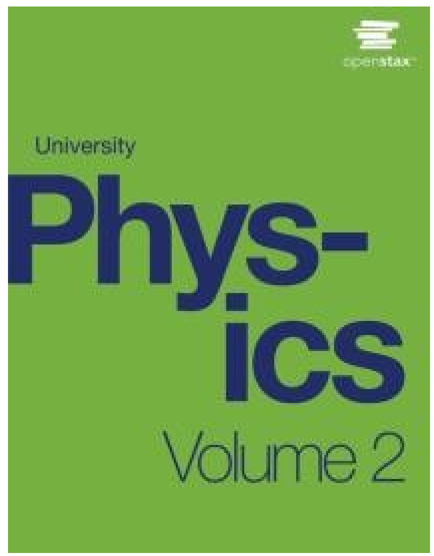
UNIVERSITY PHYSICS

Chapter 5 ELECTRIC CHARGES AND FIELDS

PowerPoint Image Slideshow



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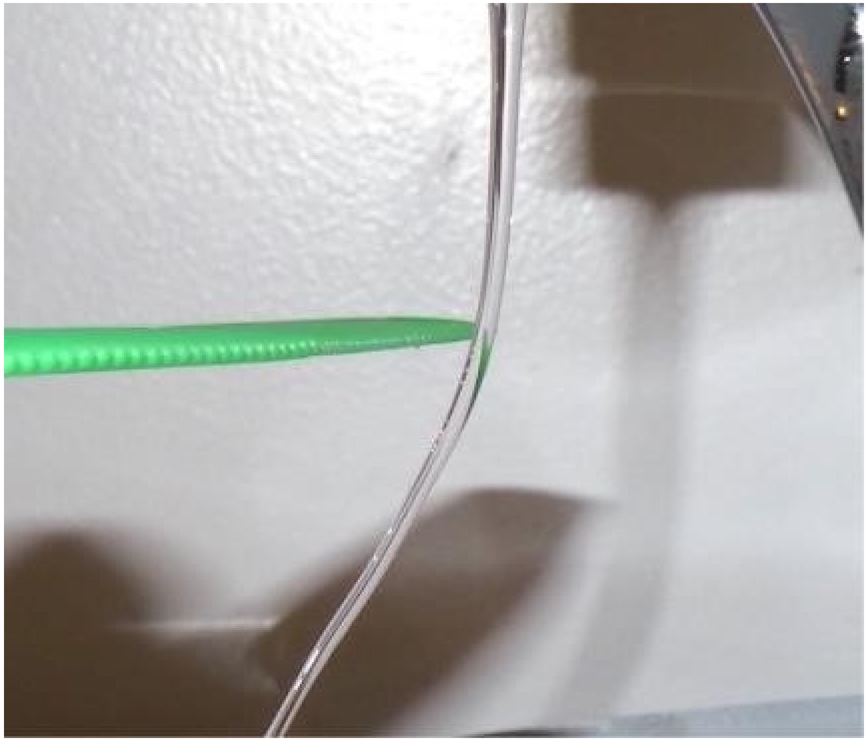
Electric Charges

FIGURE 5.1

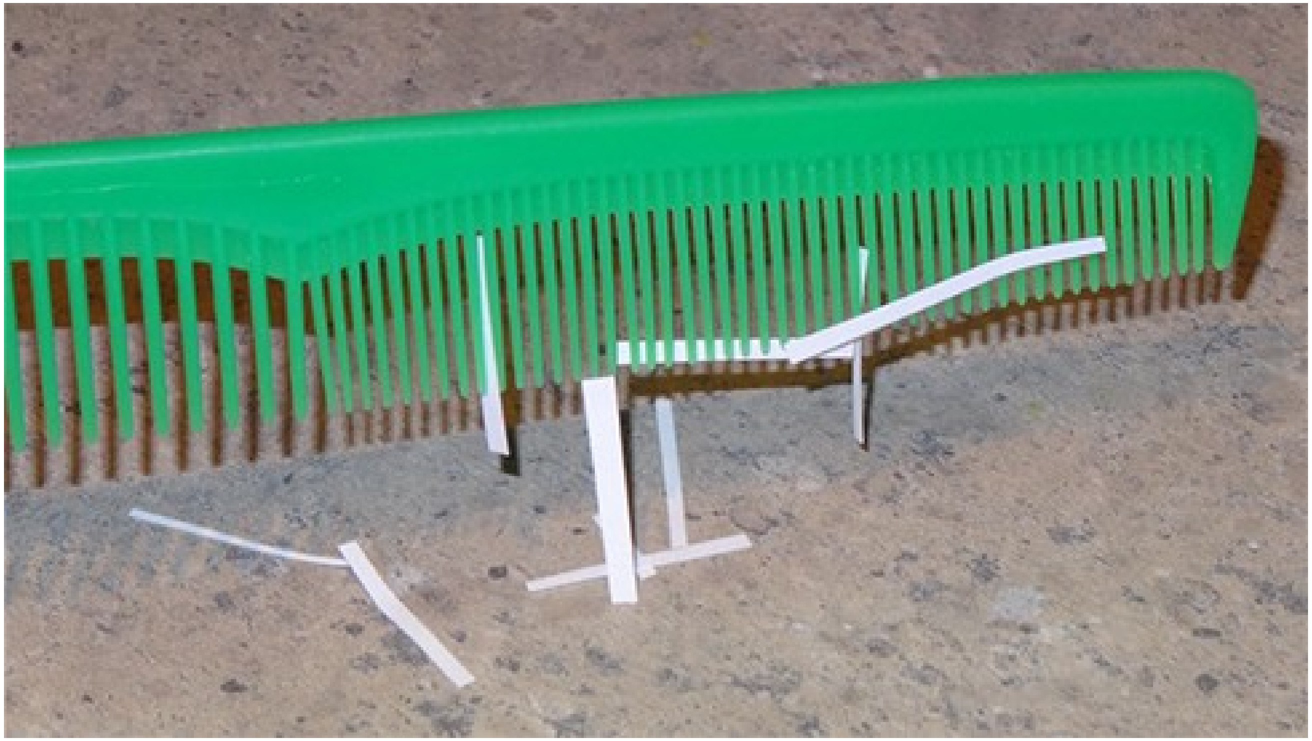
Electric charges exist all around us. They can cause objects to be repelled from each other or to be attracted to each other. (credit: modification of work by Sean McGrath)

FIGURE 5.2



An electrically charged comb attracts a stream of water from a distance. Note that the water is not touching the comb. (credit: Jane Whitney)

FIGURE 5.3

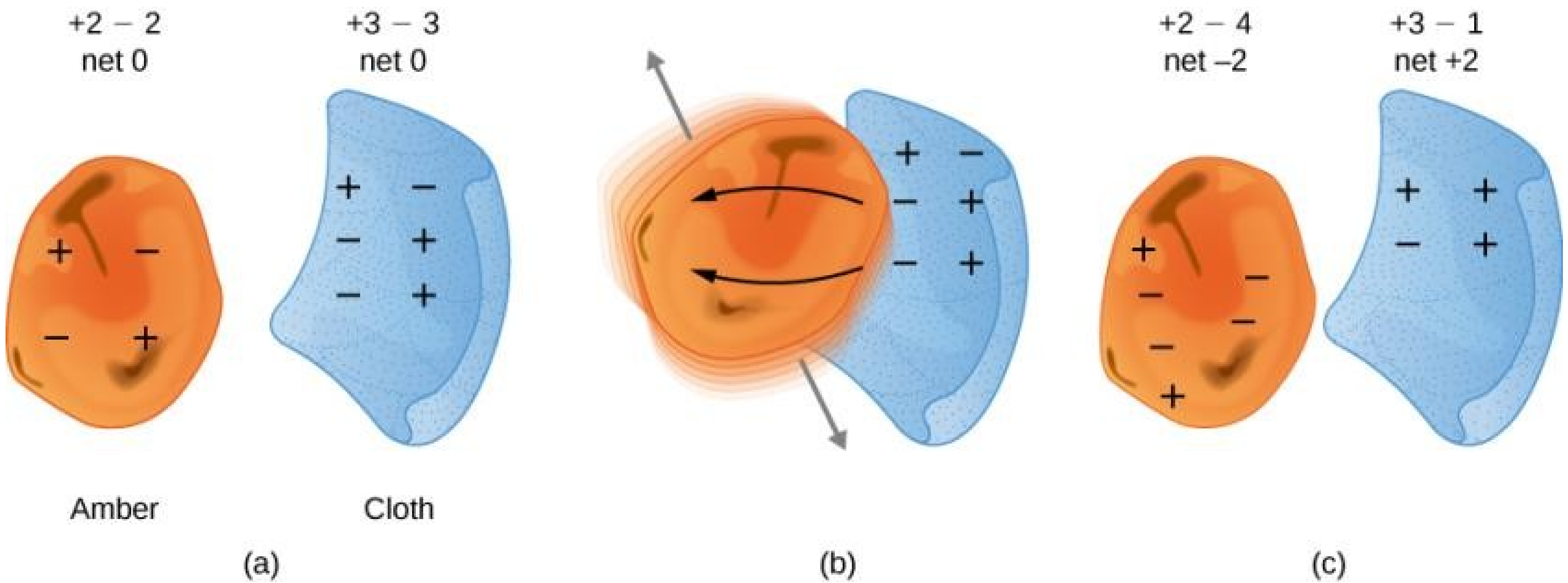


After being used to comb hair, this comb attracts small strips of paper from a distance, without physical contact. Investigation of this behavior helped lead to the concept of the electric force.

