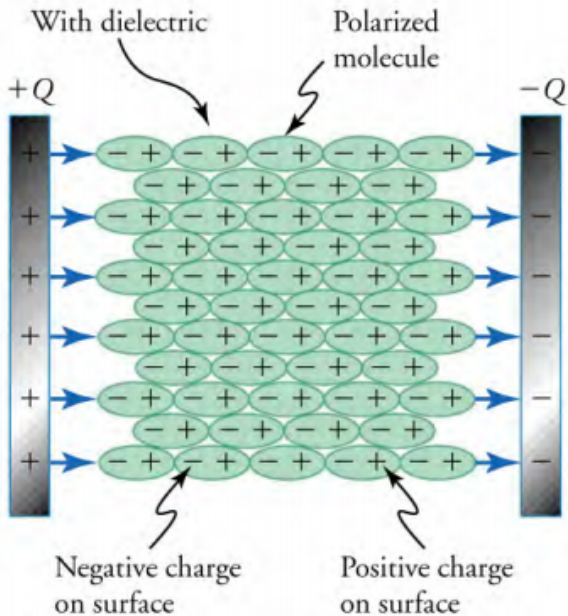
## Effects of Dielectrics

Inserting a dielectric between capacitor plates:

- Increases the capacitance by a factor  $\kappa$  (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

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## 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

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## 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  $0.0025 \text{ m}^2$  separated by a distance of  $0.5 \text{ mm}$ .

- (a) Calculate the capacitance of this capacitor.
- (b) If the capacitor is connected to a  $12 \text{ V}$  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  $\kappa$

# Thank You!

## Questions?

Practice problems: Textbook Chapter 18