Chapter 23

Electric Fields

Outline

- 23.1 Properties of Electric Charges
- 23.2 Charging Objects By Induction
- 23.3 Coulomb's Law
- 23.4 The Electric Field
- 23.6 Electric Field Lines
- 23.7 Motion of Charged Particles in a Uniform Electric Field

23.1 Properties of Electric Charges

- There are two kinds of charges in nature; charges of opposite sign attract one another and charges of the same sign repel one another.
- Total charge in an isolated system is *conserved*.
- Charge is quantized.

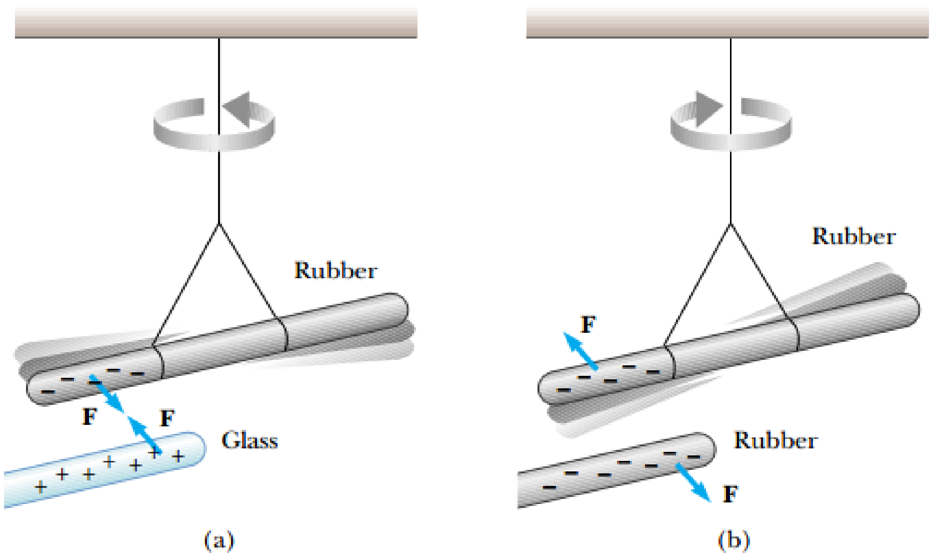


Figure 23.1 (a) A negatively charged rubber rod suspended by a thread is attracted to a positively charged glass rod. (b) A negatively charged rubber rod is repelled by another negatively charged rubber rod.

23.2 Charging Objects By Induction

- **Types of Materials:**

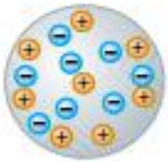
1- Conductors: *have some free electrons that can move through the materials*. ***Ex: copper, aluminum, and silver.***

2- Insulators: *have bound electrons that can* ***not*** *move through the materials*. ***Ex: glass, rubber, and wood***

3- Semiconductors: *electrical properties are somewhere between those of insulators and conductors*. ***Ex: Silicon***

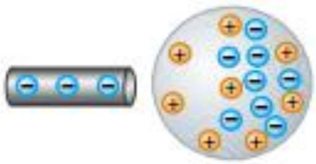
23.2 Charging Objects By Induction

(a) A neutral metallic sphere, with
equal numbers of positive and negative charges.



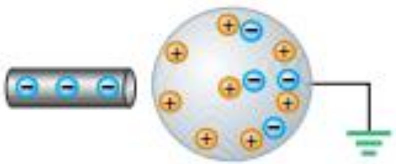
(a)

(b) The electrons on the neutral sphere are redistributed when a charged rubber rod is placed near the sphere.



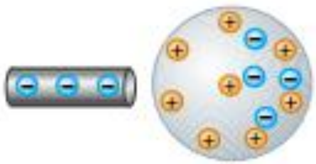
(b)

(c) When the sphere is grounded, some of its electrons leave through the ground wire.



(c)

(d) When the ground connection is removed, the sphere has excess positive charge that is nonuniformly distributed.



(d)

(e) When the rod is removed, the remaining electrons redistribute uniformly and there is a net uniform distribution of positive charge on the sphere.

(e)

23.3 Coulomb's Law

The magnitude of the electric force F between charges q_1 and q_2 separated by a distance r is given by

$$F = k_e \frac{|q_1||q_2|}{r^2} \quad [15.1]$$

where k_e is a constant called the *Coulomb constant*.

$$k = 9\times10^{9}\ \mathrm{Nm^2/C^2}$$

$$k = \frac{1}{4\pi\varepsilon_0} \quad \text{where} \quad \varepsilon_0 = 8.85\times10^{-12}\ \frac{\mathrm{C^2}}{\mathrm{Nm^2}}$$

ε_0 is the permittivity of free space

➢ **Properties of the electric force:**

1- is inversely proportional to the square of the separation r between the particles.
2- is proportional to the product of the charges q1and q2on the two particles
3- is attractive if the charges are of opposite sign and repulsive if the charges have the same sign
4- is a conservative force

23.3 Coulomb's Law

➢ ***Point Charge:***

A particle of zero size that carries an electric charge

➢ **The smallest unit of charge known in nature is the charge on an electron (-e) or a proton (+e) and has a magnitude:**