FIGURE 5.4

Borneo amber is mined in Sabah, Malaysia, from shale-sandstone-mudstone veins. When a piece of amber is rubbed with a piece of fur, the amber gains more electrons, giving it a net negative charge. At the same time, the fur, having lost electrons, becomes positively charged. (credit: “Sebakoamber”/Wikimedia Commons)

FIGURE 5.5



There are two electric charges, positive and negative.

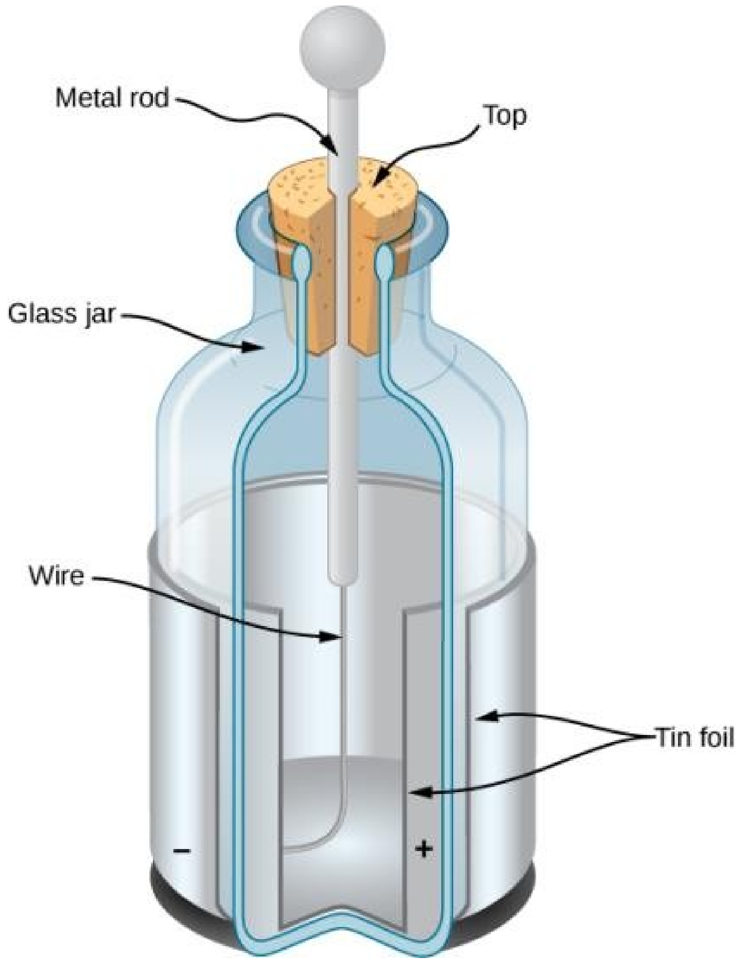
When materials are rubbed together, charges can be separated, particularly if one material has a greater affinity for electrons than another.

a) Both the amber and cloth are originally neutral, with equal positive and negative charges. Only a tiny fraction of the charges are involved, and only a few of them are shown here.

b) When rubbed together, some negative charge is transferred to the amber, leaving the cloth with a net positive charge.

c) When separated, the amber and cloth now have net charges, but the absolute value of the net positive and negative charges will be equal.

FIGURE 5.6

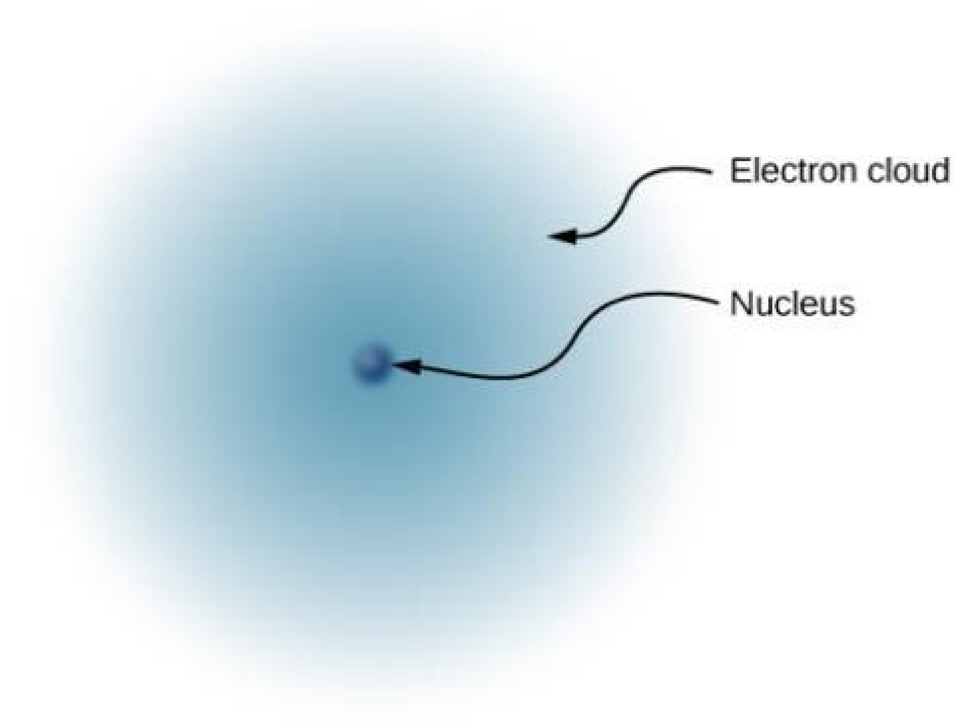


A Leyden jar (an early version of what is now called a capacitor) allowed experimenters to store large amounts of electric charge. Benjamin Franklin used such a jar to demonstrate that lightening behaved exactly like the electricity he got from the equipment in his laboratory.

You can see Leyden jars from 1789 in the Teyler museum in Haarlem, NL https://www.teylersmuseum.nl/

