Phys104 (General Phys. 2)
Electricity and Magnetism

Text book

Physics for Scientists and Engineers
(6th edition)- R. A. Serway & Jewett

- The laws of electricity and magnetism play a central role in the operation of many modern devices (TV, computers, electric motors, etc.).
- The interatomic and intermolecular forces responsible for the formation of solids and liquids are electric in nature (origin).

Chapter 23

Electric Fields

CHAPTER OUTLINE

Units

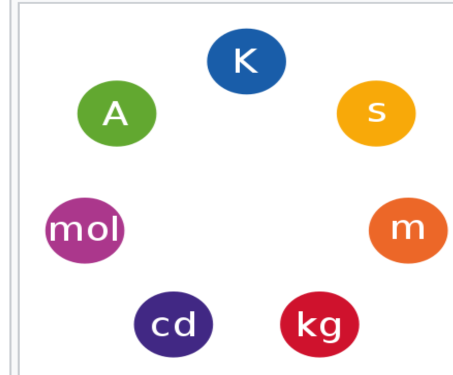
International System of Units (SI)

MKS System (meters-kilograms-seconds):
also Amperes, Volts, Ohms, Watts

Force: $F = ma$ Newtons = kg m / s^2 = 1 N

Work: $W = Fd$ Joule = Nm = kg m^2 / s^2 = 1 J

Electric Charge: Q Coulomb = 1 C
$F = K q_1 q_2 / r2$ $K = 8.99 \times 10^9$ Nm^2/C^2 (in MKS system)



The SI base units

Symbol	Name	Quantity
A	ampere	electric current
K	kelvin	temperature
s	second	time
m	metre	length
kg	kilogram	mass
cd	candela	luminous intensity
mol	mole	amount of substance

CGS System (centimeter-grams-seconds):

Force: $F = ma$ 1 dyne = g cm / s^2

Work: $W = Fd$ 1 erg = dyne-cm = g cm^2 / s^2

Electric Charge: Q esu (electrostatic unit) (statC)
$F = K q_1 q_2 / r2$ $K = 1^3$(in CGS system)

23.1 Properties of Electric Charges

➢ Existence of electric forces and charges

Running a comb through your hair on a dry day → attracts bits of paper

Inflated balloon rubbed with wool → balloon then adheres to a wall

Become *electrified* (**electrically charged)**

Two kinds of electric charges in nature:

- ❑ Negative charges (possessed by electrons)
- ❑ Positive charges (possessed by protons)

Verify that ??

Charges of the same sign repel one another
Charges with opposite signs attract one another.

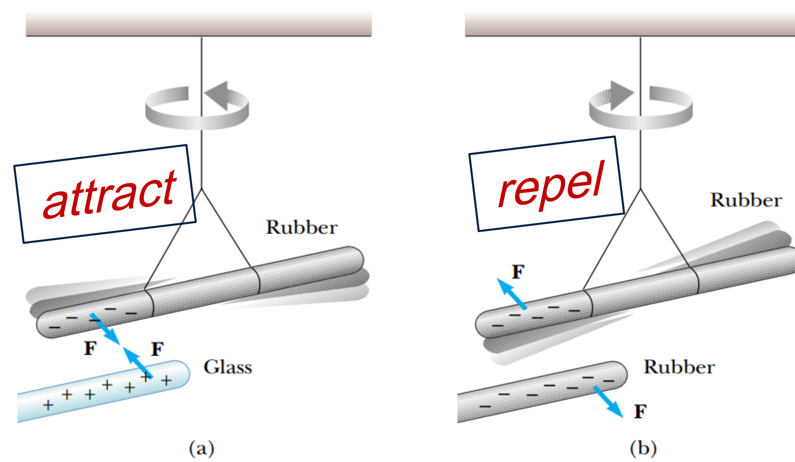


Figure 23.1 (a) A negatively charged rubber rod suspended by a thread is attracted to a positively charged glass rod. (b) A negatively charged rubber rod is repelled by another negatively charged rubber rod.

- ○ Electric charge in an isolated system ***is always conserved.***

- ○ Electric charge, q, is ***quantized***. exists as discrete packets ($q = \pm Ne$)

Quick Quiz 23.1 If you rub an inflated balloon against your hair, the two materials attract each other, as shown in Figure 23.3. Is the amount of charge present in the system of the balloon and your hair after rubbing (a) less than, (b) the same as, or (c) more than the amount of charge present before rubbing?

Quick Quiz 23.2 Three objects are brought close to each other, two at a time. When objects A and B are brought together, they repel. When objects B and C are brought together, they also repel. Which of the following are true? (a) Objects A and C possess charges of the same sign. (b) Objects A and C possess charges of opposite sign. (c) All three of the objects possess charges of the same sign. (d) One of the objects is neutral. (e) We would need to perform additional experiments to determine the signs of the charges.

