Phys102 Lecture 2

Coulomb's Law

Key Points

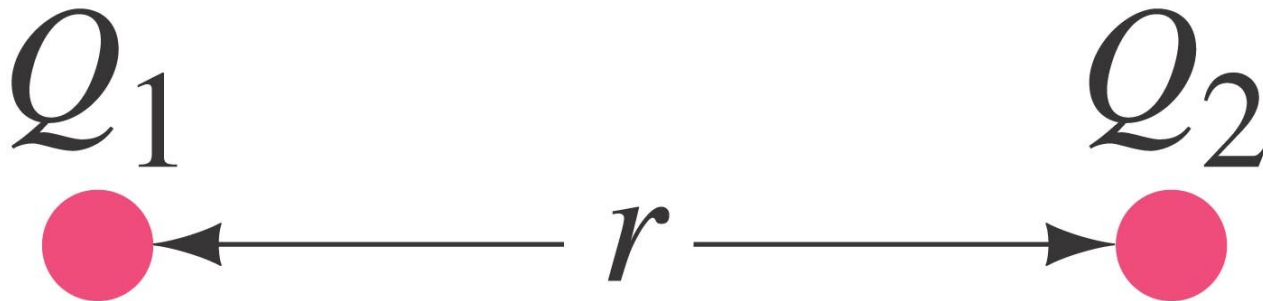- Coulomb's Law
- The electric field (**E** is a vector!)

References

SFU Ed: 21-5,6,7,8,9,10.
6th Ed: 16-6,7,8,9,+.

21-5 Coulomb's Law

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.
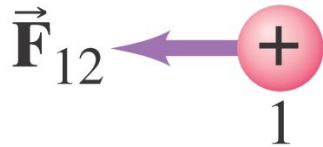
Coulomb's law:

$$F = k \frac{Q_1 Q_2}{r^2}. \qquad \text{[magnitudes]}$$
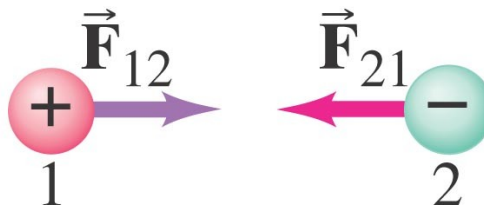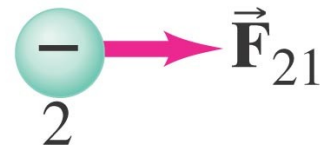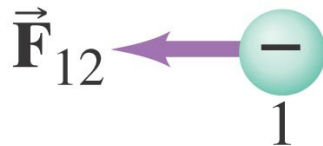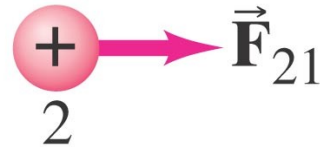
This equation gives the magnitude of the force between two charges.

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} = force on 1 due to 2

F_{21} = force on 2 due to 1

Unit of charge: coulomb, C.

The proportionality constant in Coulomb's law is then:

$$k = 8.99 \text{ x } 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2.$$

Charges produced by rubbing are typically around a microcoulomb:

$$1 \text{ } \mu\text{C} = 10^{-6} \text{ C}.$$

Charge on the electron:

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

Electric charge is quantized in units of the electron charge.

The proportionality constant k can also be written in terms of ε_0, the permittivity of free space:

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

where

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

**i-clicker question 2-1: Which charge exerts the greater force?**

Two positive point charges, $Q_1 = 50 \ \mu C$ and $Q_2 = 1 \ \mu C$, are separated by a distance ℓ. Which is larger in magnitude, the force that Q_1 exerts on Q_2 (F_{21}) or the force that Q_2 exerts on Q_1 (F_{12})?