$$e = 1.6 \times 10^{-19}\ C$$

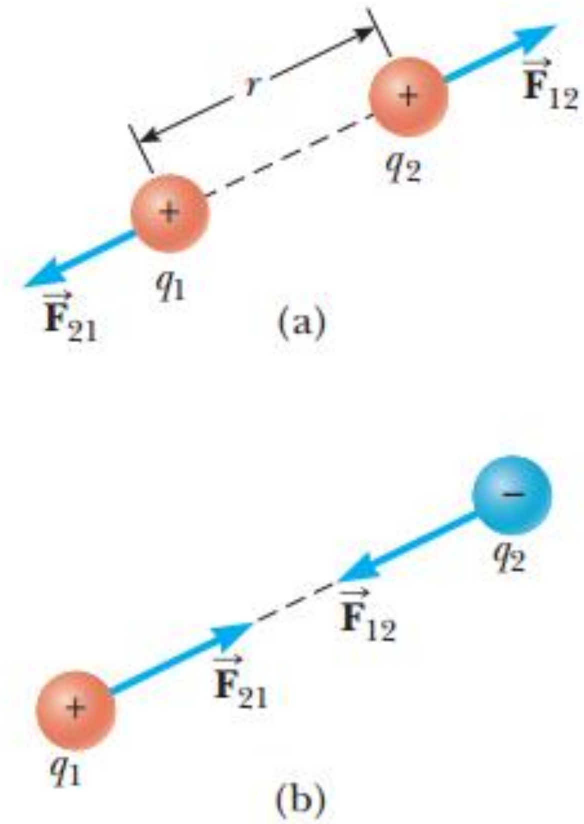
Charge and Mass of the Electron, Proton, and Neutron

Particle	Charge (C)	Mass (kg)
Electron (e)	$-1.602\,191\,7 \times 10^{-19}$	$9.109\,5 \times 10^{-31}$
Proton (p)	$+1.602\,191\,7 \times 10^{-19}$	$1.672\,61 \times 10^{-27}$
Neutron (n)	0	$1.674\,92 \times 10^{-27}$

23.3 Coulomb's Law

➢ ***Vector Nature of Electric Forces:***

$$\vec{F}_{12} = \frac{kq_1q_2}{r_{21}^2}\hat{r}_{21}$$



➢ The force F_{21} exerted by q_2 on q_1 is equal in magnitude and opposite in direction to the force F_{12} exerted by q_1 on q_2.

(a) When the charges are of the same sign, the force is repulsive.

(b)When the charges are of opposite signs, the force is attractive

23.3 Coulomb's Law

- ***Quick Quiz 23.5***

Object A has a charge of +2 *μ*C, and object B has a charge of +6 *μ*C. Which statement is true about the electric forces on the objects?

1- $F_{AB} = -3F_{BA}$

2- $F_{AB} = -F_{BA}$

3- $3F_{AB} = -F_{BA}$

4- $F_{AB} = 3F_{BA}$

5- $F_{AB} = F_{BA}$

6- $3F_{AB} = F_{BA}$

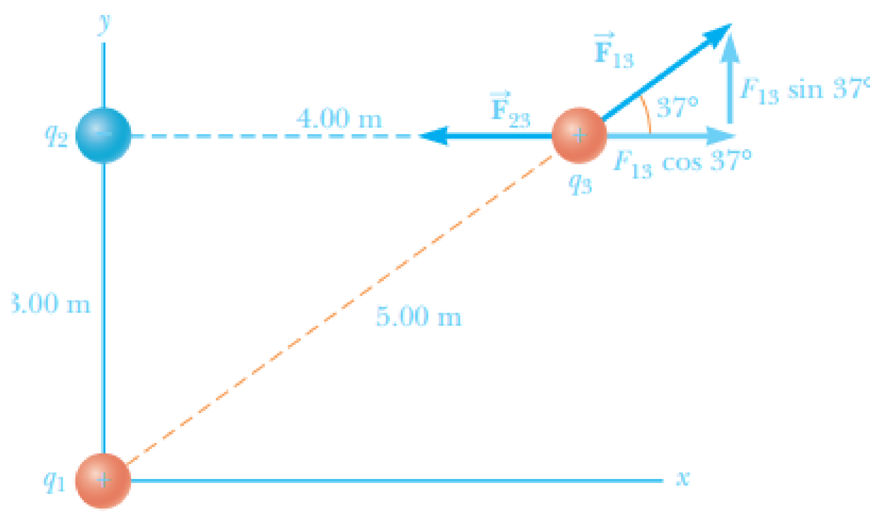
23.3 Coulomb's Law

➢ *When more than two charges are present, the force between any pair of them is given by:*

$$F1 = F21 + F31 + F41$$

Example :

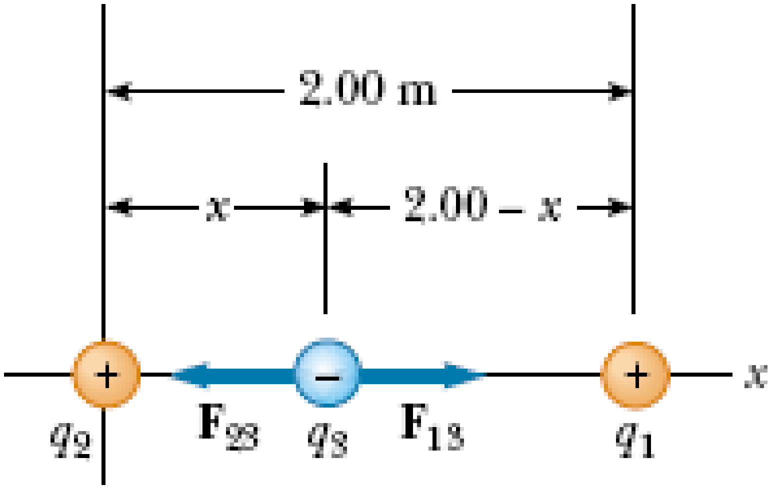
Problem Consider three point charges at the corners of a triangle, as shown in Figure 15.8, where $q_1 = 6.00 \times 10^{-9}$ C, $q_2 = -2.00 \times 10^{-9}$ C, and $q_3 = 5.00 \times 10^{-9}$ C. **(a)** Find the components of the force $\vec{\mathbf{F}}_{23}$ exerted by q_2 on q_3. **(b)** Find the components of the force $\vec{\mathbf{F}}_{13}$ exerted by q_1 on q_3. **(c)** Find the resultant force on q_3, in terms of components and also in terms of magnitude and direction.