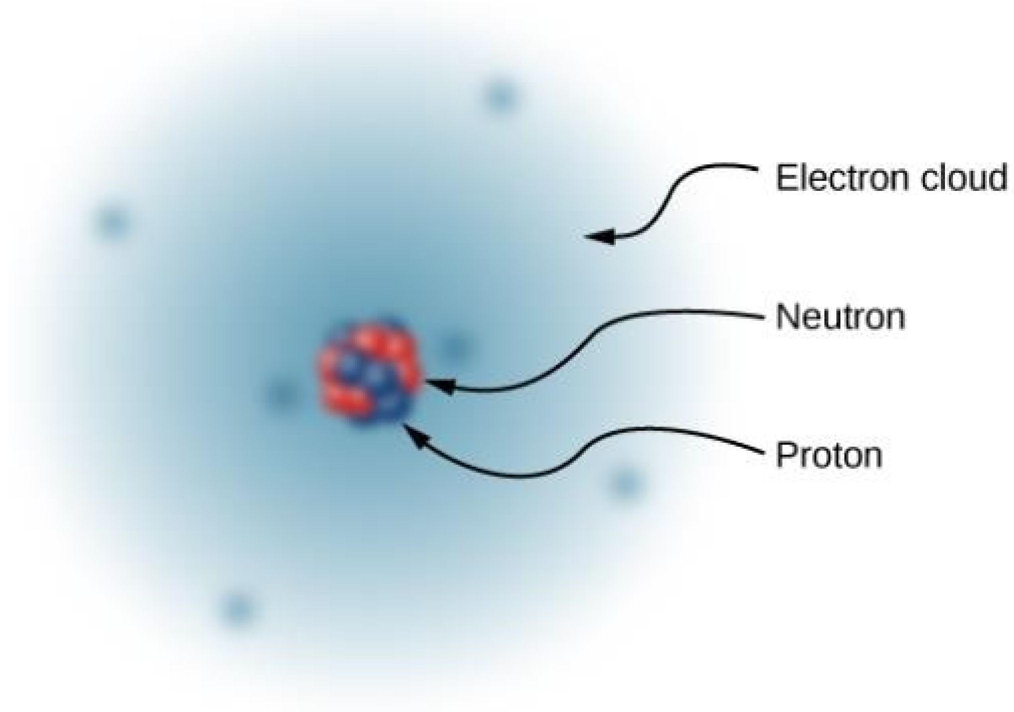
Polarization

FIGURE 5.7



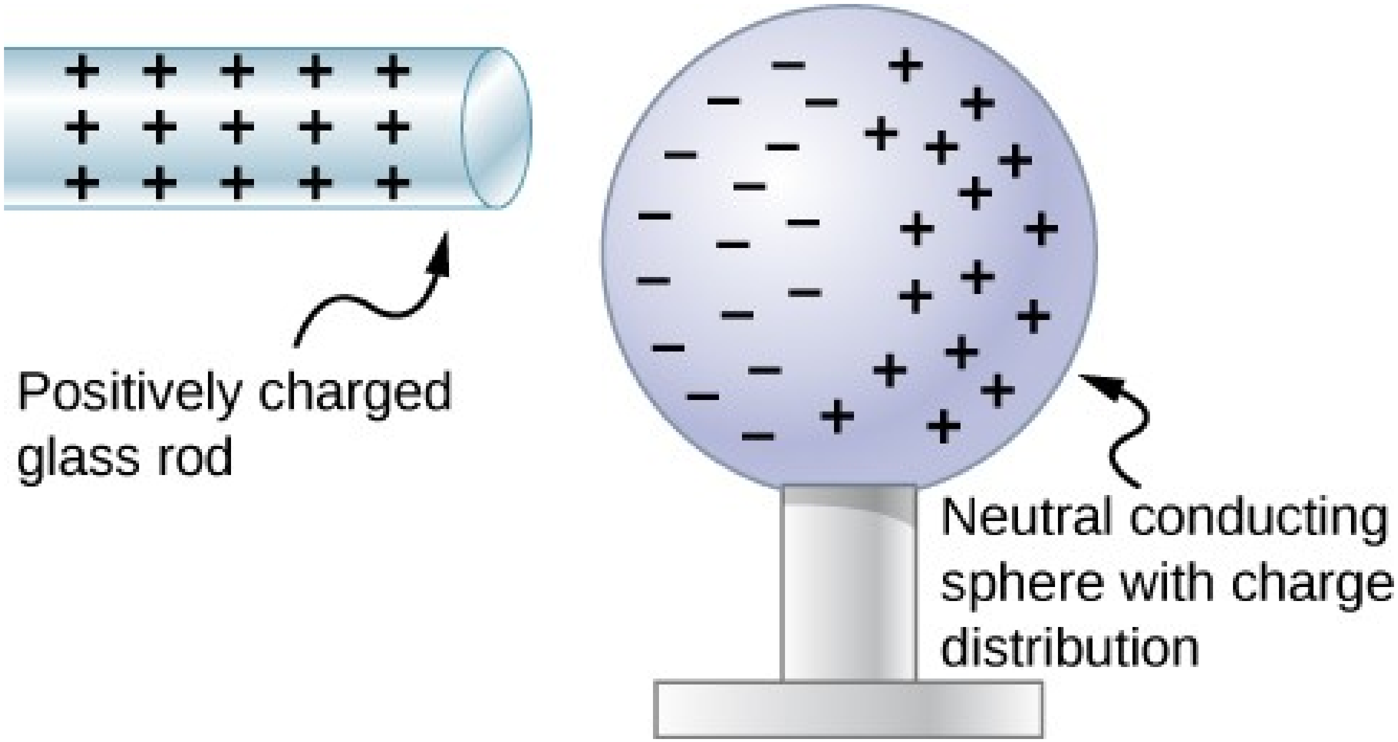
This simplified model of a hydrogen atom shows a positively charged nucleus (consisting, in the case of hydrogen, of a single proton), surrounded by an electron “cloud.” The charge of the electron cloud is equal (and opposite in sign) to the charge of the nucleus, but the electron does not have a definite location in space; hence, its representation here is as a cloud. Normal macroscopic amounts of matter contain immense numbers of atoms and molecules, and, hence, even greater numbers of individual negative and positive charges.

FIGURE 5.8



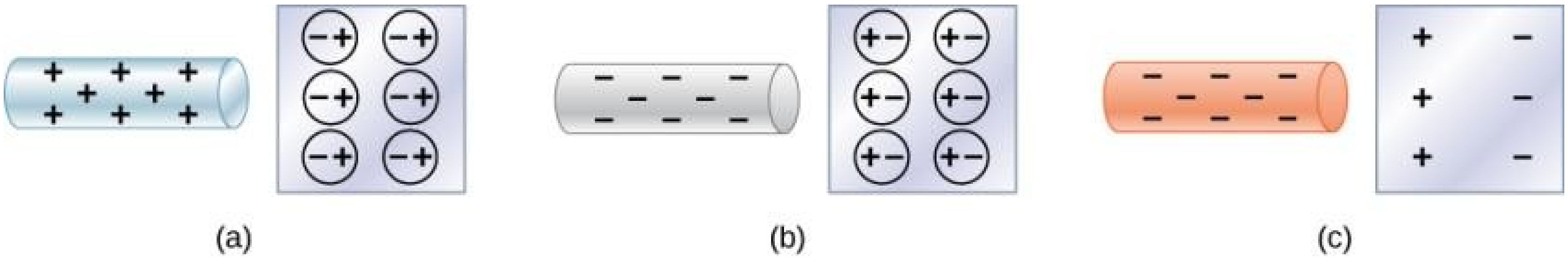
The nucleus of a carbon atom is composed of six protons and six neutrons. As in hydrogen, the surrounding six electrons do not have definite locations and so can be considered to be a sort of cloud surrounding the nucleus.

FIGURE 5.10



Induced polarization. A positively charged glass rod is brought near the left side of the conducting sphere, attracting negative charge and leaving the other side of the sphere positively charged. Although the sphere is overall still electrically neutral, it now has a charge distribution, so it can exert an electric force on other nearby charges. Furthermore, the distribution is such that it will be attracted to the glass rod.

FIGURE 5.11



Both positive and negative objects attract a neutral object by polarizing its molecules.

a) A positive object brought near a neutral insulator polarizes its molecules. There is a slight shift in the distribution of the electrons orbiting the molecule, with unlike charges being brought nearer and like charges moved away. Since the electrostatic force decreases with distance, there is a net attraction.

b) A negative object produces the opposite polarization, but again attracts the neutral object.

c) The same effect occurs for a conductor; since the unlike charges are closer, there is a net attraction.

FIGURE 5.12

Charging by induction.

a) Two uncharged or neutral metal spheres are in contact with each other but insulated from the rest of the world.

b) A positively charged glass rod is brought near the sphere on the left, attracting negative charge and leaving the other sphere positively charged.

c) The spheres are separated before the rod is removed, thus separating negative and positive charges.

d) The spheres retain net charges after the inducing rod is removed—without ever having been touched by a charged object.

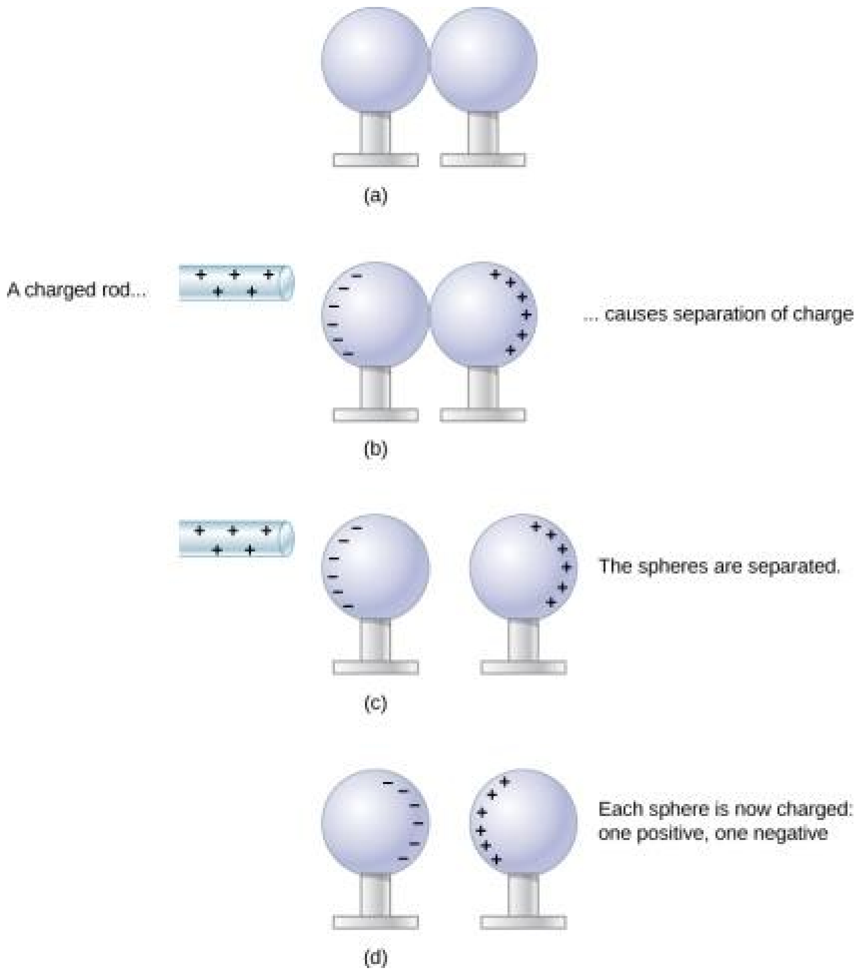
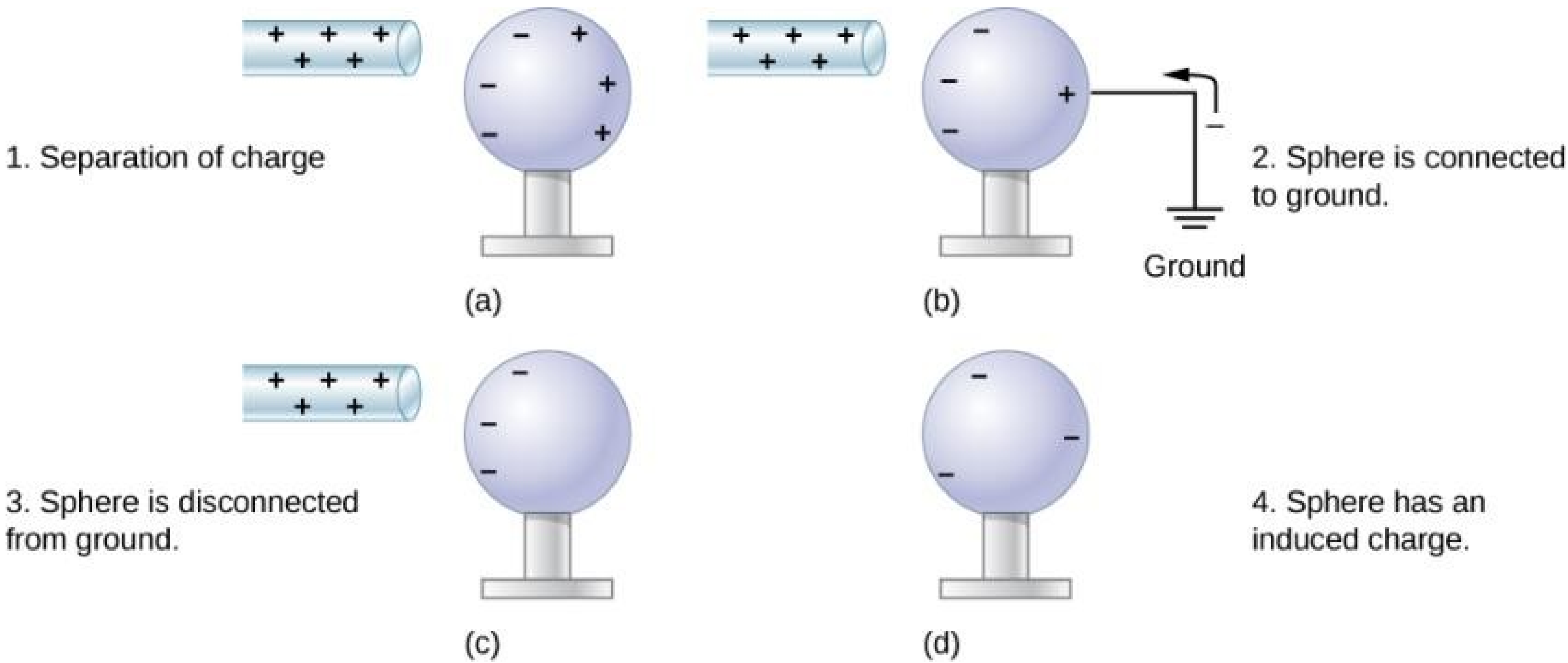