$Q_1 = 50 \ \mu C$ $\hspace{6cm}$ $Q_2 = 1 \ \mu C$

ℓ

A) $F_{21} > F_{12}$
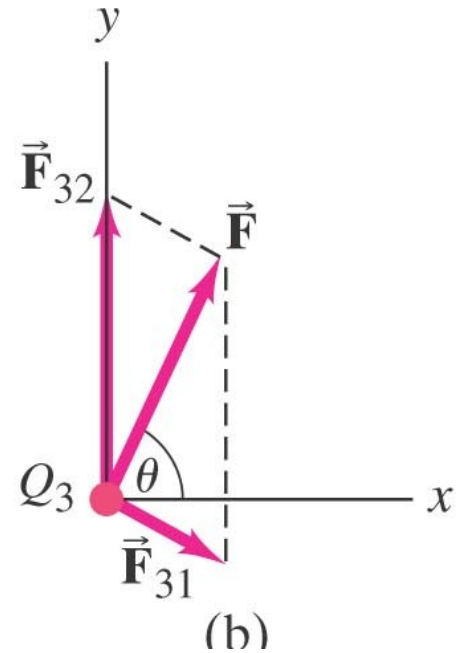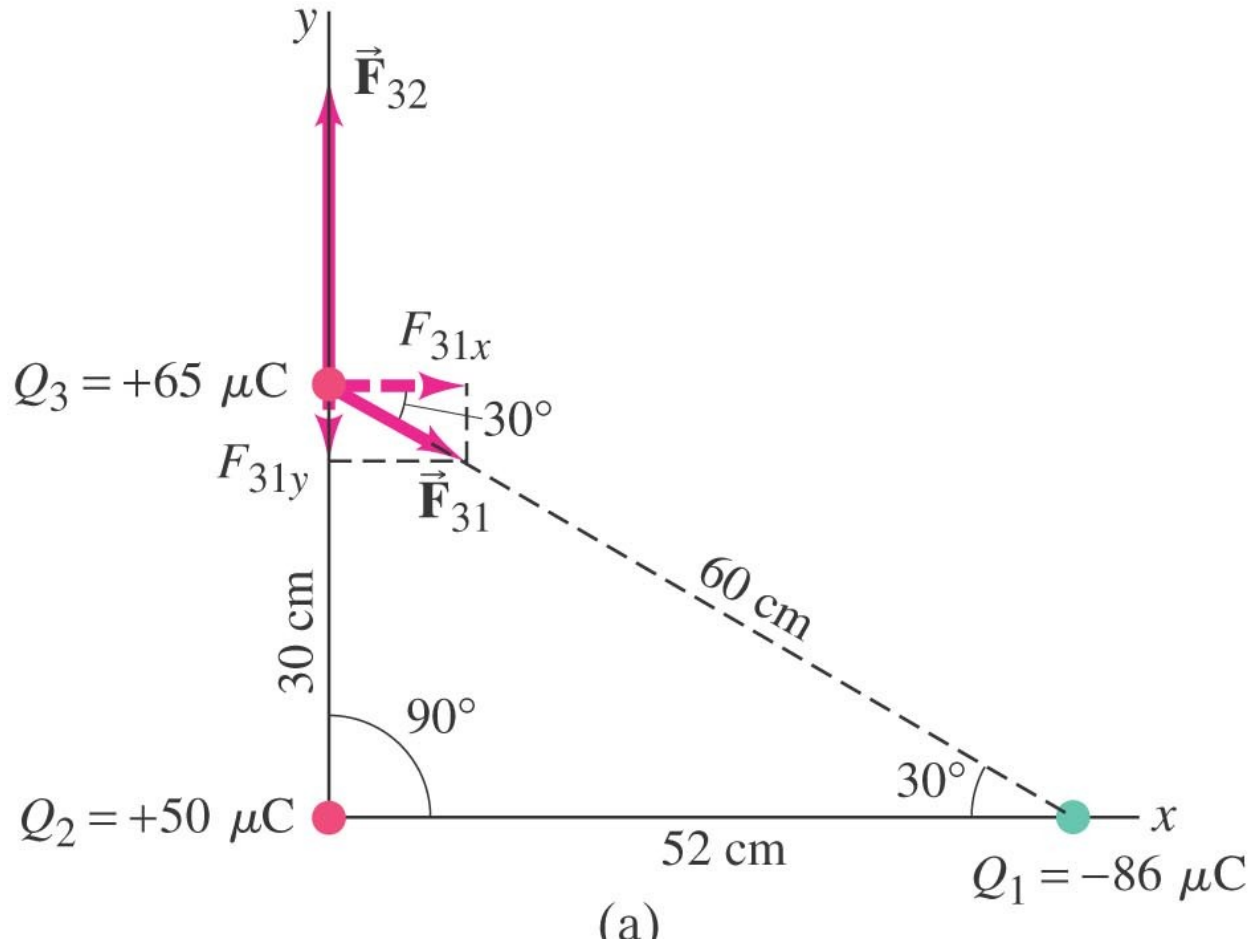B) $F_{12} > F_{21}$
C) $F_{12} = F_{21}$

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 μC on the right) due to the other two charges.
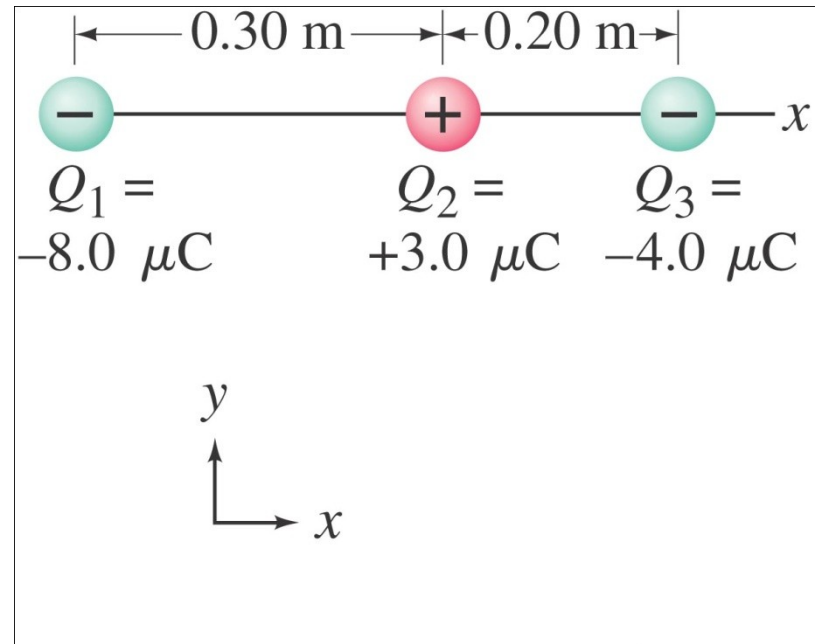
Example 21-3: Electric force using vector components.