23.2 Charging Objects By Induction

*Ability of electrons to move through the material **if possible***

1- **Electrical conductors**: are materials which have some free electrons that can move relatively freely through the material. *Ex. copper, aluminum and silver.*

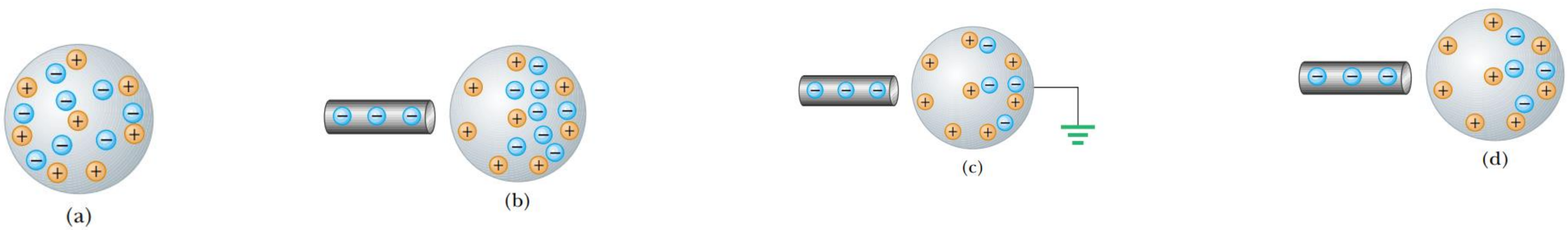
2- **Electrical insulators**: are materials in which all of the electrons are bound to atoms and can not move relatively freely through the material.
Ex. glass, rubber and wood.

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

Quick Quiz 23.3 Three objects are brought close to each other, two at a time. When objects A and B are brought together, they attract. When objects B and C are brought together, they repel. From this, we conclude that (a) objects A and C possess charges of the same sign. (b) objects A and C possess charges of opposite sign. (c) all three of the objects possess charges of the same sign. (d) one of the objects is neutral. (e) we need to perform additional experiments to determine information about the charges on the objects.

Induction process in conductors and insulators

Charging an conducting object



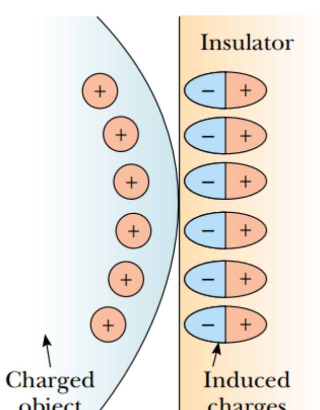
A neutral metallic sphere, with
equal numbers of positive and negative charges.

Electrons on
the neutral sphere are redistributed when a charged rubber rod is near.

Sphere is grounded, some of its electrons leave through the ground
wire.

Sphere has excess positive charge
that is nonuniformly distributed

Charges Realignment in insulator



To induces a charge distribution on the surface of an insulator due to
realignment of charges in the molecules.

Charging by induction requires no contact with the object inducing the charge.
In contrast to charging by rubbing (that is, by conduction) does require contact between the two objects.

23.3 Coulomb's Law

Coulomb measured the magnitudes of electric forces between charged objects using the torsion balance.

confirmed that the electric force between two small charged spheres is proportional to the *inverse square* of their separation distance r, ($F_e \, \alpha \frac{1}{r^2}$).

The electric force properties between *two stationary charged particles*

- is inversely proportional to the square of the separation r between the particles
- is proportional to the product of the charges q_1 and q_2 on the two particles;
- is attractive if the charges are of opposite sign and repulsive if the charges have the same sign;
- is a conservative force.

❖ Point charge : a particle of zero size that carries an electric charge.

The smallest unit of **charge (*e*)** known in nature is the charge on an electron (- e) or a proton (+ e) and has a magnitude e $= 1.6 \times 10^{-19}\ C$,
1 C of charge ≈ the charge of 6.2×10^{18} electrons or protons.

Table 23.1

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	$1.674\,92 \times 10^{-27}$

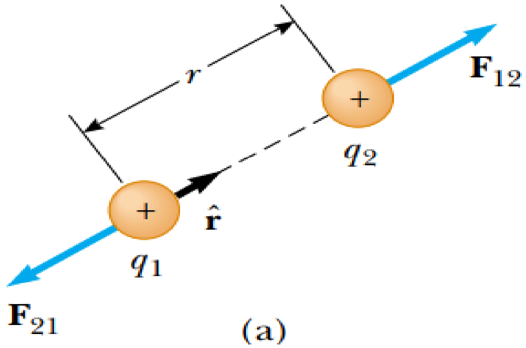
Coulomb's law

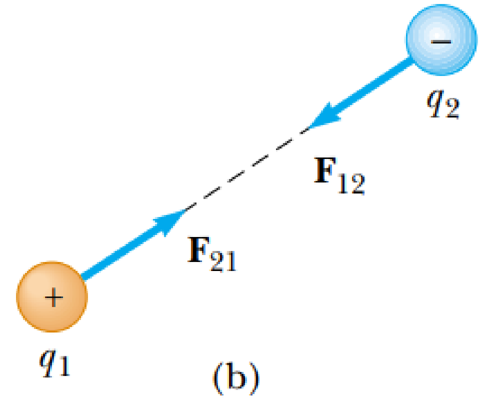
States the magnitude of the electric force (the Coulomb force) between two point charges is:

$$\boxed{F_e = k_e \frac{|q_1||q_2|}{r^2}}$$

k_e is Coulomb constant. In SI unit ($k_e = 8.9 \times 10^9 \mathrm{N.}m^2/C^2$)