FIGURE 5.13



Charging by induction using a ground connection.

a) A positively charged rod is brought near a neutral metal sphere, polarizing it.

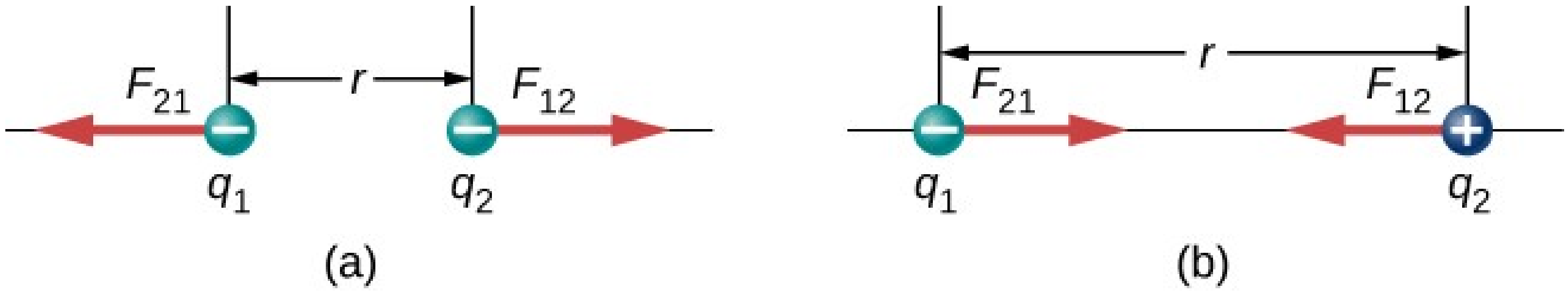
b) The sphere is grounded, allowing electrons to be attracted from Earth's ample supply.

c) The ground connection is broken.

d) The positive rod is removed, leaving the sphere with an induced negative charge.

Electric force

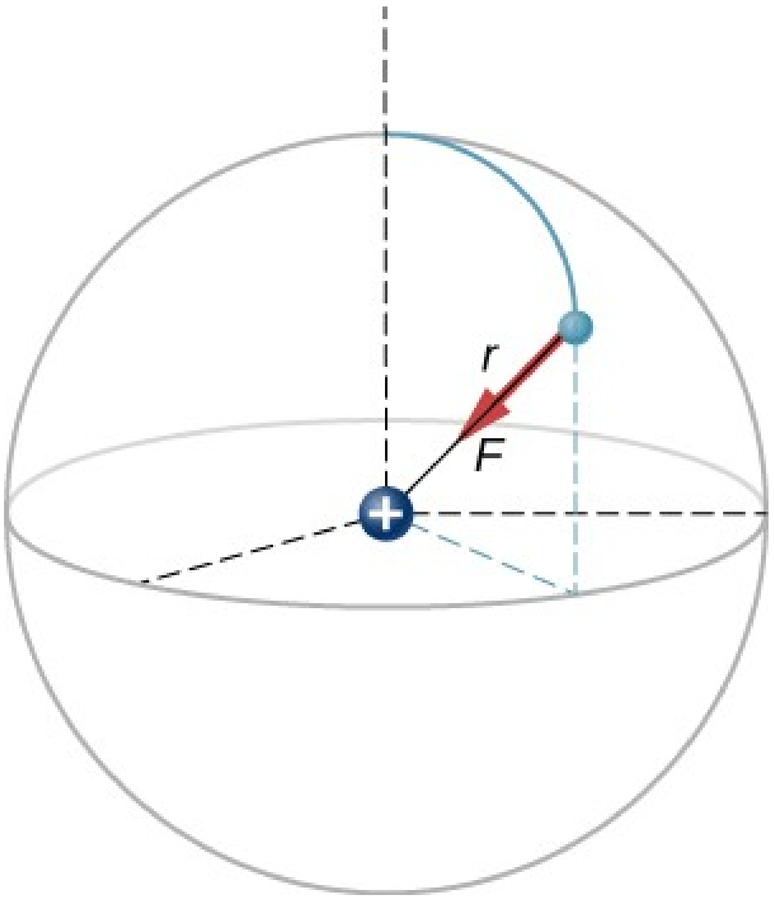
FIGURE 5.14



$$F = \frac{K q_1 q_2}{r^2}$$

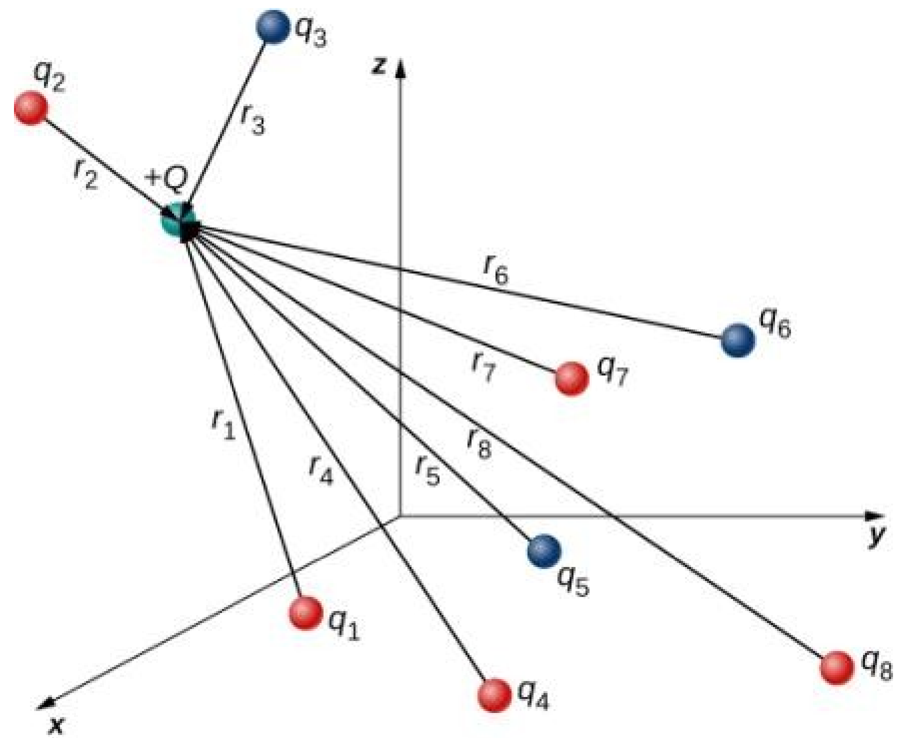
The electrostatic force between point charges q_1 and q_2 separated by a distance r is given by Coulomb's law. Note that Newton's third law (every force exerted creates an equal and opposite force) applies as usual—the force on q_1 is equal in magnitude and opposite in direction to the force it exerts on q_2. (a) Like charges; (b) unlike charges.

FIGURE 5.15



A schematic depiction of a hydrogen atom, showing the force on the electron. This depiction is only to enable us to calculate the force; the hydrogen atom does not really look like this. Recall **Figure 5.7**.