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

$Q_3 = +65\ \mu C$

$Q_2 = +50\ \mu C$

$\vec{F}_{32}$

F_{31x}

$+30°$

$\vec{F}_{31}$

F_{31y}

30 cm

90°

52 cm

60 cm

30°

$Q_1 = -86\ \mu C$

x

y

(a)

y

$\vec{F}_{32}$

$\vec{F}$

Q_3

θ

x

$\vec{F}_{31}$

(b)
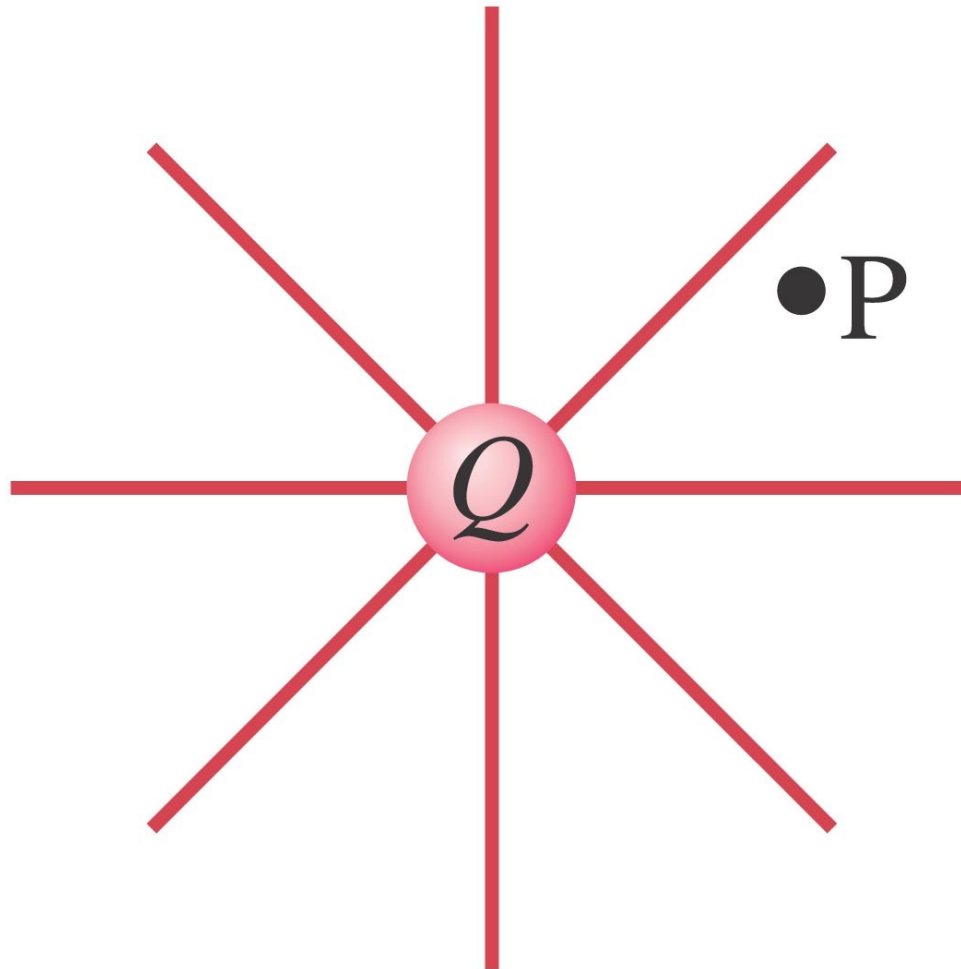
21-6 The Electric Field

The electric field is defined as the force on a small charge, divided by the magnitude of the charge:

$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}}{q}.$$
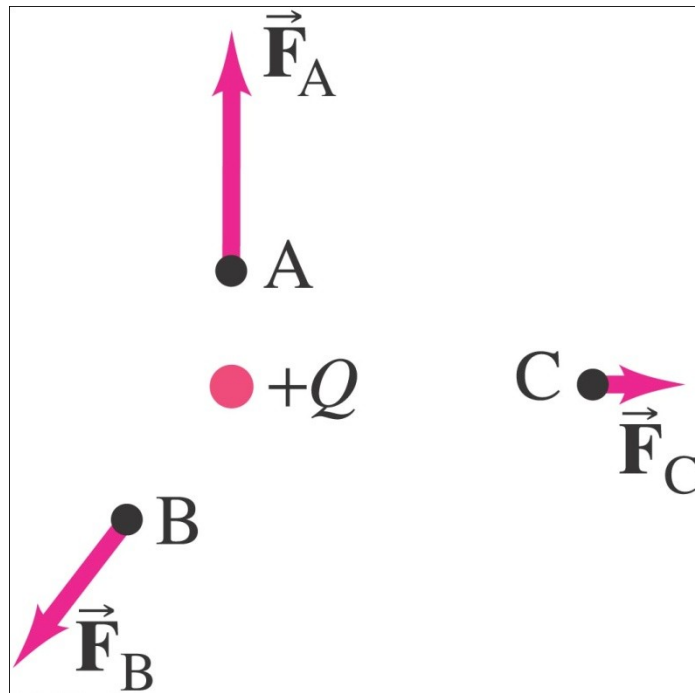
21-6 The Electric Field

An electric field surrounds every charge.