23.3 Coulomb's Law

Example 23.3 Page 713: Resultant Force

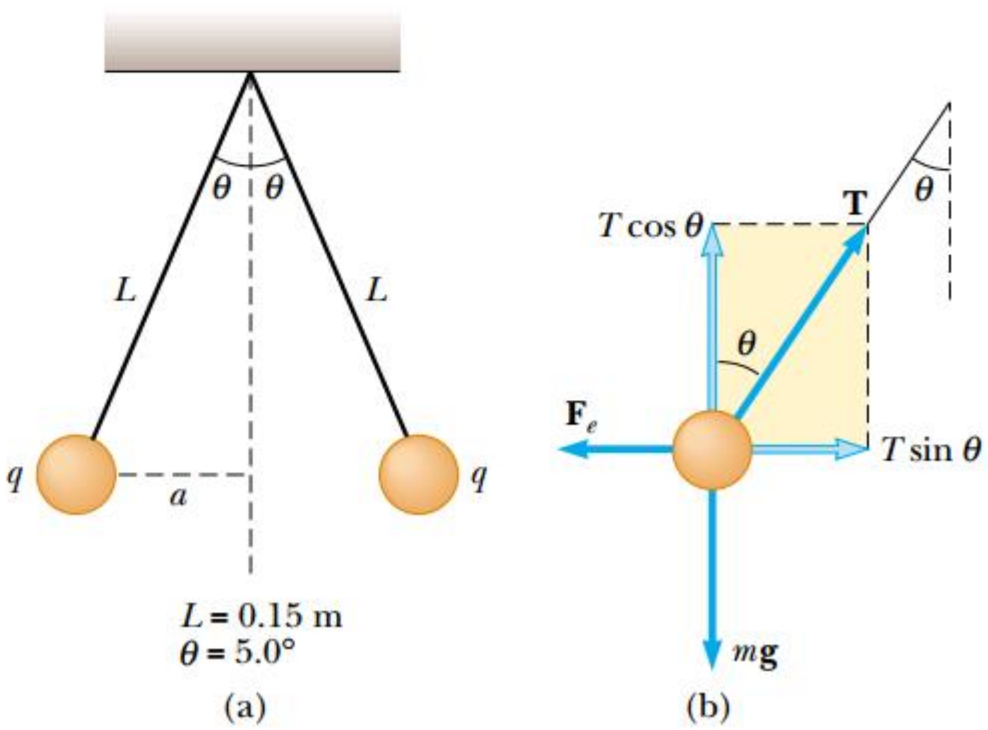
Three point charges lie along the x axis as shown in Figure 23.9. The positive charge $q_1 = 15.0\ \mu C$ is at $x = 2.00$ m, the positive charge $q_2 = 6.00\ \mu C$ is at the origin, and the resultant force acting on q_3 is zero. What is the x coordinate of q_3?



23.3 Coulomb's Law

Example 23.4 Page 714:   Charge on the Spheres

Two identical small charged spheres, each having a mass of 3.0×10^{-2} kg, hang in equilibrium as shown in Figure 23.10a. The length of each string is 0.15 m, and the angle θ is 5.0°. Find the magnitude of the charge on each sphere.



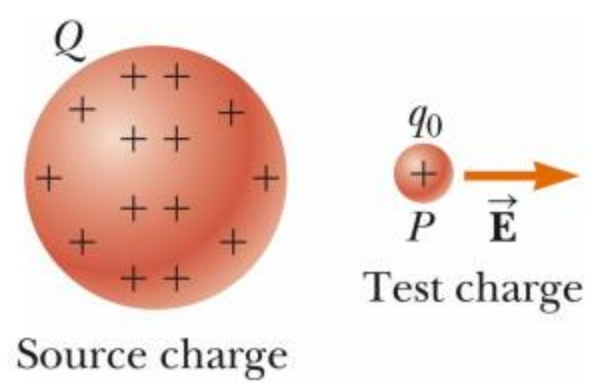
23.4 The Electric Field

- An electric field is said to exist in the region of space around a charged object (the source charge). When another charged object (the test charge) enters this electric field, an electric force acts on it.
- The test charge serves as a *detector* of the electric field.

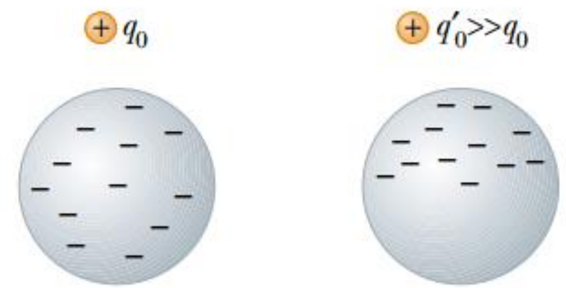
The electric field $\vec{\mathbf{E}}$ produced by a charge Q at the location of a small "test" charge q_0 is defined as the electric force $\vec{\mathbf{F}}$ exerted by Q on q_0 divided by the test charge q_0:

$$\vec{\mathbf{E}} \equiv \frac{\vec{\mathbf{F}}}{q_0} \qquad [15.3]$$

SI unit: newton per coulomb (N/C)



- When using Equation 15.3, we assume that the test charge *q_0 is small enough* that it does not disturb the charge distribution responsible for the electric field