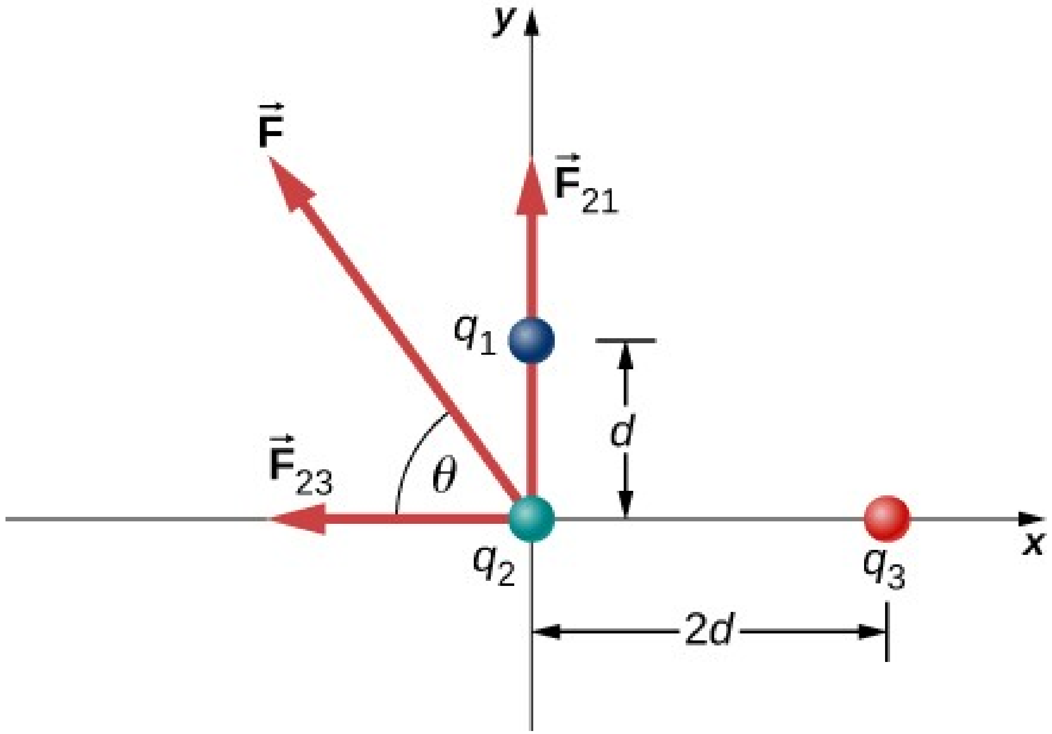
FIGURE 5.16



The eight source charges each apply a force on the single test charge Q. Each force can be calculated independently of the other seven forces. This is the essence of the superposition principle.

Forces from different charges are additive.

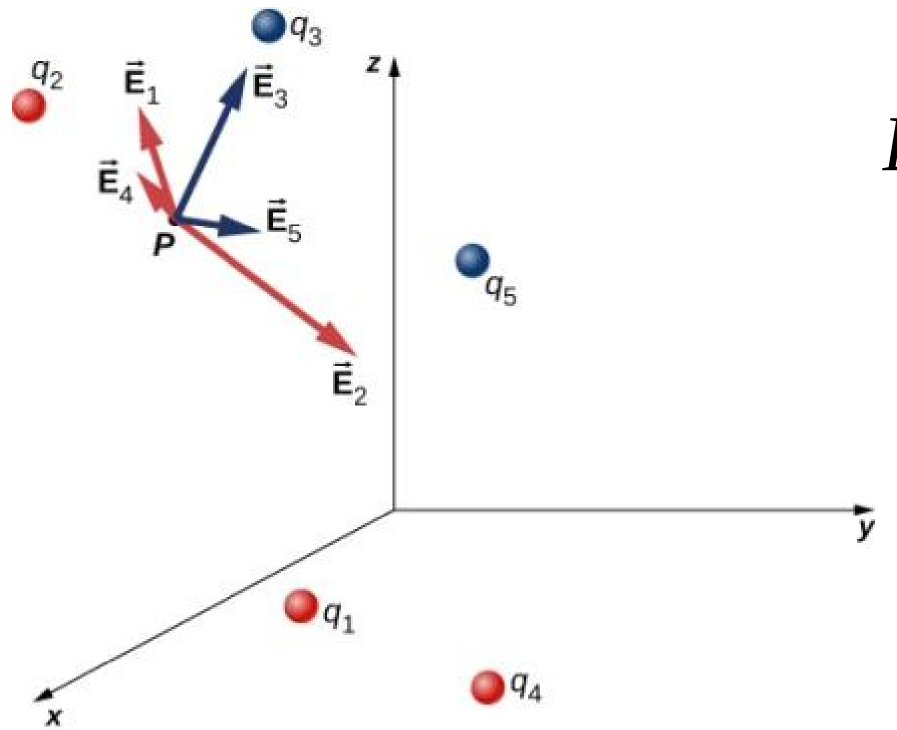
FIGURE 5.17



Source charges q_1 and q_3 each apply a force on q_2.

Electric field

FIGURE 5.18



$$E = \frac{Kq}{r^2}$$

Each of these eight source charges creates its own electric field at every point in space; shown here are the field vectors at an arbitrary point *P*. Like the electric force, the net electric field obeys the superposition principle.

The electric field points where a positive charge wants to go.

FIGURE 5.19

A schematic representation of a helium atom. Again, helium physically looks nothing like this, but this sort of diagram is helpful for calculating the electric field of the nucleus.

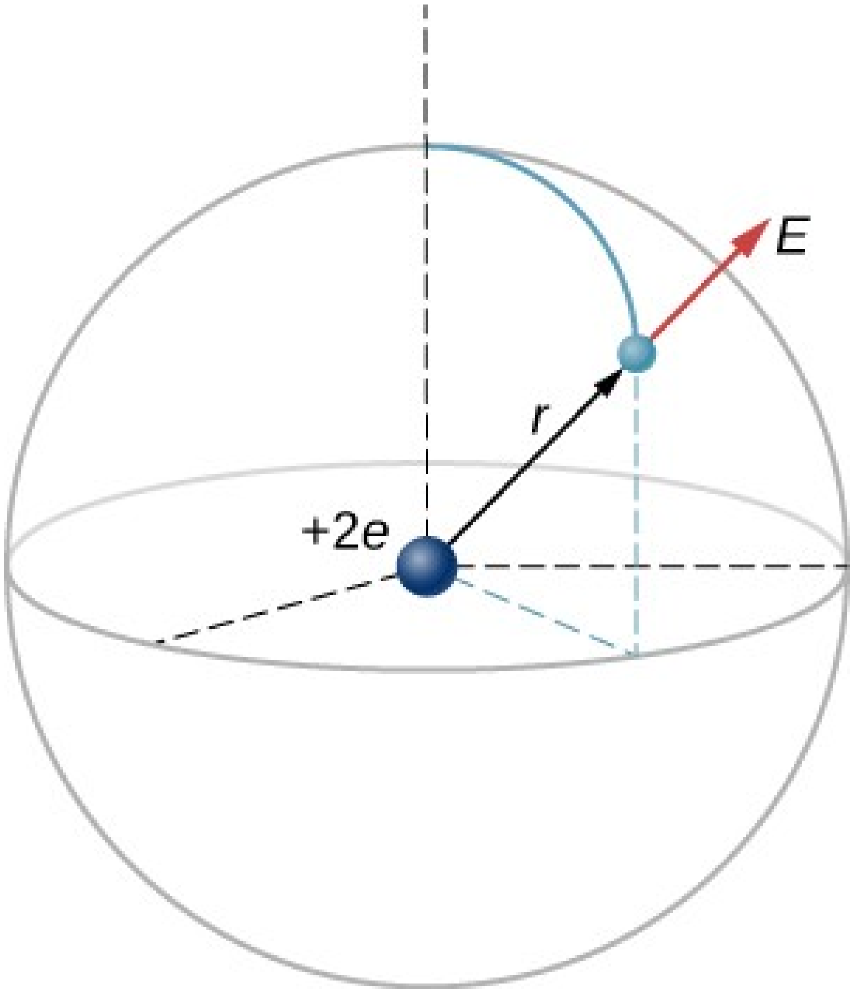
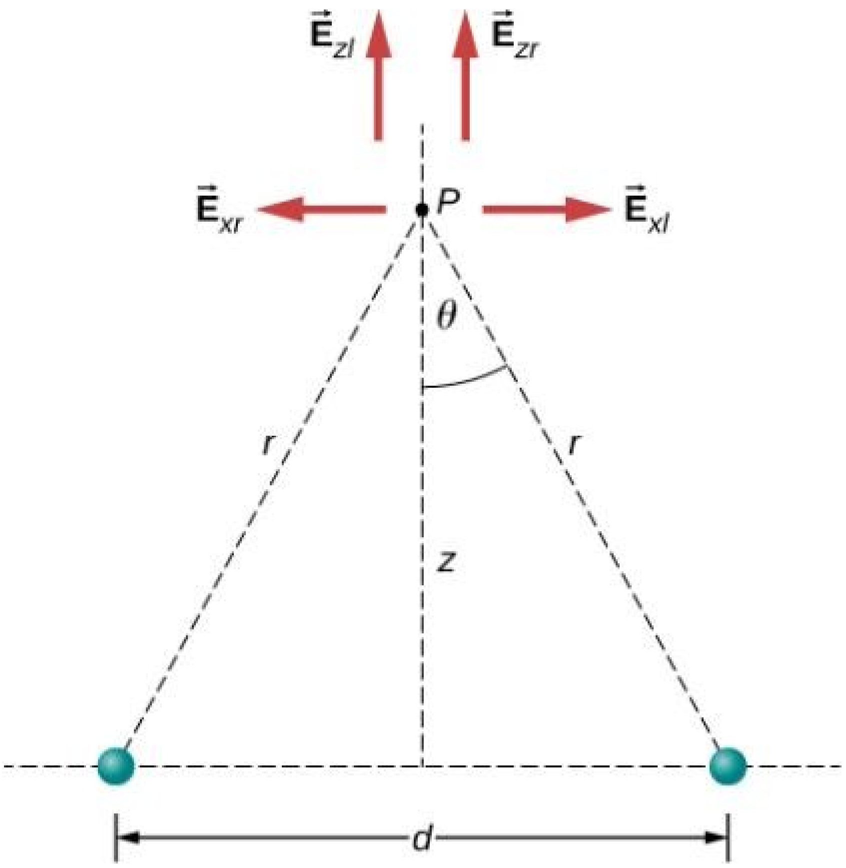