21-6 The Electric Field

For a point charge:

$$E = \frac{F}{q} = \frac{kqQ/r^2}{q}$$

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

or, in terms of ϵ_0 as in Eq. 21–2 $(k = 1/4\pi\epsilon_0)$:

$$E = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}. \qquad\qquad \text{[single point charge]}$$

21-6 The Electric Field

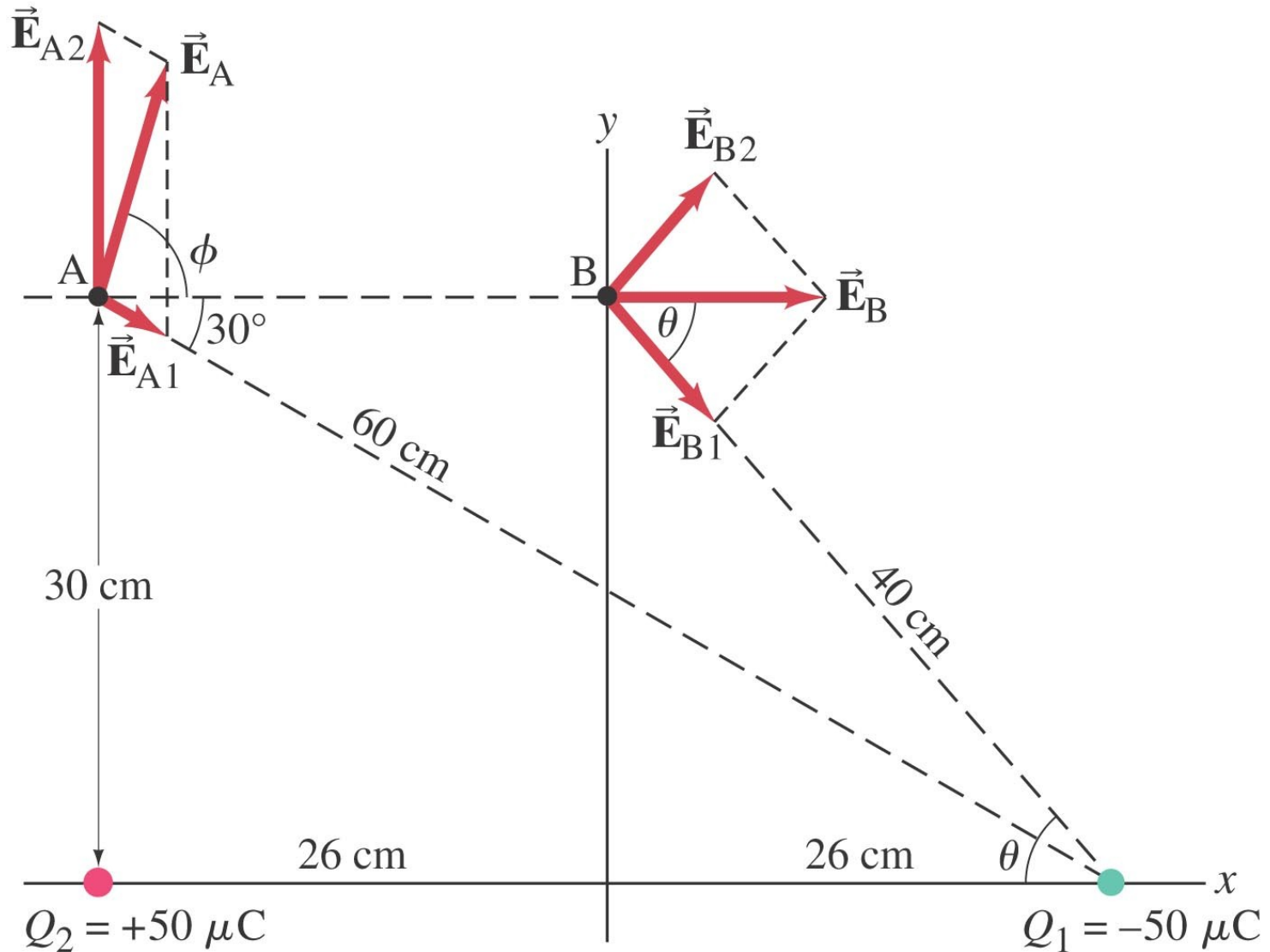**Force on a point charge in an electric field:**

$$\vec{F} = q\vec{E}.$$
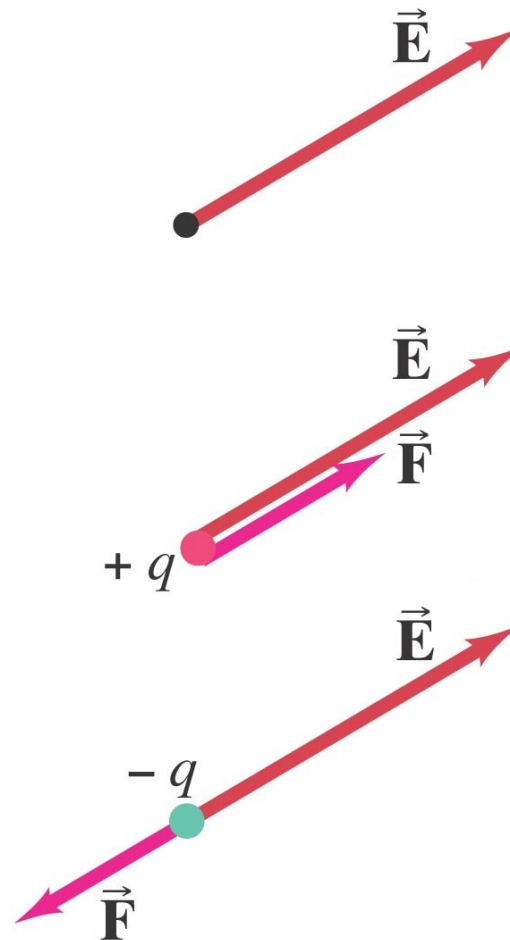
Example 21-8: Electric field above two point charges.

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.