Quick Quiz 23.4 Object A has a charge of $+2\ \mu$C, and object B has a charge of $+6\ \mu$C. Which statement is true about the electric forces on the objects? (a) $F_{AB} = -3F_{BA}$ (b) $F_{AB} = -F_{BA}$ (c) $3F_{AB} = -F_{BA}$ (d) $F_{AB} = 3F_{BA}$ (e) $F_{AB} = F_{BA}$ (f) $3F_{AB} = F_{BA}$





The electric force exerted by a charge q_1 on a second charge q_2 , written F_{12}, is

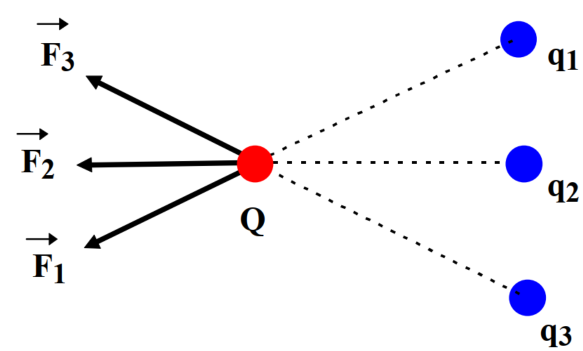
$$\boxed{\overrightarrow{F_{12}} = k_e \frac{q_1 q_2}{r^2} \hat{r}}$$

The electric force exerted by q_2 on q_1 is equal in magnitude to the force exerted by q_1 on $q_2$and in the opposite direction. i.e. $\boxed{\overrightarrow{F_{12}} = \overrightarrow{-F_{21}}}$

- ✓ product q_1q_2 is positive; the force is repulsive
- ✓ product q_1q_2 is negative; the force is attractive

several point charges q_1, q_2, q_3,… exert
Electric forces on a charge Q is

$$\boxed{\vec{F} = \overrightarrow{F_1} + \vec{F_2} + \vec{F_3} + \cdots}$$

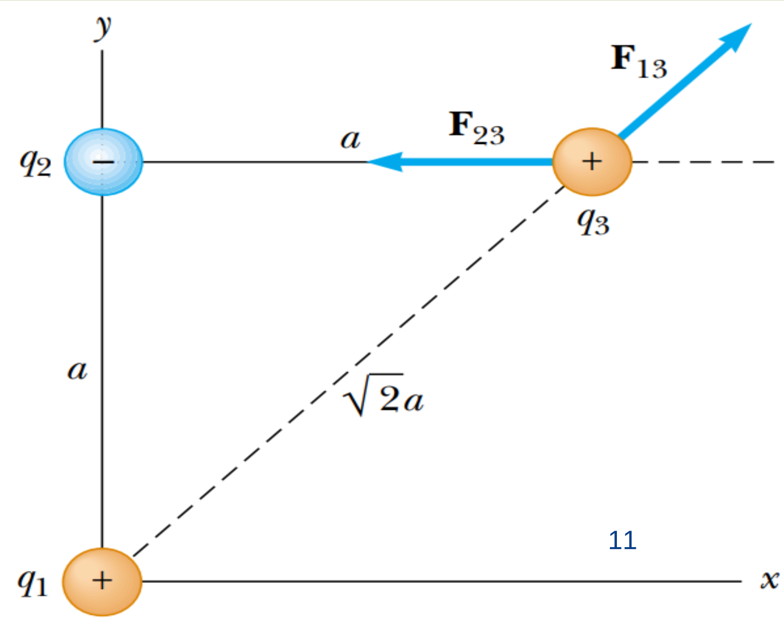


Example 23.1 The Hydrogen Atom

The electron and proton of a hydrogen atom are separated (on the average) by a distance of approximately 5.3×10^{-11} m. Find the magnitudes of the electric force and the gravitational force between the two particles.

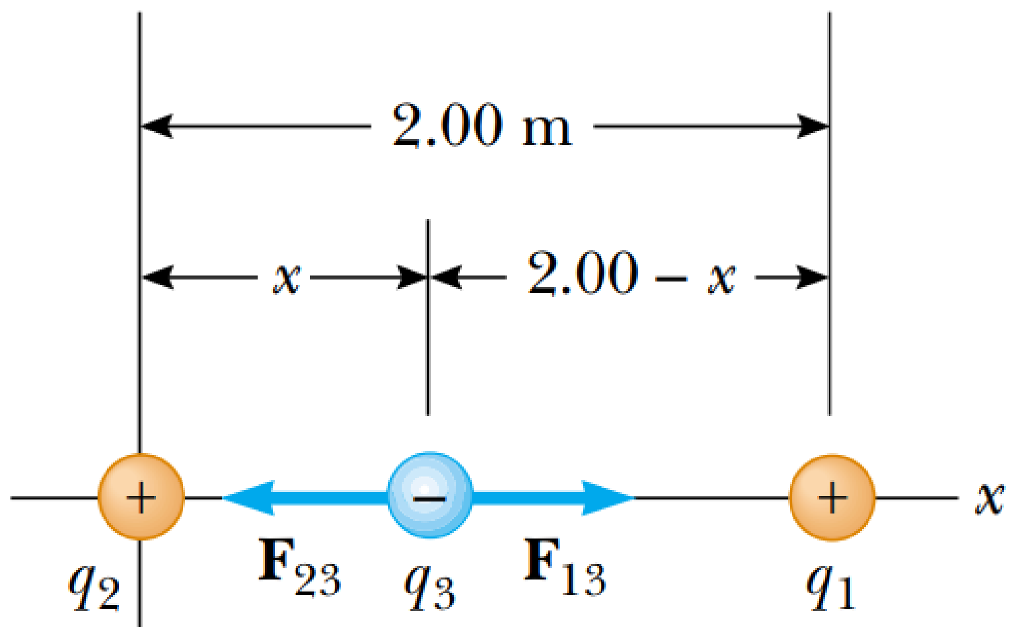
Example 23.2 Find the Resultant Force

Consider three point charges located at the corners of a right triangle as shown in Figure 23.7, where $q_1 = q_3 = 5.00\ \mu C$, $q_2 = -2.00\ \mu C$, and $a = 0.100$ m. Find the resultant force exerted on q_3.