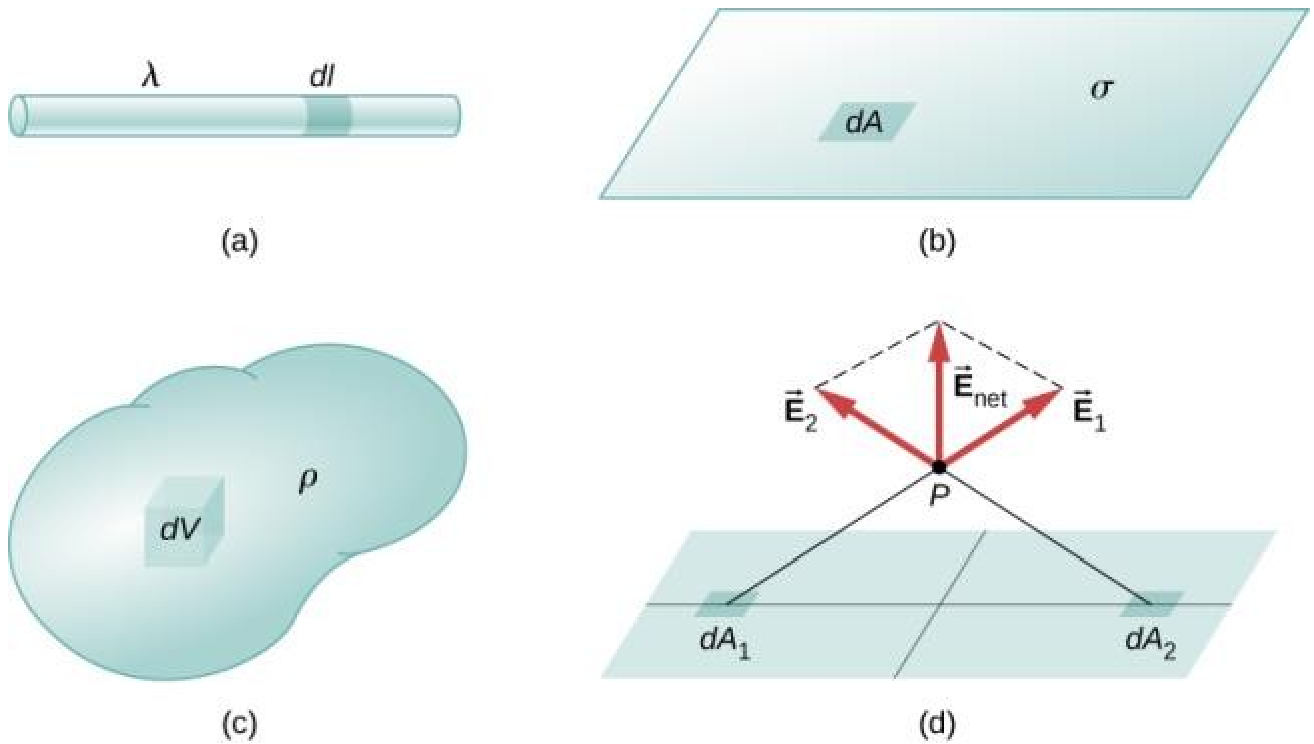
FIGURE 5.21



Note that the horizontal components of the electric fields from the two charges cancel each other out, while the vertical components add together.

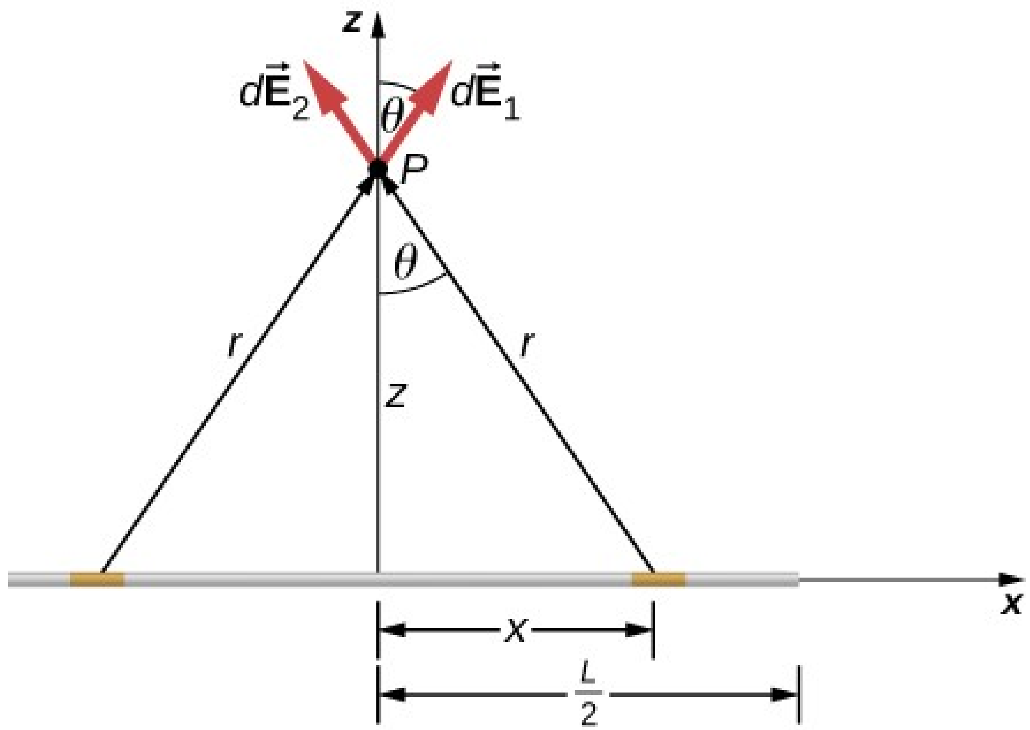
More complicated calculations

FIGURE 5.22



The configuration of charge differential elements for a (a) line charge, (b) sheet of charge, and (c) a volume of charge. Also note that (d) some of the components of the total electric field cancel out, with the remainder resulting in a net electric field.

FIGURE 5.23



A uniformly charged segment of wire. The electric field at point *P* can be found by applying the superposition principle to symmetrically placed charge elements and integrating.

FIGURE 5.24

The system and variable for calculating the electric field due to a ring of charge.