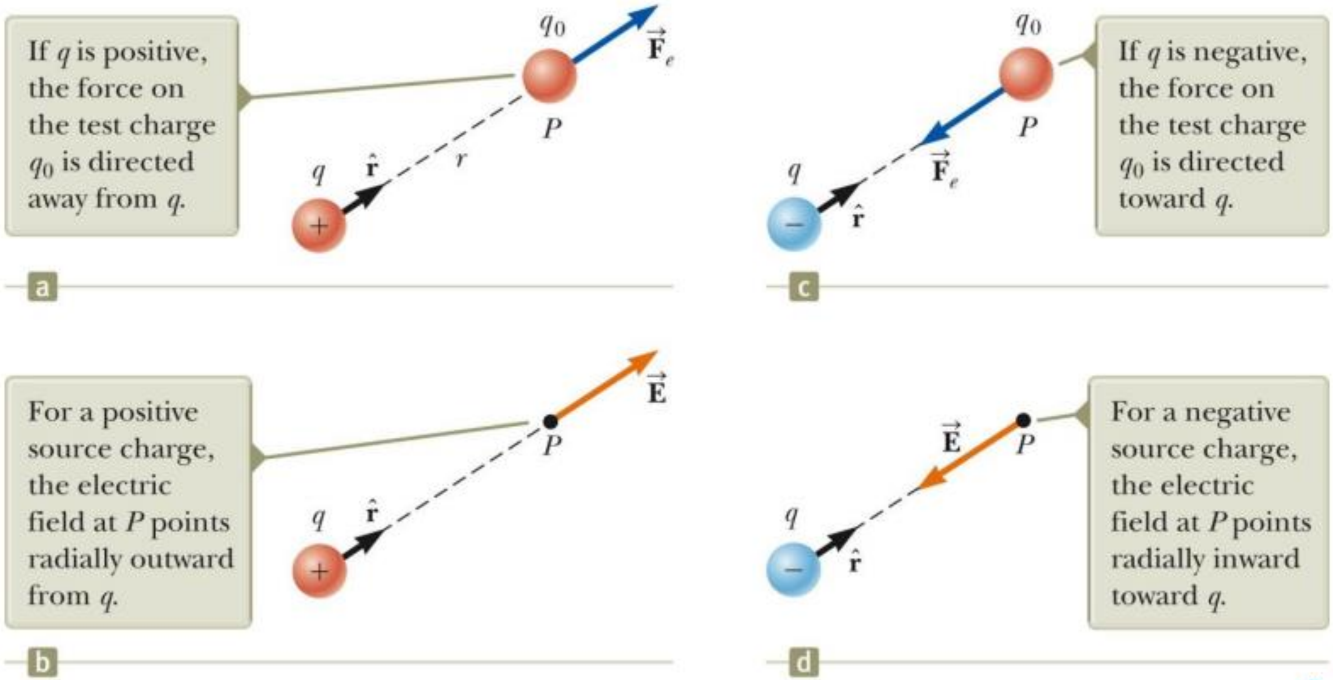
(a) (b)

23.4 The Electric Field

$$\mathbf{F}_e = q\mathbf{E}$$

- If q is positive, the force and the field are in the same direction.
- If q is negative, the force and the field are in opposite directions.

- ***The direction of an electric field:***



Section 23.4

CENGAGE Learning

23.4 The Electric Field

- **According to Coulomb's law, the force exerted by q on the test Charge is:**

$$\mathbf{F}_e = k_e \frac{q q_0}{r^2} \hat{\mathbf{r}}$$

$$\mathbf{E} = k_e \frac{q}{r^2} \hat{\mathbf{r}}$$

- **At any point P, the total electric field due to a group of source charges equals the vector sum of the electric fields of all the charges.**

$$\mathbf{E} = k_e \sum_i \frac{q_i}{{r_i}^2} \hat{\mathbf{r}}_i$$

23.4 The Electric Field

- ***Quick Quiz 23.6***

A test charge of +3 μC is at a point P where an external electric field is directed to the right and has a magnitude of 4 × 106 N/C. If the test charge is replaced with another test charge of –3 μC, the external electric field at P