$\vec{E}_{A2}$ $\vec{E}_A$

y $\vec{E}_{B2}$

A ϕ B $\vec{E}_B$

θ

$30°$

$\vec{E}_{A1}$ $\vec{E}_{B1}$

60 cm

40 cm

30 cm

26 cm   26 cm θ x

$Q_2 = +50\ \mu C$ $Q_1 = -50\ \mu C$

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!

21-8 Field Lines

The electric field can be represented by field lines. These lines start on a positive charge and end on a negative charge.
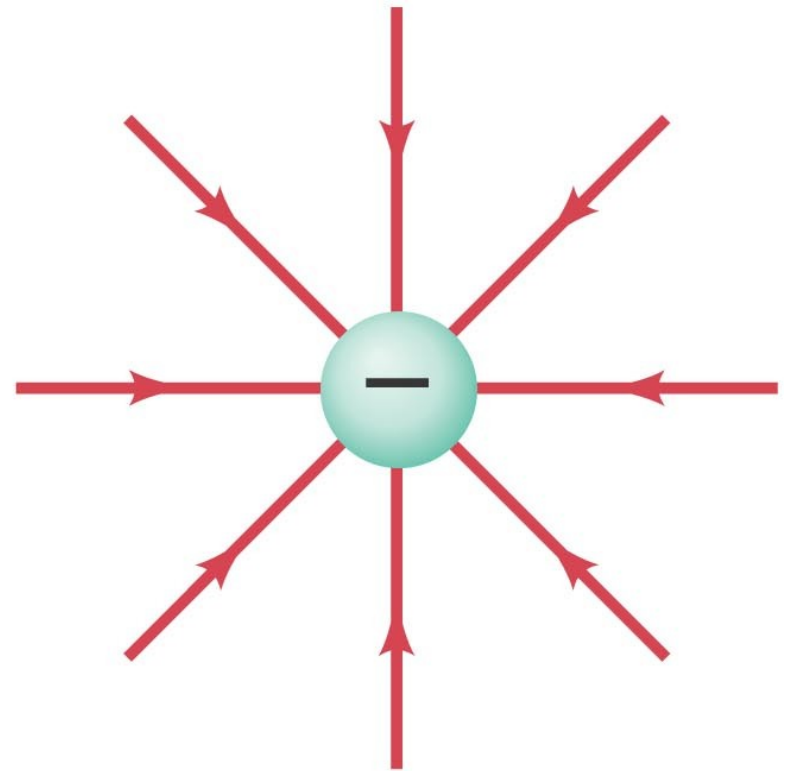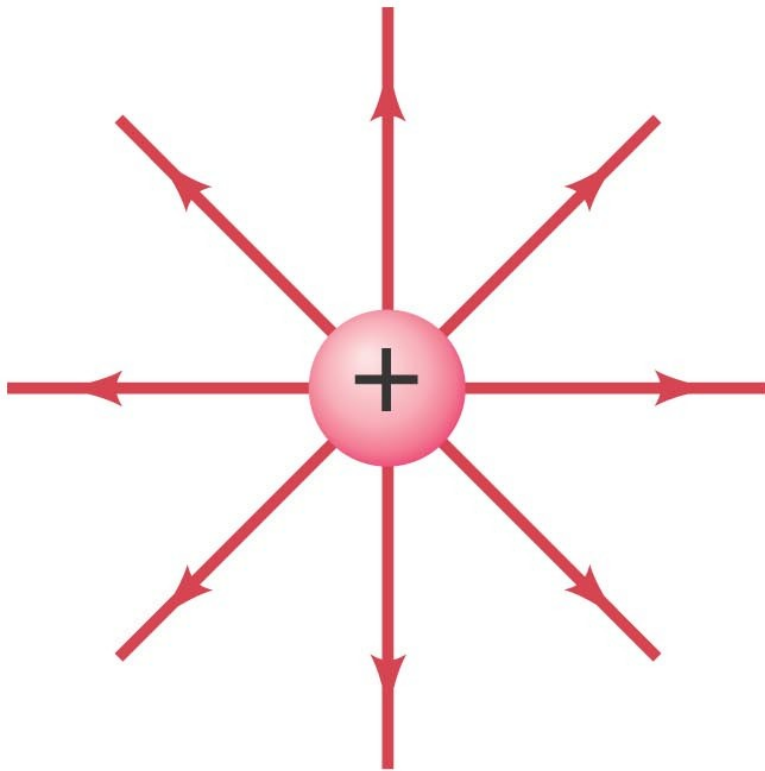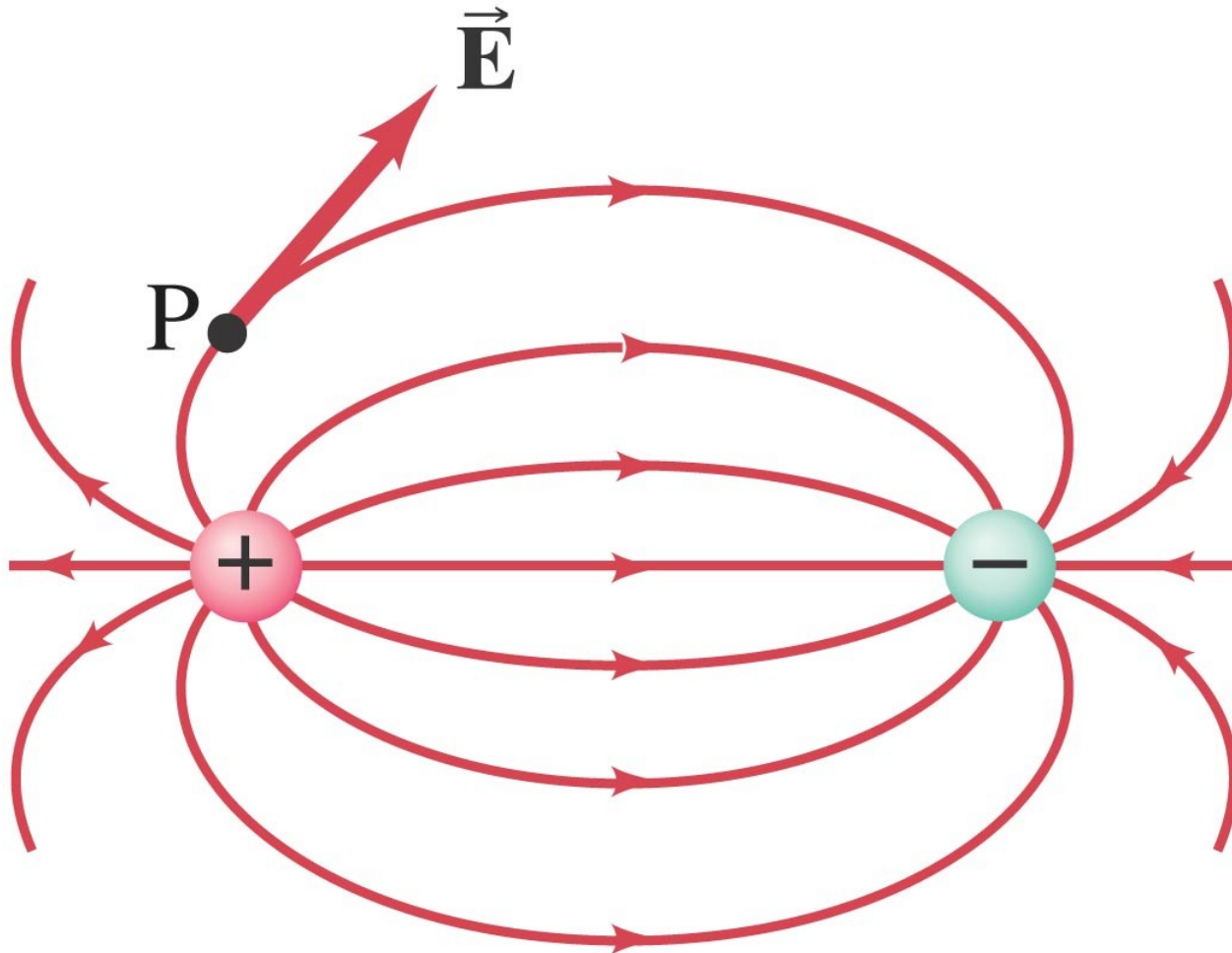
21-8 Field Lines