Example 23.3 Where Is the Resultant Force Zero?

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?



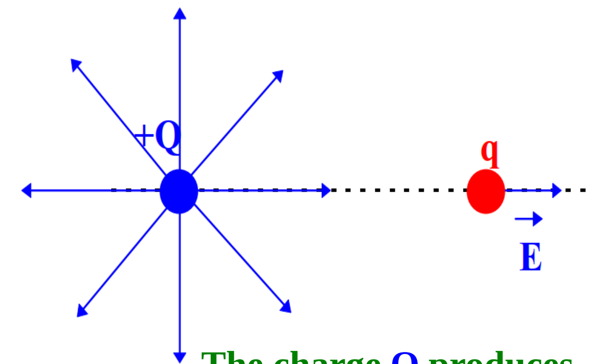
Problem 1:

A +15 μC charge is located 40 cm from a +3.0 μC charge. What is the magnitude of the electrostatic force on the larger charge and on the smaller charge (in N)?

Problem 2:

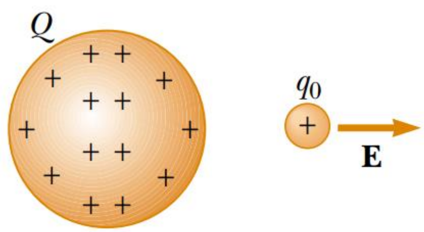
Two point particles have charges q_1 and q_2 and are separated by a distance d. Particle q_2 experiences an electrostatic force of 12 N due to particle q_1. If the charges of both particles are doubled and if the distance between them is doubled, what is the magnitude of the electrostatic force between them (in N)?

23.4 The Electric Field



The charge **Q** produces an electric field which in turn produces a force on the charge **q**

- ❖ Field forces can act through space, producing an effect even when no physical contact occurs between interacting objects.
- ❖ 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, electric force acts on it.



Electric Field – Definition

The electric field due to the source charge at the location of the test charge to be the electric force on the test charge per unit charge.

the electric field vector E at a point in space is defined as the electric force $\mathbf{F}_e$ acting on a positive test charge q_0 placed at that point divided by the test charge:

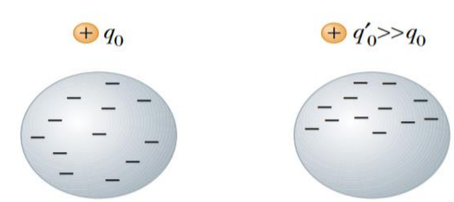
$$\mathbf{E} \equiv \frac{\mathbf{F}_e}{q_0} \tag{23.7}$$

Equation 23.7 can be rearranged as

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

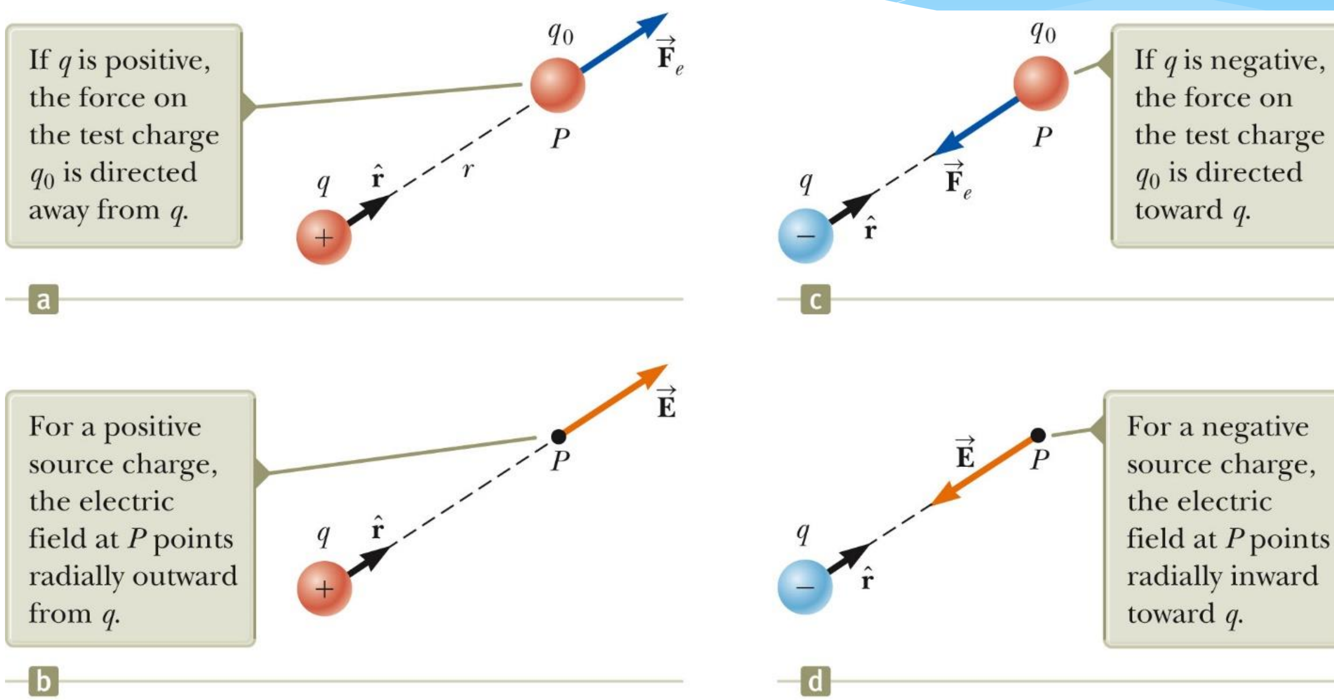
- ❖ The test charge serves ***as a detector*** of the electric field