1- *is unaffected*

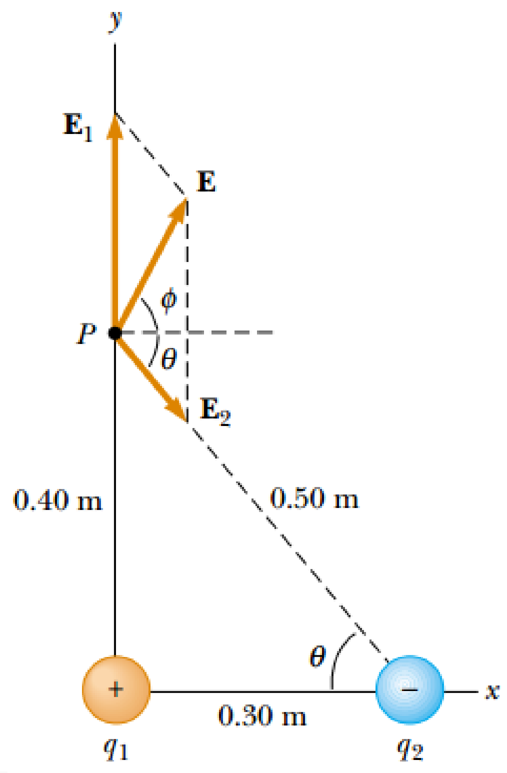
2- reverses direction

3- changes in a way that cannot be determined

23.4 The Electric Field

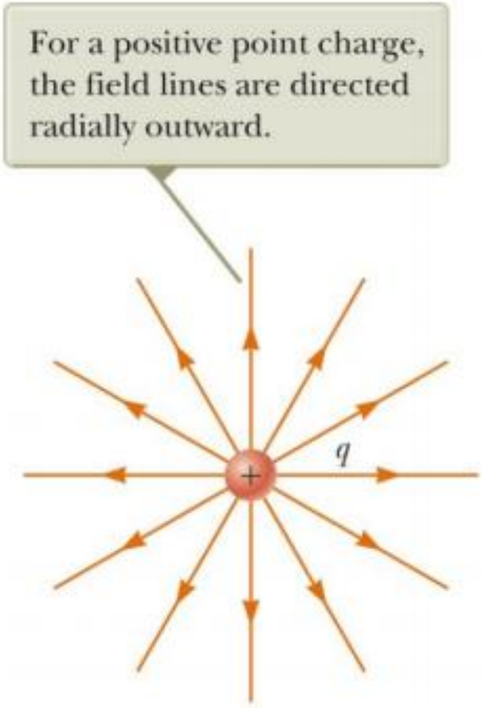
- ***Example 23.5 Page 718***

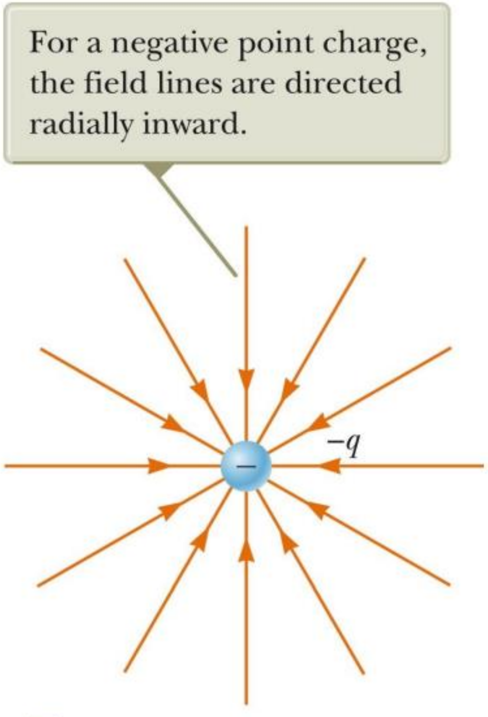
A charge $q_1 = 7.0\ \mu C$ is located at the origin, and a second charge $q_2 = -5.0\ \mu C$ is located on the x axis, 0.30 m from the origin (Fig. 23.14). Find the electric field at the point P, which has coordinates (0, 0.40) m.



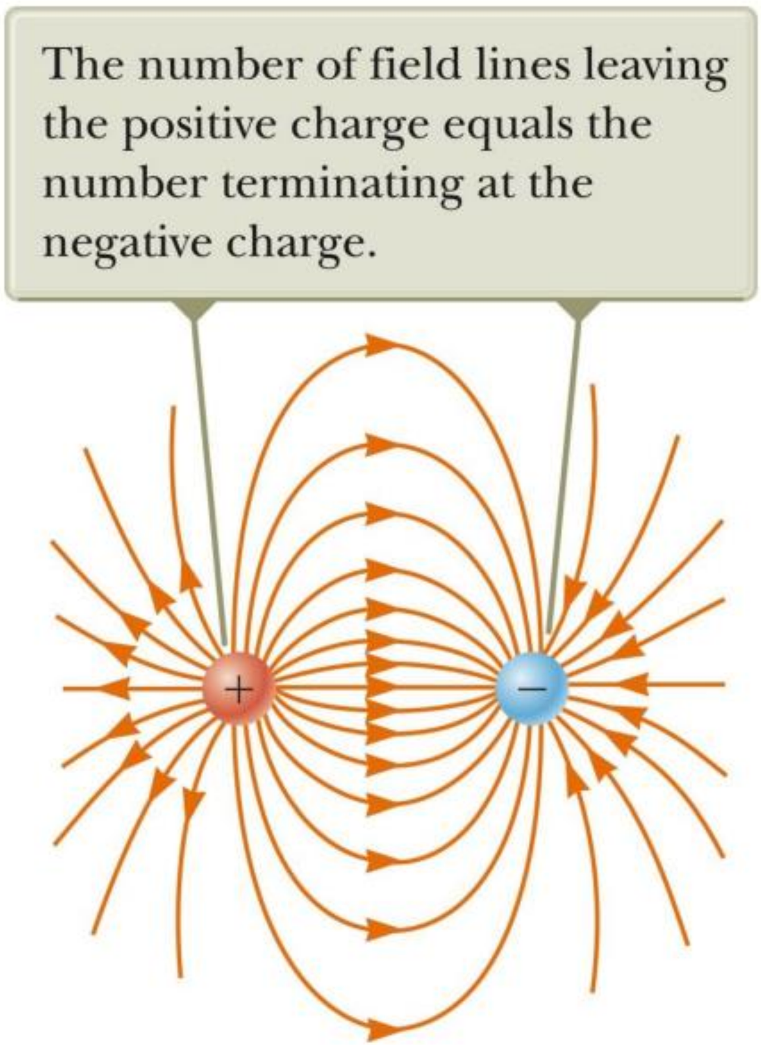
23.6 Electric Field Lines

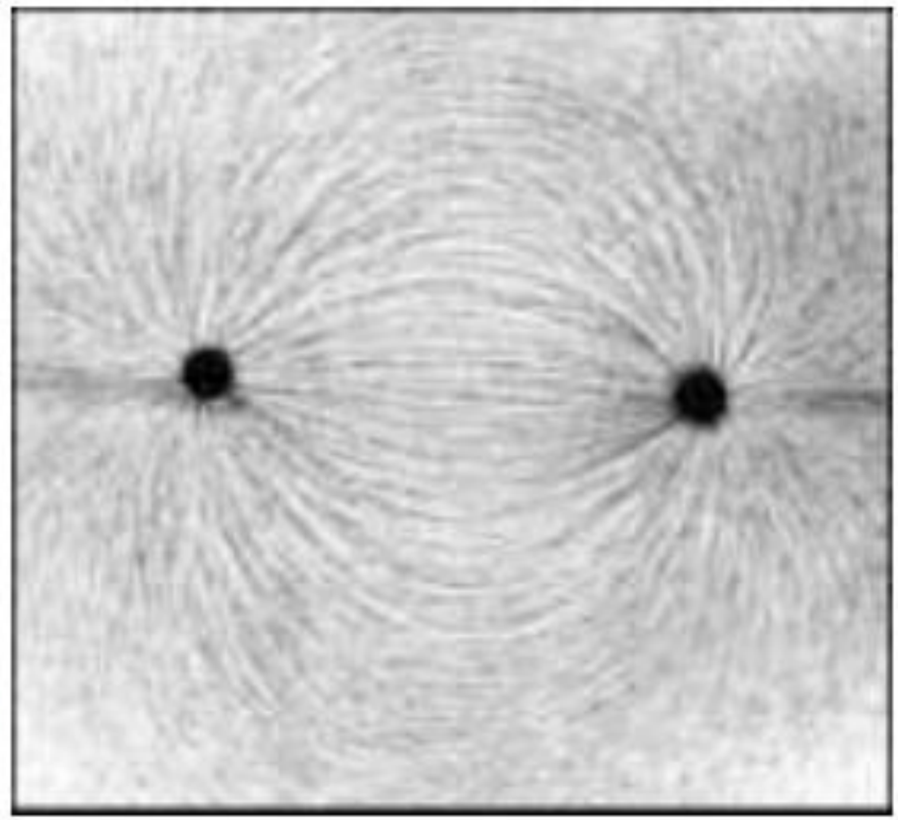
- Used for visualizing electric field patterns.
- The electric field vector E is tangent to the electric field lines at each point.
- E is large when the field lines are close together and small when the lines are far apart





