Chapter 21
Electric Charge and Electric Field
Units of Chapter 21

• Static Electricity; Electric Charge and Its Conservation
• Electric Charge in the Atom
• Insulators and Conductors
• Induced Charge; the Electroscope
• Coulomb’s Law
• The Electric Field
• Electric Field Calculations for Continuous Charge Distributions
Units of Chapter 21

- Field Lines
- Electric Fields and Conductors
- Motion of a Charged Particle in an Electric Field
- Electric Dipoles
- Electric Forces in Molecular Biology: DNA
- Photocopy Machines and Computer Printers Use Electrostatics
Objects can be charged by rubbing
Charge comes in two types, positive and negative; like charges repel and opposite charges attract.
Electric charge is conserved – the arithmetic sum of the total charge cannot change in any interaction.
21-2 Electric Charge in the Atom

Atom:

Nucleus (small, massive, positive charge)

Electron cloud (large, very low density, negative charge)
21-2 Electric Charge in the Atom

Polar molecule: neutral overall, but charge not evenly distributed
Conductor:
Charge flows freely
Metals

Insulator:
Almost no charge flows
Most other materials

Some materials are semiconductors.
Metal objects can be charged by conduction:

Neutral metal rod

Charged metal object

Metal rod acquires charge by contact
21-4 Induced Charge; the Electroscope

They can also be charged by induction, either while connected to ground or not:

Neutral metal rod

Metal rod still neutral, but with a separation of charge
Nonconductors won’t become charged by conduction or induction, but will experience charge separation:
The electroscope can be used for detecting charge.
21-4 Induced Charge; the Electroscope

The electroscope can be charged either by conduction or by induction.
21-4 Induced Charge; the Electroscope

The charged electroscope can then be used to determine the sign of an unknown charge.
Experiment shows that the electric force between two charges is proportional to the product of the charges and inversely proportional to the distance between them.
Coulomb’s law:

\[ F = k \frac{Q_1 Q_2}{r^2}. \]

This equation gives the magnitude of the force between two charges.
The force is along the line connecting the charges, and is attractive if the charges are opposite, and repulsive if they are the same.

\[ F_{12} = \text{force on 1 due to 2} \]

\[ F_{21} = \text{force on 2 due to 1} \]
21-5 Coulomb’s Law

Unit of charge: coulomb, C.

The proportionality constant in Coulomb’s law is then:

\[ k = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2. \]

Charges produced by rubbing are typically around a microcoulomb:

\[ 1 \mu \text{C} = 10^{-6} \text{ C}. \]
21-5 Coulomb’s Law

Charge on the electron:

\[ e = 1.602 \times 10^{-19} \text{ C.} \]

Electric charge is quantized in units of the electron charge.
21-5 Coulomb’s Law

The proportionality constant $k$ can also be written in terms of $\varepsilon_0$, the permittivity of free space:

$$F = \frac{1}{4\pi \varepsilon_0} \frac{Q_1 Q_2}{r^2},$$

where

$$\varepsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2.$$
21-5 Coulomb’s Law

Conceptual Example 21-1: Which charge exerts the greater force?

Two positive point charges, \( Q_1 = 50 \, \mu\text{C} \) and \( Q_2 = 1 \, \mu\text{C} \), are separated by a distance \( \ell \). Which is larger in magnitude, the force that \( Q_1 \) exerts on \( Q_2 \) or the force that \( Q_2 \) exerts on \( Q_1 \)?
Example 21-2: Three charges in a line.

Three charged particles are arranged in a line, as shown. Calculate the net electrostatic force on particle 3 (the $-4.0 \mu C$ on the right) due to the other two charges.
Example 21-3: Electric force using vector components.

Calculate the net electrostatic force on charge $Q_3$ shown in the figure due to the charges $Q_1$ and $Q_2$. 

\[ Q_3 = +65 \, \mu C \]
\[ Q_2 = +50 \, \mu C \]
\[ Q_1 = -86 \, \mu C \]
Conceptual Example 21-4: Make the force on $Q_3$ zero.

In the figure, where could you place a fourth charge, $Q_4 = -50 \mu C$, so that the net force on $Q_3$ would be zero?
The electric field is defined as the force on a small charge, divided by the magnitude of the charge:

\[ \vec{E} = \frac{\vec{F}}{q} \]
An electric field surrounds every charge.
21-6 The Electric Field

For a point charge:

\[ E = \frac{F}{q} = \frac{kqQ}{r^2} \]

\[ E = k \frac{Q}{r^2}; \quad \text{[single point charge]} \]

or, in terms of \( \epsilon_0 \) as in Eq. 21–2 \( (k = 1/4\pi\epsilon_0) \):

\[ E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}. \quad \text{[single point charge]} \]
21-6 The Electric Field

Force on a point charge in an electric field:

\[ \vec{F} = q \vec{E}. \]
Example 21-6: Electric field of a single point charge.

Calculate the magnitude and direction of the electric field at a point P which is 30 cm to the right of a point charge $Q = -3.0 \times 10^{-6}$ C.

$Q = -3.0 \times 10^{-6}$ C

$E = 3.0 \times 10^5$ N/C

$Q = +3.0 \times 10^{-6}$ C

$E = 3.0 \times 10^5$ N/C
Example 21-7: \( E \) at a point between two charges. Two point charges are separated by a distance of 10.0 cm. One has a charge of \(-25 \, \mu C\) and the other \(+50 \, \mu C\). (a) Determine the direction and magnitude of the electric field at a point \( P \) between the two charges that is 2.0 cm from the negative charge. (b) If an electron (mass = \(9.11 \times 10^{-31}\) kg) is placed at rest at \( P \) and then released, what will be its initial acceleration (direction and magnitude)?
Example 21-8: $\vec{E}$ above two point charges.

Calculate the total electric field (a) at point A and (b) at point B in the figure due to both charges, $Q_1$ and $Q_2$. 

\[ Q_2 = +50 \, \mu C \]
\[ Q_1 = -50 \, \mu C \]
Problem solving in electrostatics: electric forces and electric fields

1. Draw a diagram; show all charges, with signs, and electric fields and forces with directions.

2. Calculate forces using Coulomb’s law.

3. Add forces vectorially to get result.

4. Check your answer!
Summary of Chapter 21 Sec. 1-6

- Two kinds of electric charge – positive and negative.
- Charge is conserved.
- Charge on electron:
  \[ e = 1.602 \times 10^{-19} \text{ C.} \]
- Conductors: electrons free to move.
- Insulators: nonconductors.
• Charge is quantized in units of $e$.

• Objects can be charged by conduction or induction.

• Coulomb’s law:  
  \[ F = k \frac{Q_1 Q_2}{r^2}. \]

\[ F = \frac{1}{4\pi \epsilon_0} \frac{Q_1 Q_2}{r^2}, \]

where

\[ \epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12} \text{C}^2/\text{N}\cdot\text{m}^2. \]

• Electric field is force per unit charge:
  \[ \vec{E} = \frac{\vec{F}}{q}. \]
Summary of Chapter 21 Sec. 1-6

• Electric field of a point charge:

\[
E = \frac{F}{q} = \frac{kqQ/r^2}{q} = \frac{kQ}{r^2}, \quad \text{[single point charge]}
\]
Chapter 21: 6, 12, 16, 18, 27, 28