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)

Electric field directions :



The vector **E** has the SI units of newtons per coulomb (N/C).

According to Coulomb's law, the force exerted by q on the test charge is

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

Because the electric field at P, the position of the test charge, is defined by $\mathbf{E} = \mathbf{F}_e/q_0$,

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

Electric field due to a finite number of point charges

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.

$$\mathbf{E} = k_e \sum_i \frac{q_i}{r_i^{\,2}} \hat{\mathbf{r}}_i \qquad (23.10)$$

where r_i is the distance from the ith source charge q_i to the point P and $\hat{\mathbf{r}}_i$ is a unit vector directed from q_i toward P.

Quick Quiz 23.6 A test charge of $+3\ \mu\text{C}$ is at a point P where an external electric field is directed to the right and has a magnitude of 4×10^6 N/C. If the test charge is replaced with another test charge of $-3\ \mu\text{C}$, the external electric field at P (a) is unaffected (b) reverses direction (c) changes in a way that cannot be determined

Example 23.5 Electric Field Due to Two Charges

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.

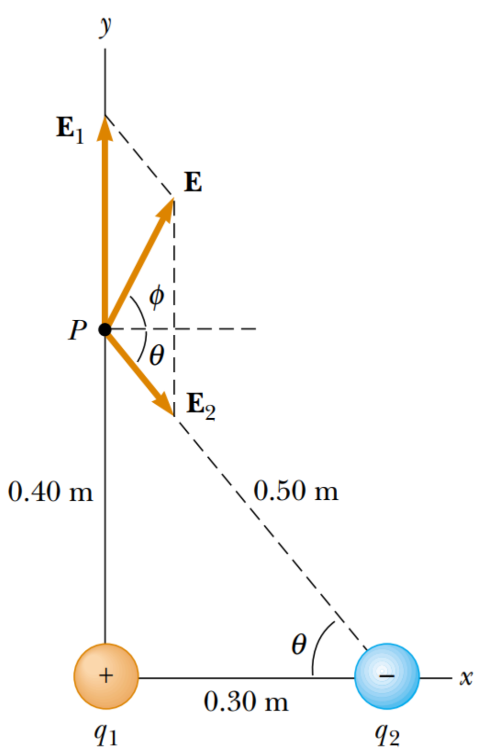


Figure 23.14 (Example 23.5) The total electric field $\mathbf{E}$ at P equals the vector sum $\mathbf{E}_1 + \mathbf{E}_2$, where $\mathbf{E}_1$ is the field due to the positive charge q_1 and $\mathbf{E}_2$ is the field due to the negative charge q_2.

Solution First, let us find the magnitude of the electric field at P due to each charge. The fields $\mathbf{E}_1$ due to the 7.0-μC charge and $\mathbf{E}_2$ due to the -5.0-μC charge are shown in Figure 23.14. Their magnitudes are

$$E_1 = k_e \frac{|q_1|}{r_1^2} = (8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}) \frac{(7.0 \times 10^{-6}\ \mathrm{C})}{(0.40\ \mathrm{m})^2}$$
$$= 3.9 \times 10^5\ \mathrm{N/C}$$

$$E_2 = k_e \frac{|q_2|}{r_2^2} = (8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}) \frac{(5.0 \times 10^{-6}\ \mathrm{C})}{(0.50\ \mathrm{m})^2}$$
$$= 1.8 \times 10^5\ \mathrm{N/C}$$

The vector $\mathbf{E}_1$ has only a y component. The vector $\mathbf{E}_2$ has an x component given by $E_2 \cos\theta = \frac{3}{5}E_2$ and a negative y component given by $-E_2 \sin\theta = -\frac{4}{5}E_2$. Hence, we can express the vectors as

$$\mathbf{E}_1 = 3.9 \times 10^5 \hat{\mathbf{j}}\ \mathrm{N/C}$$

$$\mathbf{E}_2 = (1.1 \times 10^5 \hat{\mathbf{i}} - 1.4 \times 10^5 \hat{\mathbf{j}})\ \mathrm{N/C}$$

The resultant field $\mathbf{E}$ at P is the superposition of $\mathbf{E}_1$ and $\mathbf{E}_2$:

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 = (1.1 \times 10^5 \hat{\mathbf{i}} + 2.5 \times 10^5 \hat{\mathbf{j}})\ \mathrm{N/C}$$

From this result, we find that $\mathbf{E}$ makes an angle ϕ of 66° with the positive x axis and has a magnitude of 2.7×10^5 N/C.