23.6 Electric Field Lines

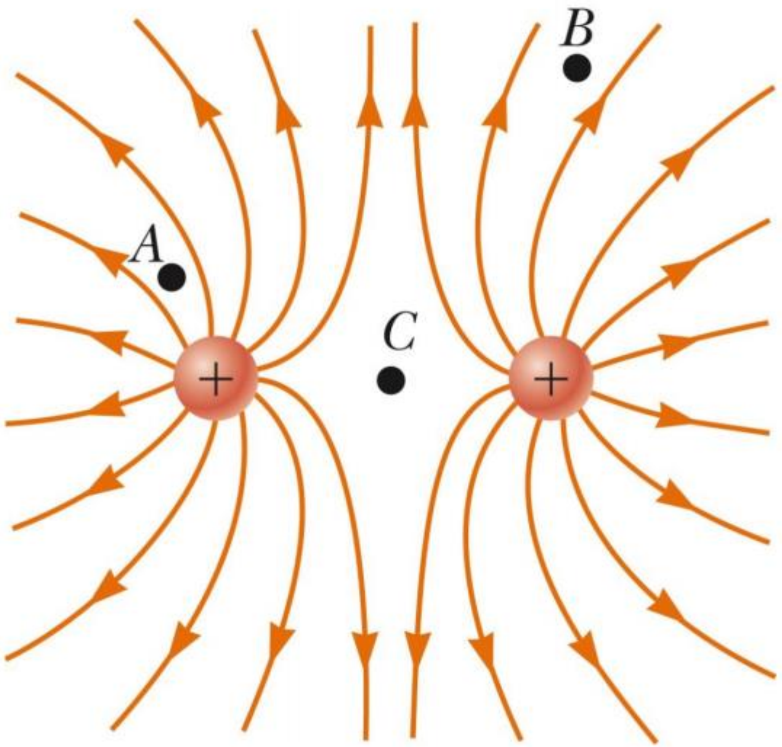


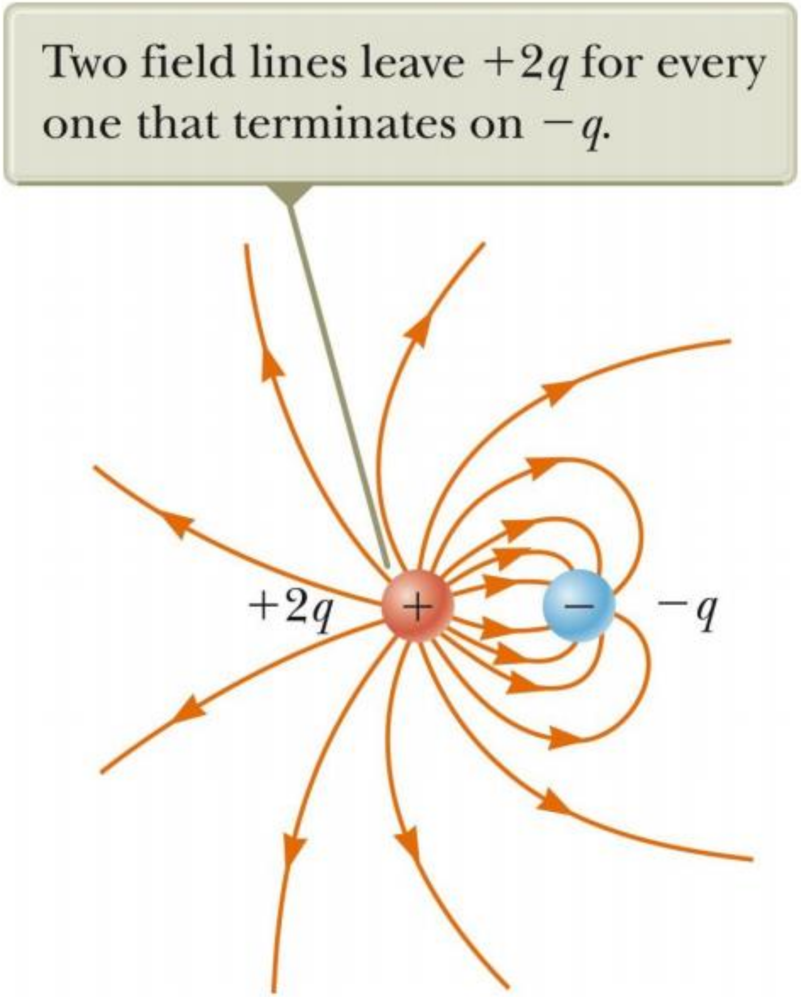


Courtesy of Harold M. Waage, Princeton University

(b)