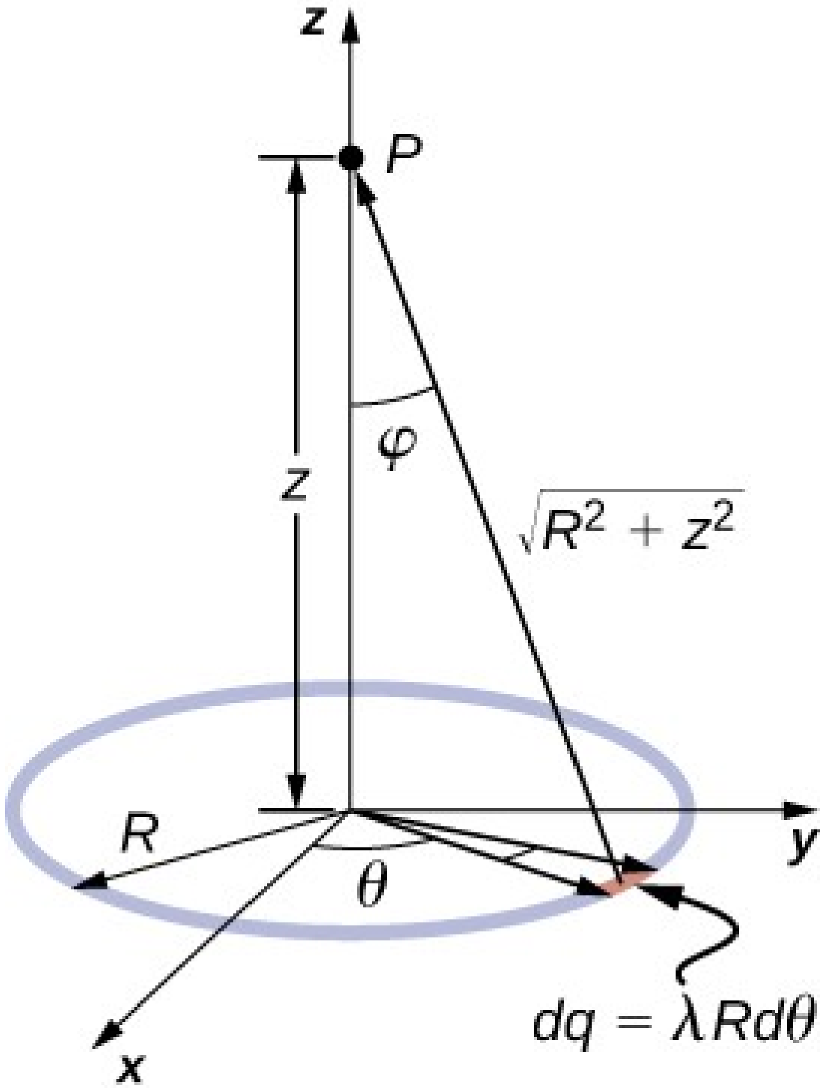
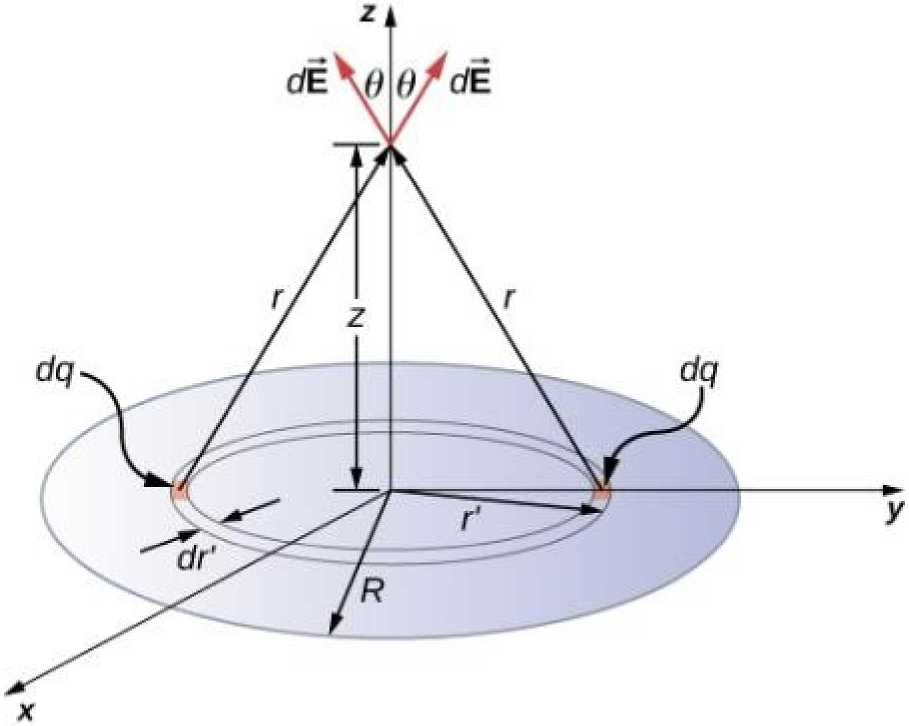
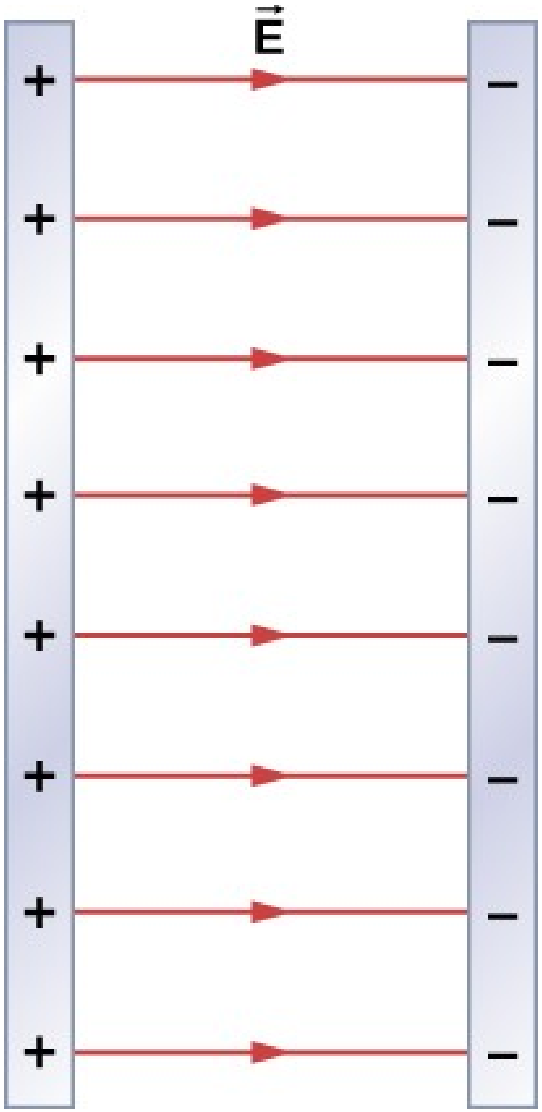


FIGURE 5.25



A uniformly charged disk. As in the line charge example, the field above the center of this disk can be calculated by taking advantage of the symmetry of the charge distribution.

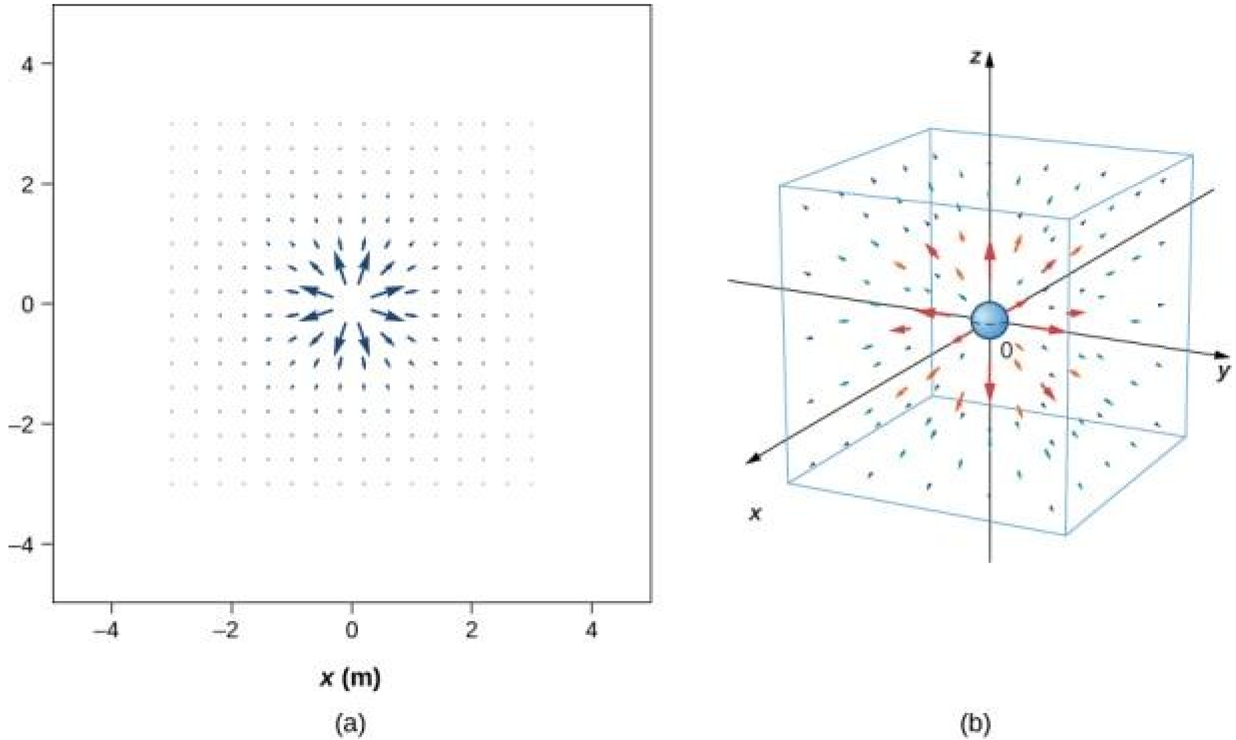
FIGURE 5.26



Two charged infinite planes. Note the direction of the electric field.

End

FIGURE 5.27



The electric field of a positive point charge. A large number of field vectors are shown. Like all vector arrows, the length of each vector is proportional to the magnitude of the field at each point. (a) Field in two dimensions; (b) field in three dimensions.

FIGURE 5.28

The vector field of a dipole. Even with just two identical charges, the vector field diagram becomes difficult to understand.