23.6 Electric Field Lines

❖ A way of visualizing electric field patterns

❖ The electric field vector E is tangent to the electric field line at each point.

❖ The number of lines per unit area through a surface perpendicular to the lines is proportional to the magnitude of the electric field in that region.

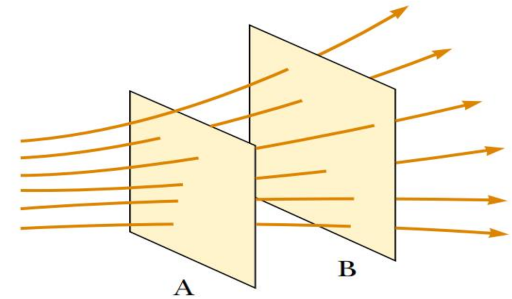
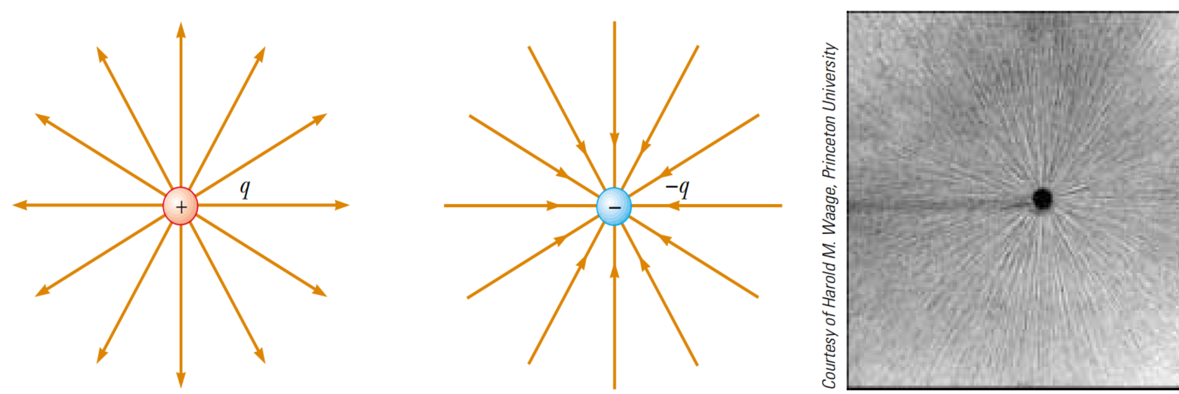


Figure 23.20 Electric field lines penetrating two surfaces. The magnitude of the field is greater on surface A than on surface B.

Field lines are close together where the electric field is strong and far apart where the field is weak.

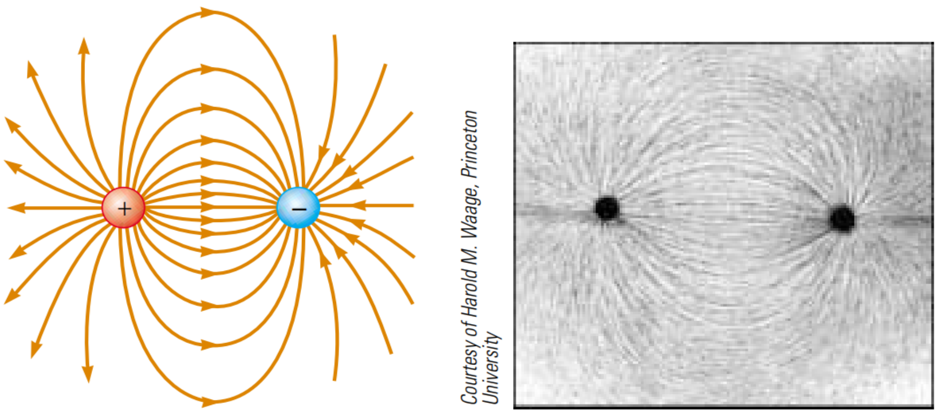
➢ The electric field lines for a point charge.

(a) *Positive* point charge, the lines are directed *radially outward.*
(b) For *a negative* point charge, the lines are directed *radially inward.*

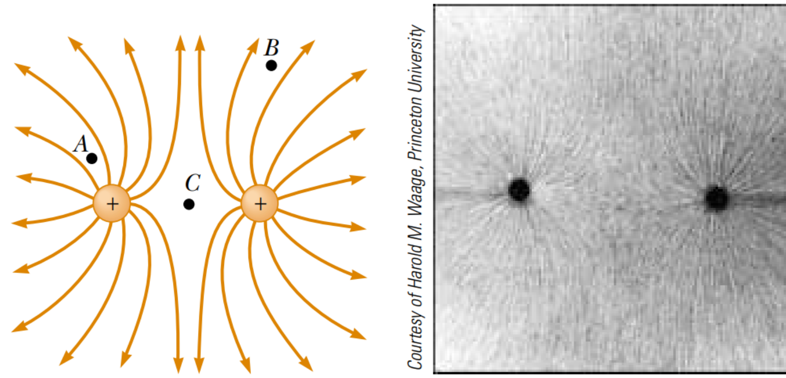


(a) (b) (c)

Electric field lines for two point charges



(a) (b)



(a) (b)

Field lines starting from any positively charged object and ending on any negatively charged object