23.6 Electric Field Lines

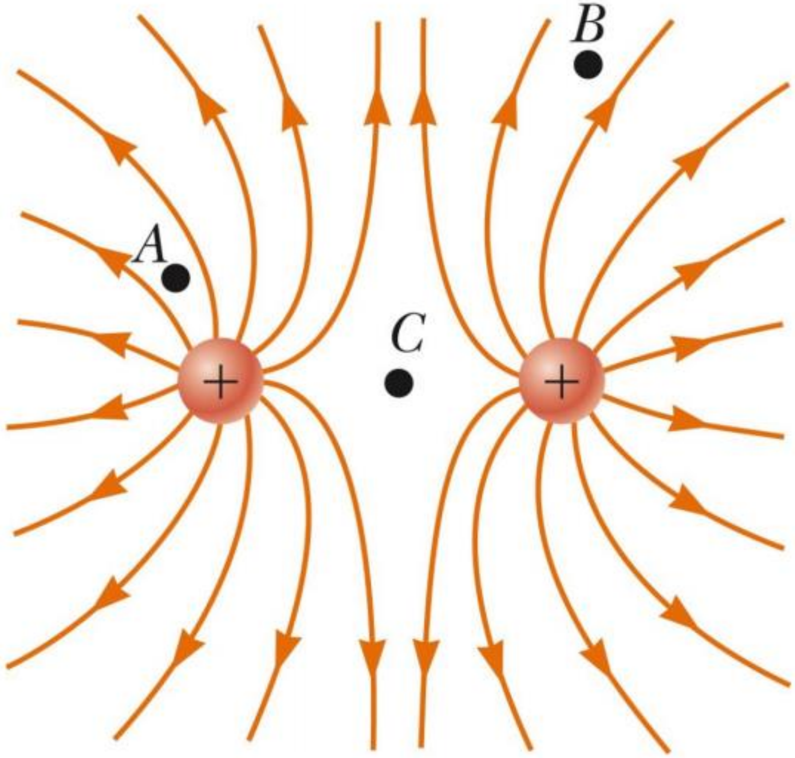




23.6 Electric Field Lines

➢ ***Quick Quiz 23.8***

Rank the magnitude of the electric field at points A, B, and C shown in this figure (greatest magnitude first).



23.7 Motion of Charged Particles in a Uniform Electric Field

- When a charged particle is placed in an electric field, it experiences an electrical force.
- If this is the only force on the particle, it must be the net force and *causes the particle to accelerate* according to Newton's second law.

$$\mathbf{F}_e = q\mathbf{E} = m\mathbf{a}$$

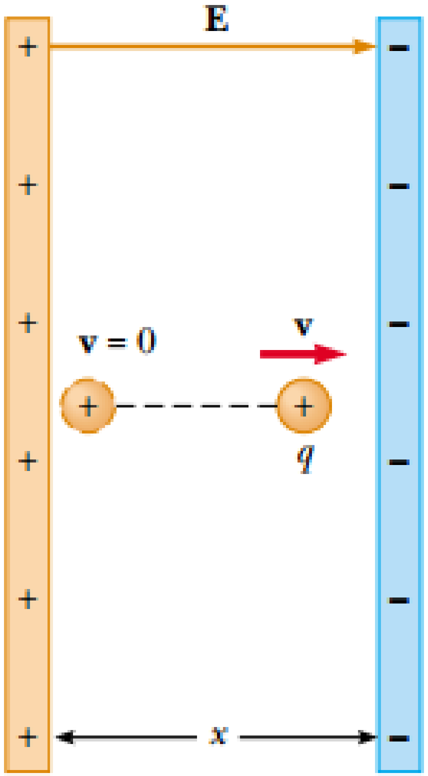
$$\mathbf{a} = \frac{q\mathbf{E}}{m}$$

- If E is uniform (that is, constant in magnitude and direction), then the acceleration is constant.
- If the particle has a *positive charge*, its acceleration is in the direction of the electric field. If the particle has a *negative charge*, its acceleration is in the direction ***opposite*** the electric field

23.7 Motion of Charged Particles in a Uniform Electric Field

Example 23.10 Page 726: An Accelerating Positive Charge

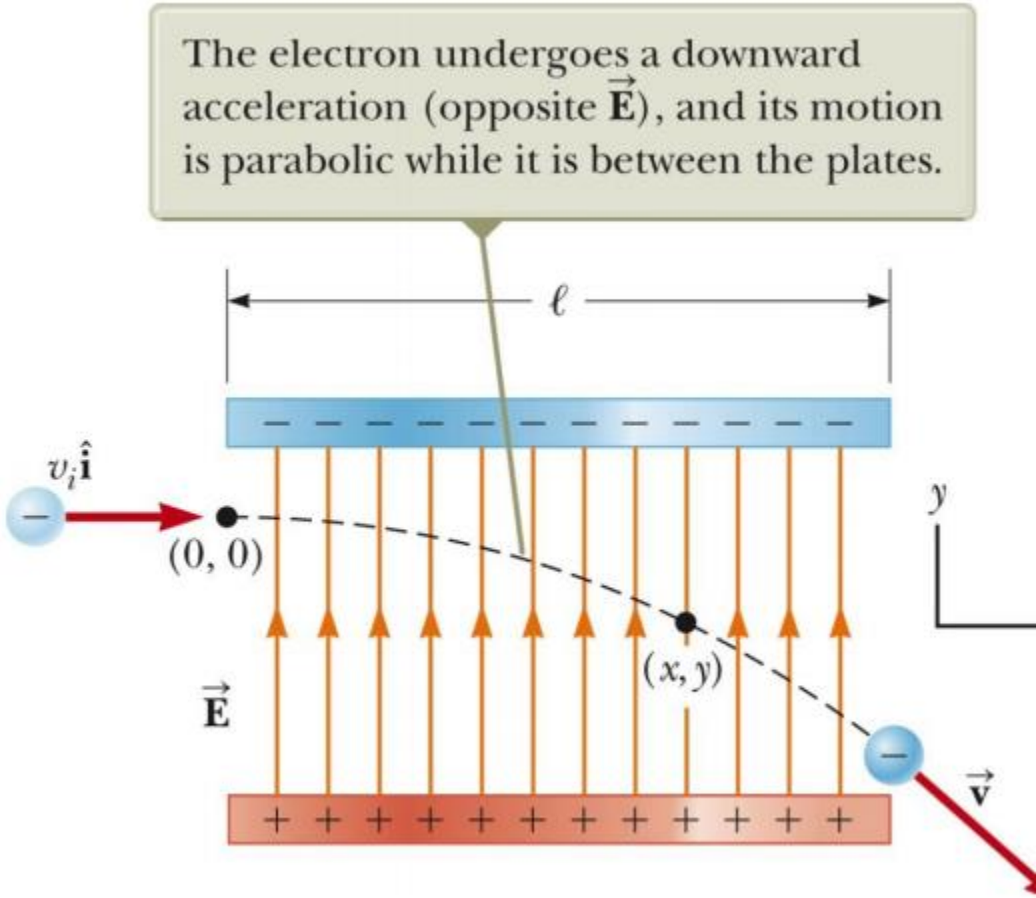
A positive point charge *q* of mass *m* is released from rest in a uniform electric field E directed along the x axis, as shown in the Figure. Describe its motion