The number of field lines starting (ending) on a positive (negative) charge is proportional to the magnitude of the charge.
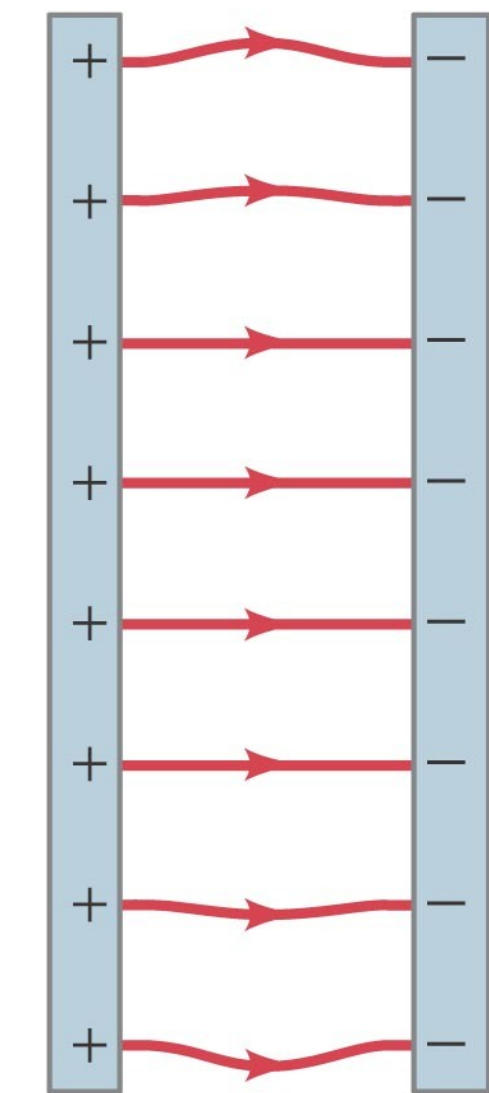
The electric field is stronger where the field lines are closer together.

21-8 Field Lines

Electric dipole: two equal charges, opposite in sign:

21-8 Field Lines

$+Q$ $-Q$

The electric field between two closely spaced, oppositely charged parallel plates is constant.