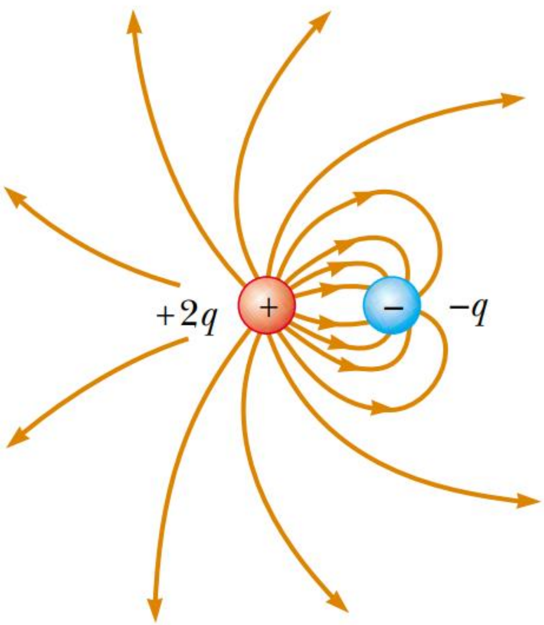
The number of lines leaving the positive charge equals the number terminating at the negative charge.

electric field lines for two positive point charges.

Quick Quiz 23.7 Rank the magnitudes of the electric field at points *A*, *B*, and *C* shown in Figure 23.23a (greatest magnitude first).

Quick Quiz 23.8 Which of the following statements about electric field lines associated with electric charges is false? (a) Electric field lines can be either straight or curved. (b) Electric field lines can form closed loops. (c) Electric field lines begin on positive charges and end on negative charges. (d) Electric field lines can never intersect with one another.

Electric field lines associated with multiple charges



The electric field lines for a point charge +2q and a second point charge -q. Note that two lines leave +2q for every one that terminates on -q.

40. Figure P23.40 shows the electric field lines for two point charges separated by a small distance. (a) Determine the ratio q_1/q_2. (b) What are the signs of q_1 and q_2?

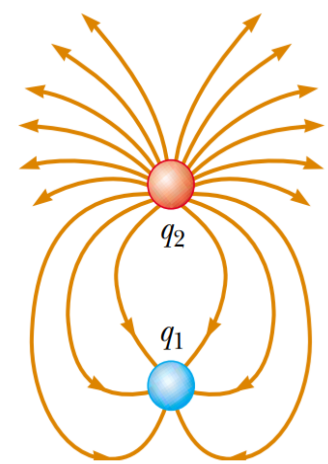


Figure P23.40

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 exerted* on the particle, it must be the net force and ***cause the particle to accelerate*** according to Newton's second law

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

The ***acceleration*** of the particle

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

- 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.

Example 23.10 An Accelerating Positive Charge

A positive point charge q of mass m is released from rest in a uniform electric field $\mathbf{E}$ directed along the x axis, as shown in Figure 23.25. Describe its motion.

$$x_f = x_i + v_i t + \tfrac{1}{2}at^2$$

$$v_f = v_i + at$$

$$v_f{}^2 = v_i{}^2 + 2a(x_f - x_i)$$

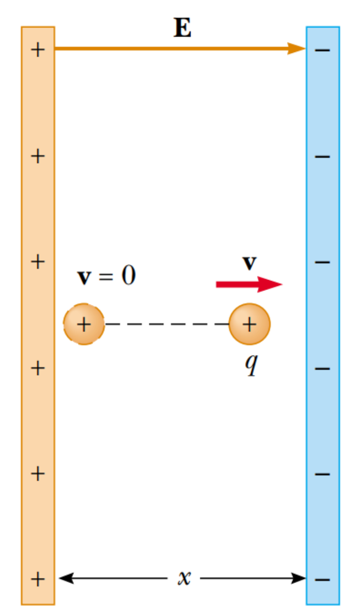


Figure 23.25 (Example 23.10) A positive point charge q in a uniform electric field $\mathbf{E}$ undergoes constant acceleration in the direction of the field.

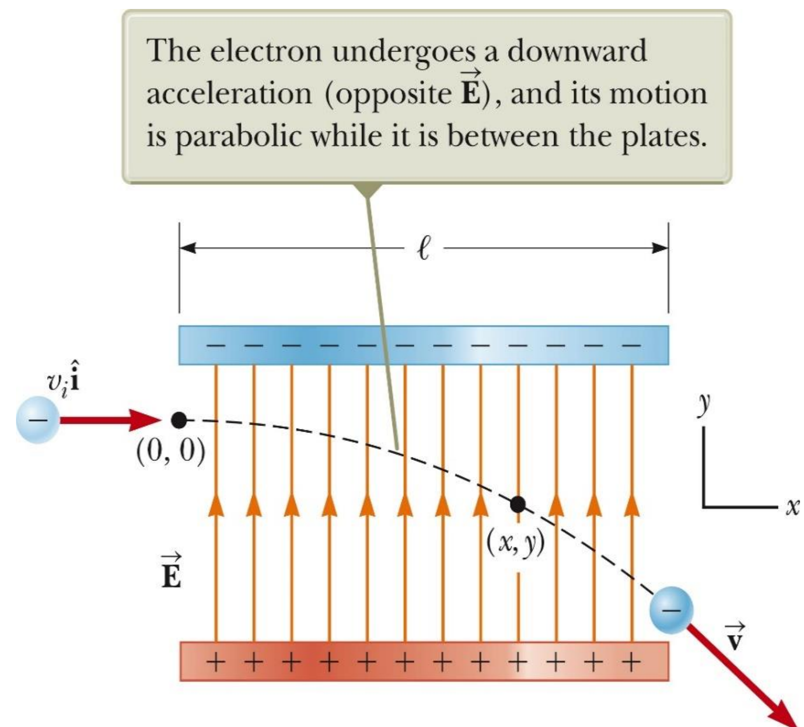
Motion of charged particle in 2-D

- The electron is projected horizontally into a uniform electric field from origin with initial velocity V_i.