23.7 Motion of Charged Particles in a Uniform Electric Field

- An electron of charge -e is projected horizontally into this field from the origin with an initial velocity v_i

- Because the electric field E in the Figure is in the positive y direction, the acceleration of the electron is in the negative y direction



23.7 Motion of Charged Particles in a Uniform Electric Field

<u>Example 23.11 Page 727: An Accelerated Electron</u>

An electron enters the region of a uniform electric field as shown in previous Figure, with vi =3.00x10^6 m/s and E=200N/C. The horizontal length of the plates is L= 0.100m.

A- Find the acceleration of the electron while it is in the electric field.

B- If the electron enters the field at time t =0, find the time at which it leaves the field.

C- If the vertical position of the electron as it enters the field is y= 0, what is its vertical position when it leaves the field?

Chapter Problems

1) Three point charges are located at the corners of an equilateral triangle as shown in the Figure below. Calculate the resultant electric force on the 7.00-μC charge.

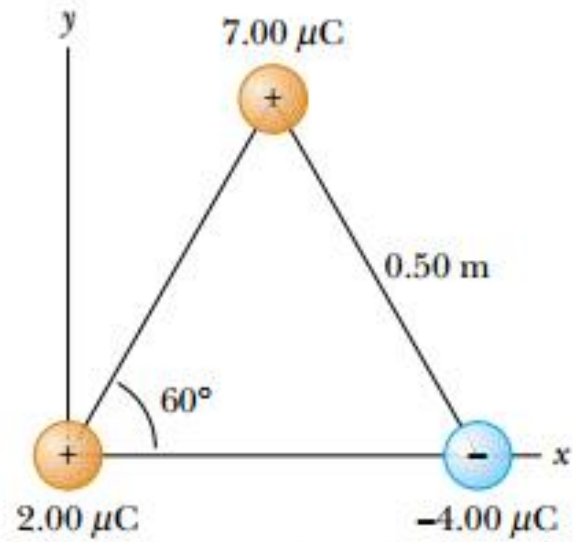


Figure P23.7 Problems 7 and 18.

Chapter Problems

Four point charges are at the corners of a square of side a as shown in Figure P23.21. (a) Determine the magnitude and direction of the electric field at the location of charge q. (b) What is the resultant force on q?

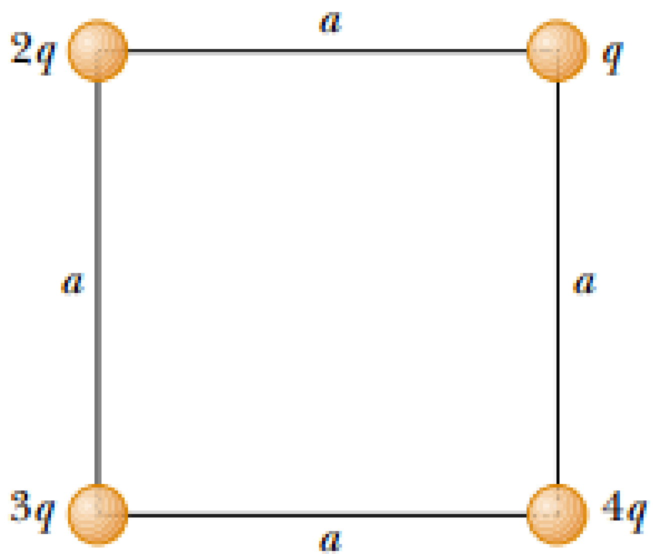


Figure P23.21

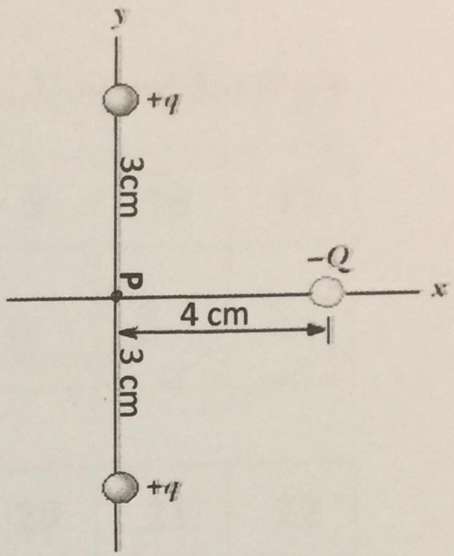
Chapter Problems

س27 - 32) وضعت ثلاث شحنات كما هو موضح بالشكل المرفق:

(q =5μC & Q = 30μC)

Q 27-32) Three charges are located as shown in the given figure:

(q = 5μC & Q = 30μC)



س27) المركبة الافقية للقوة المؤثرة على الشحنة Q تساوي:

Q27) The X-component of the force acting on the charge Q equals:

A. Zero B. – 650 N
C. 432 N D. – 864 N

س28) المركبة الرأسية للقوة المؤثرة على الشحنة Q تساوي:

Q28) The Y-component of the force acting on the charge Q equals:

A. Zero B. – 648 N C. 432 N D. – 864 N

س29) زاوية ميل محصلة القوة الكهربية المؤثرة على الشحنة Q على المحور السيني تساوي:

Q29) The inclination angle of the net electric force acting on the charge Q on X-axis equals:

A. 30° B. 90° C. 180° D. 270°