21-8 Field Lines

Summary of field lines:

1. Field lines indicate the direction of the field; the field is tangent to the line.

2. The magnitude of the field is proportional to the density of the lines.

3. Field lines start on positive charges and end on negative charges; the number is proportional to the magnitude of the charge.
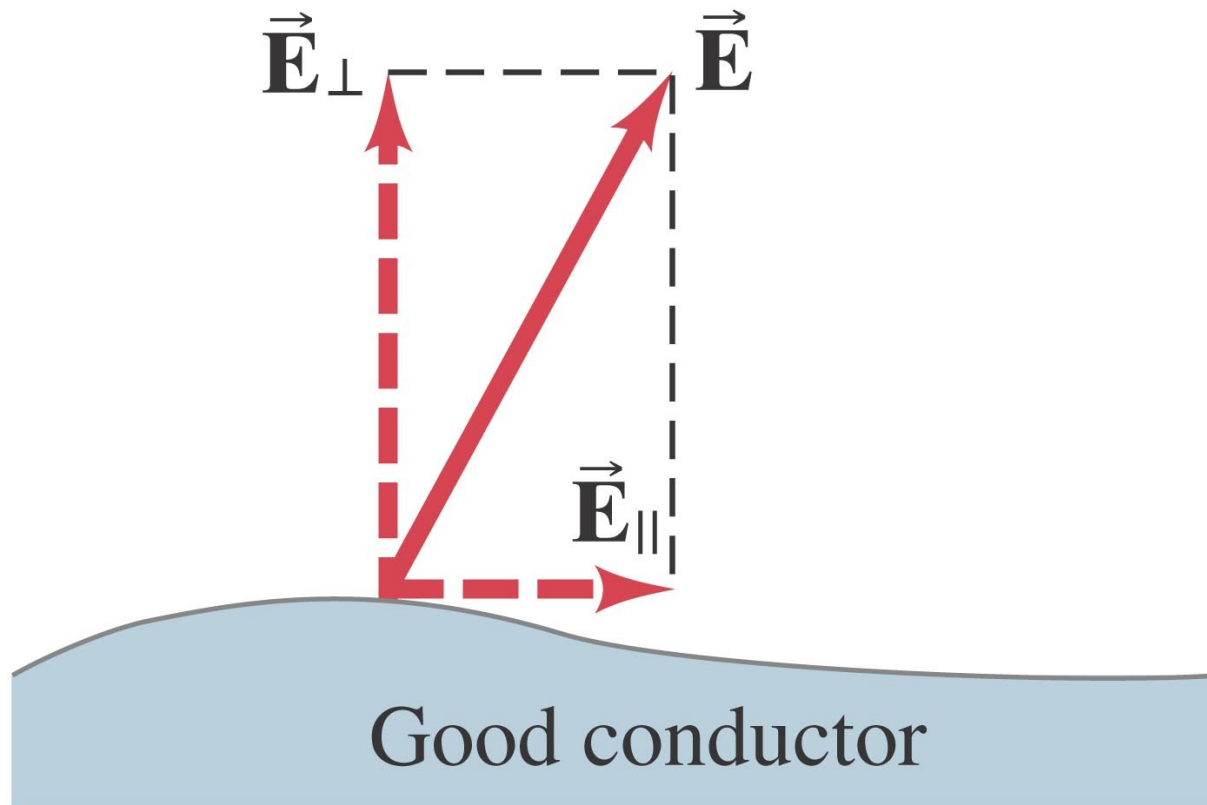
21-9 Electric Fields and Conductors

The static electric field inside a conductor is zero – if it were not, the charges would move.
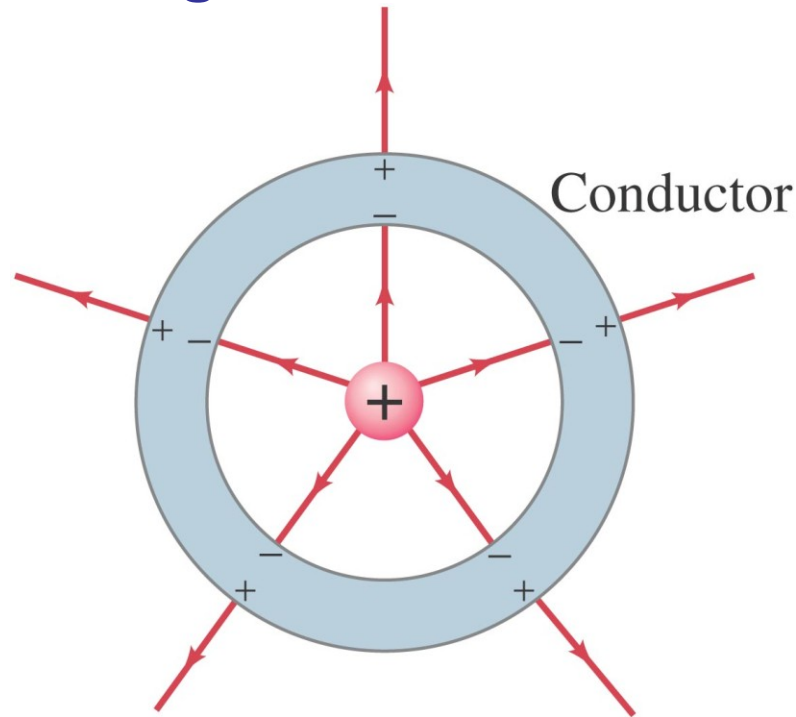
Conductor

The net charge on a conductor resides on its outer surface.