The electron (negatively charged):

The acceleration undergoes *downward* with *opposite* the direction of the field.

The motion is *parabolic* while between the plates.



Example 23.11 An Accelerated Electron

An electron enters the region of a uniform electric field as shown in Figure 23.26, with $v_i = 3.00 \times 10^6$ m/s and $E = 200$ N/C. The horizontal length of the plates is $\ell = 0.100$ m.

(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 $y_i = 0$, what is its vertical position when it leaves the field?

Conceptual questions (page 729 & 730)

1. Explain what is meant by the term "a neutral atom." Explain what "a negatively charged atom" means.
2. A charged comb often attracts small bits of dry paper that then fly away when they touch the comb. Explain.

5. Explain from an atomic viewpoint why charge is usually transferred by electrons.

11. When defining the electric field, why is it necessary to specify that the magnitude of the test charge be very small?

16. Explain why electric field lines never cross.

18. A free electron and a free proton are released in identical electric fields. Compare the electric forces on the two particles. Compare their accelerations.

19. Explain what happens to the magnitude of the electric field created by a point charge as r approaches zero.

20. An object with negative charge is placed in a region of space where the electric field is directed vertically upward. What is the direction of the electric force exerted on this charge?

21. A charge $4q$ is at a distance r from a charge $-q$. Compare the number of electric field lines leaving the charge $4q$ with the number entering the charge $-q$. Where do the extra lines beginning on $4q$ end?

22. Consider two equal point charges separated by some distance d. At what point (other than ∞) would a third test charge experience no net force?

24. If the electron in Figure 23.26 is projected into the electric field with an arbitrary velocity $\mathbf{v}_i$ (at an arbitrary angle to $\mathbf{E}$), will its trajectory still be parabolic? Explain.

25. Would life be different if the electron were positively charged and the proton were negatively charged? Does the choice of signs have any bearing on physical and chemical interactions? Explain.

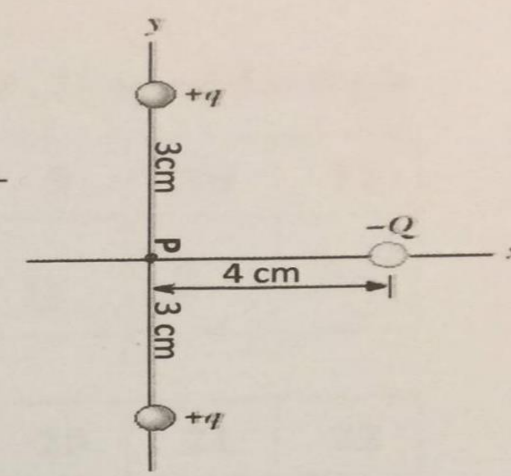
26. Why should a ground wire be connected to the metal support rod for a television antenna?

Selected Solved Problems (page 730 - 734)

4. Two protons in an atomic nucleus are typically separated by a distance of 2×10^{-15} m. The electric repulsion force between the protons is huge, but the attractive nuclear force is even stronger and keeps the nucleus from bursting apart. What is the magnitude of the electric force between two protons separated by 2.00×10^{-15} m?

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°

10. Two small beads having positive charges $3q$ and q are fixed at the opposite ends of a horizontal, insulating rod, extending from the origin to the point $x = d$. As shown in Figure P23.10, a third small charged bead is free to slide on the rod. At what position is the third bead in equilibrium? Can it be in stable equilibrium?

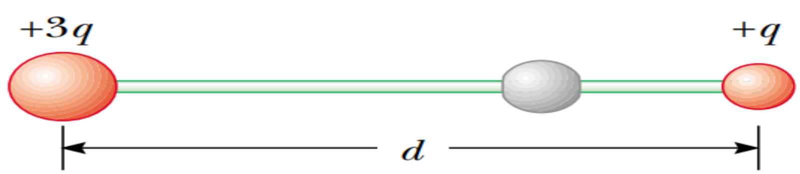


Figure P23.10

15. In Figure P23.15, determine the point (other than infinity) at which the electric field is zero.

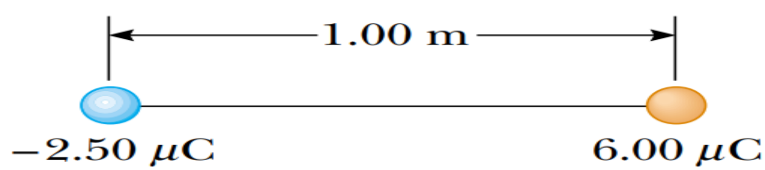


Figure P23.15

39. A negatively charged rod of finite length carries charge with a uniform charge per unit length. Sketch the electric field lines in a plane containing the rod.