21-9 Electric Fields and Conductors

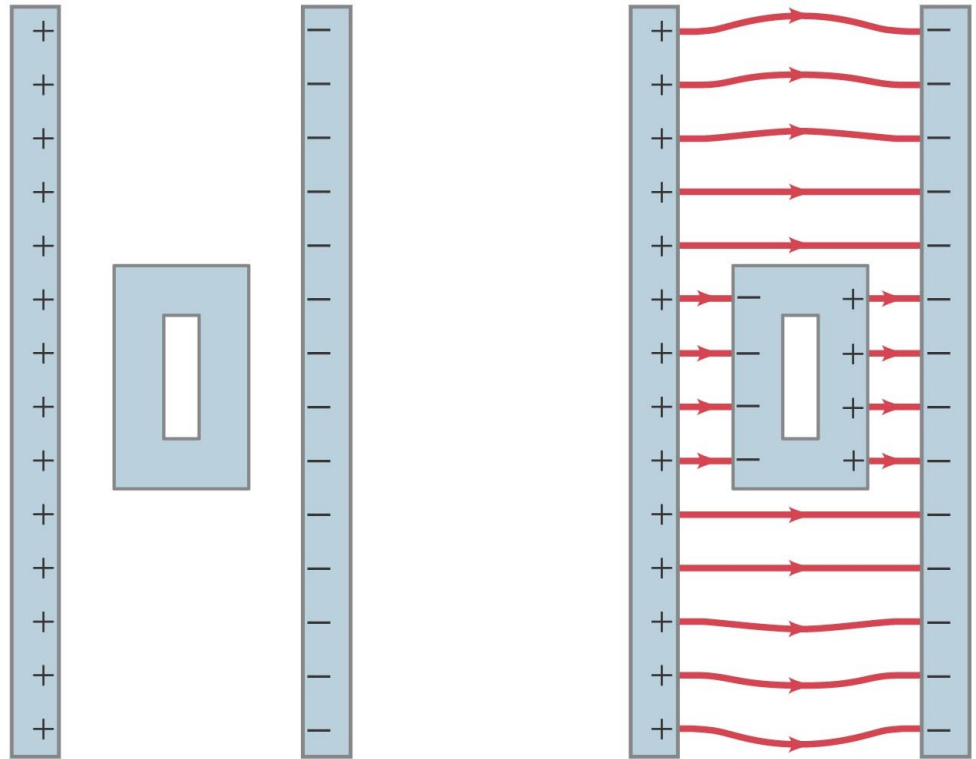**The electric field is perpendicular to the surface of a conductor – again, if it were not, charges would move.**

Good conductor

21-9 Electric Fields and Conductors

Conceptual Example 21-14: Shielding, and safety in a storm.

A neutral hollow metal box is placed between two parallel charged plates as shown. What is the field like inside the box?

# 21-10 Motion of a Charged Particle in an Electric Field

The force on an object of charge q in an electric field $\vec{E}$ is given by:

$$\vec{F} = q\,\vec{E}$$

Therefore, if we know the mass and charge of a particle, we can describe its subsequent motion in an electric field.

Example 21-15: Electron accelerated by electric field.

An electron (mass m = 9.11 x 10^{-31} kg) is accelerated in the uniform field   (E = 2.0 x 10^4 N/C) between two parallel charged plates. The separation of the plates is 1.5 cm. The electron is accelerated from rest near the negative plate and passes $\vec{E}$ through a tiny hole in the positive plate. (a) With what speed does it leave the hole? (b) Show that the gravitational force can be ignored. Assume the hole is so small that it does not affect the uniform field between the plates.
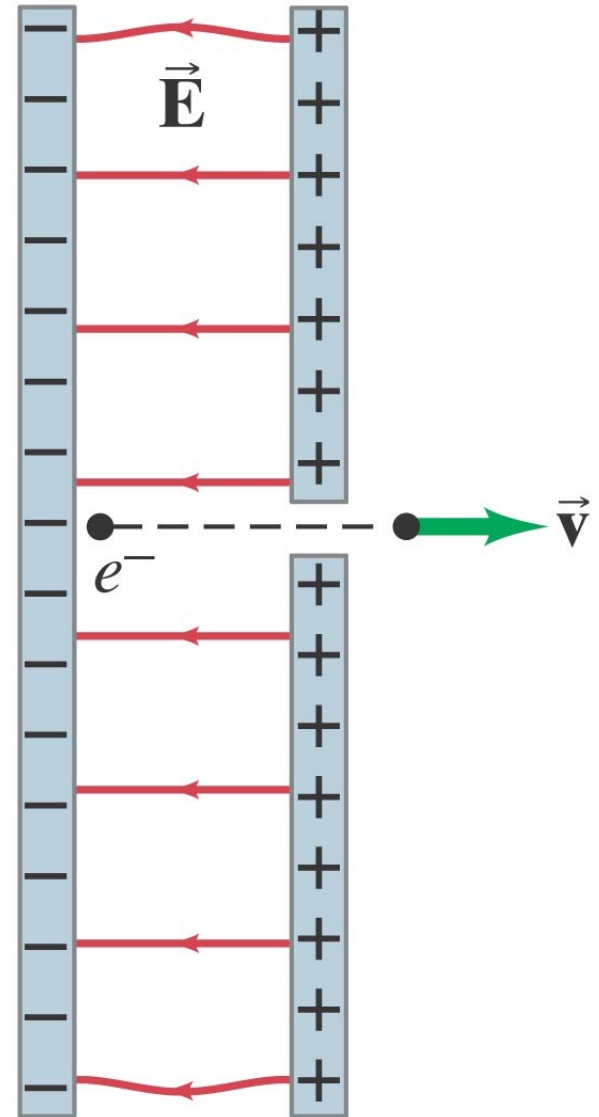
Example 21-16: Electron moving perpendicular to $\vec{E}$.

Suppose an electron traveling with speed v_0 = 1.0 x 10^7 m/s enters a uniform electric field $\vec{E}$, which is at right angles to v_0 as shown. Describe its motion by giving the equation of its path while in the electric field. Ignore gravity.