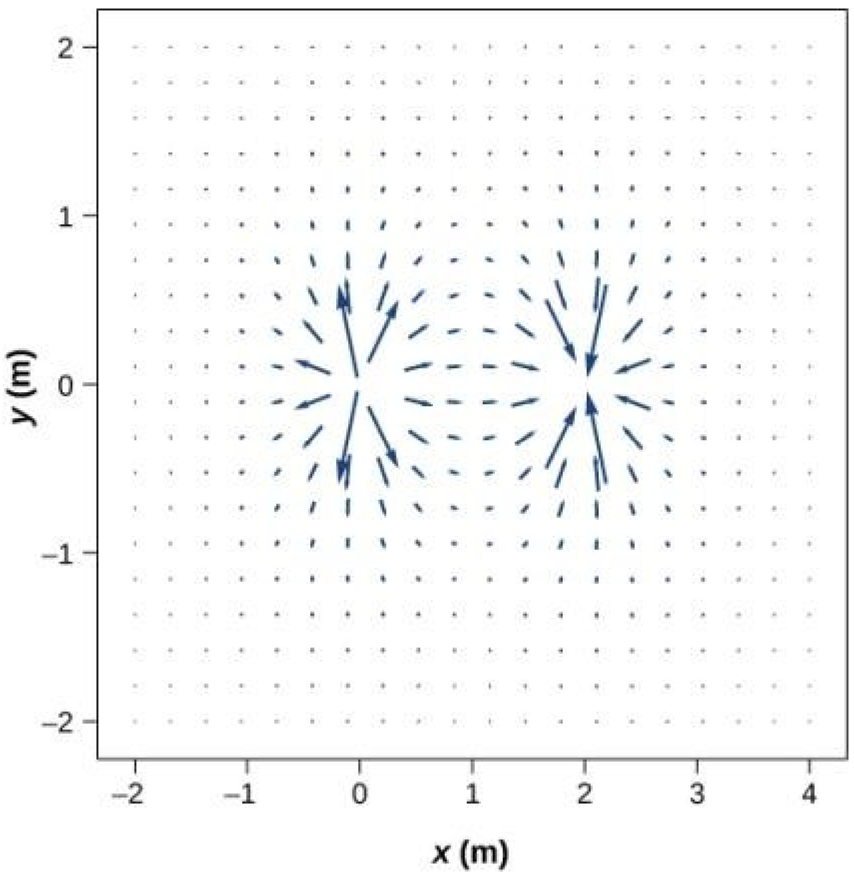
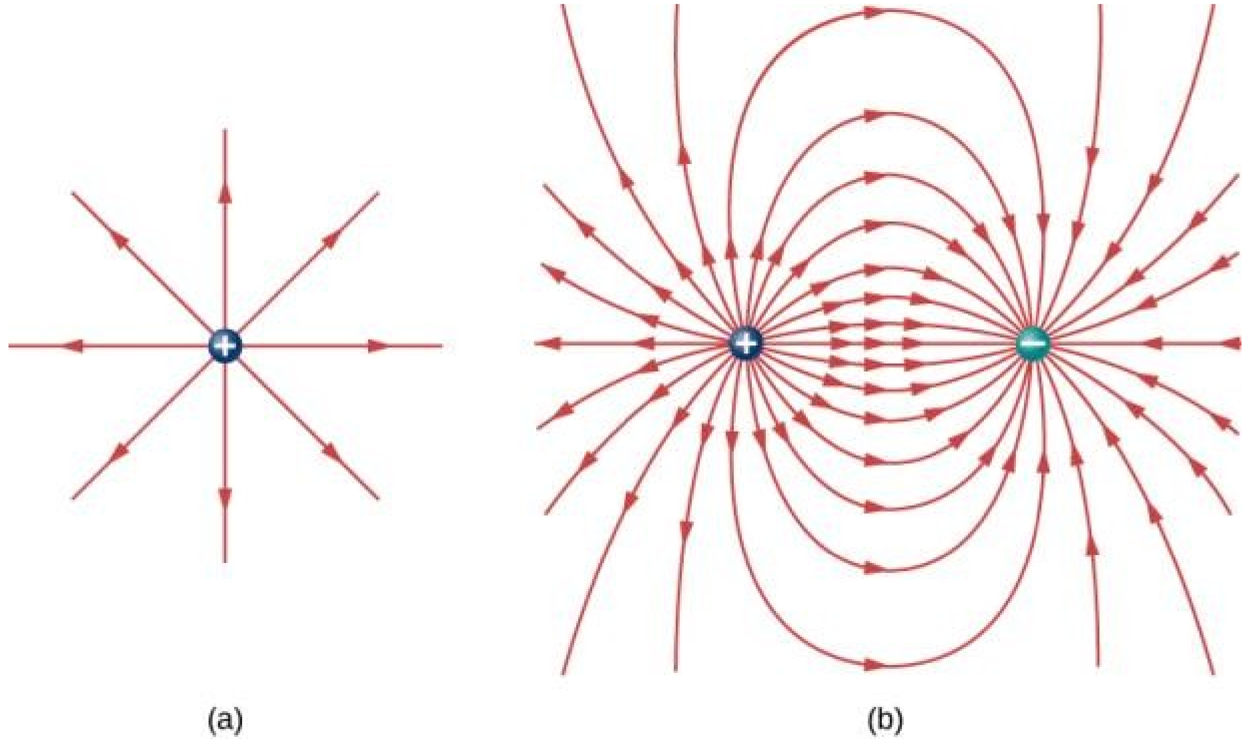
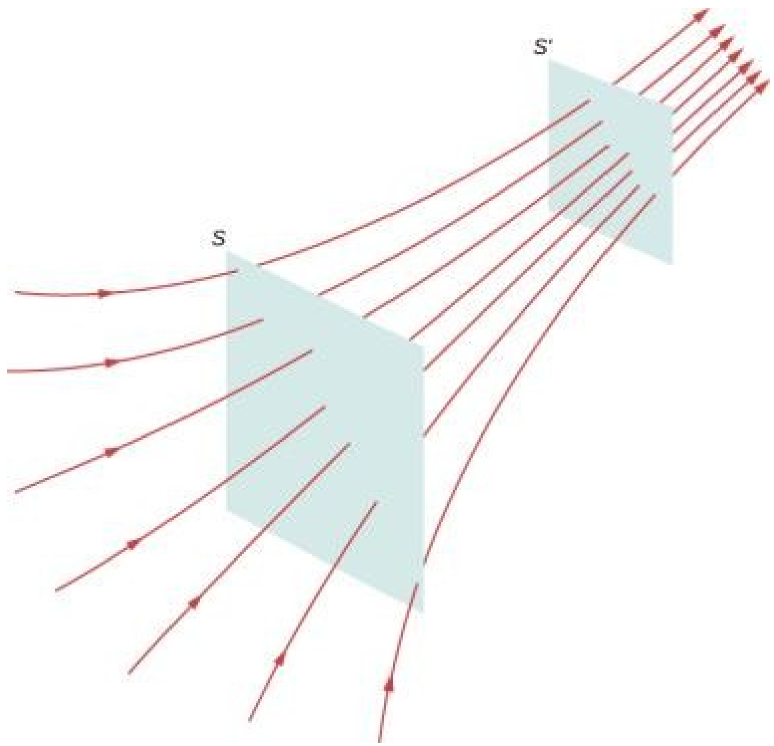


FIGURE 5.29



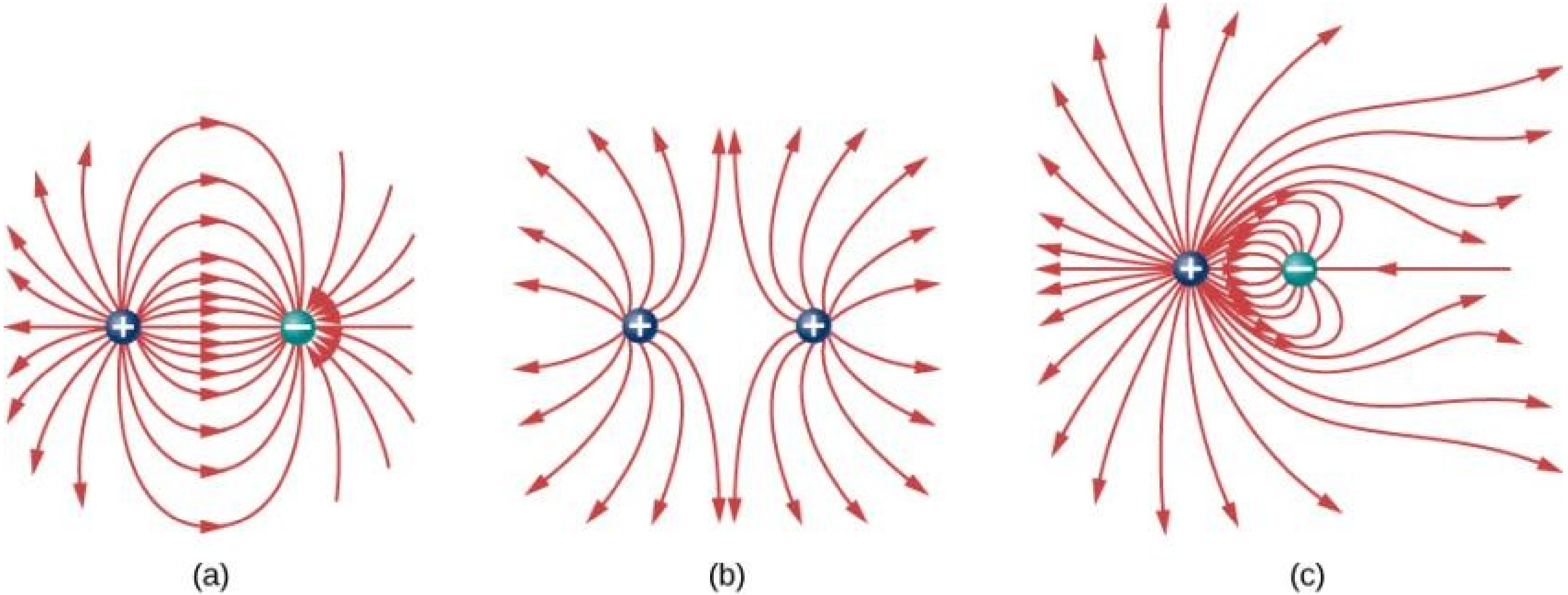
a) The electric field line diagram of a positive point charge.
b) The field line diagram of a dipole. In both diagrams, the magnitude of the field is indicated by the field line density. The field *vectors* (not shown here) are everywhere tangent to the field lines.

FIGURE 5.30



Electric field lines passing through imaginary areas. Since the number of lines passing through each area is the same, but the areas themselves are different, the field line density is different. This indicates different magnitudes of the electric field at these points.

FIGURE 5.31



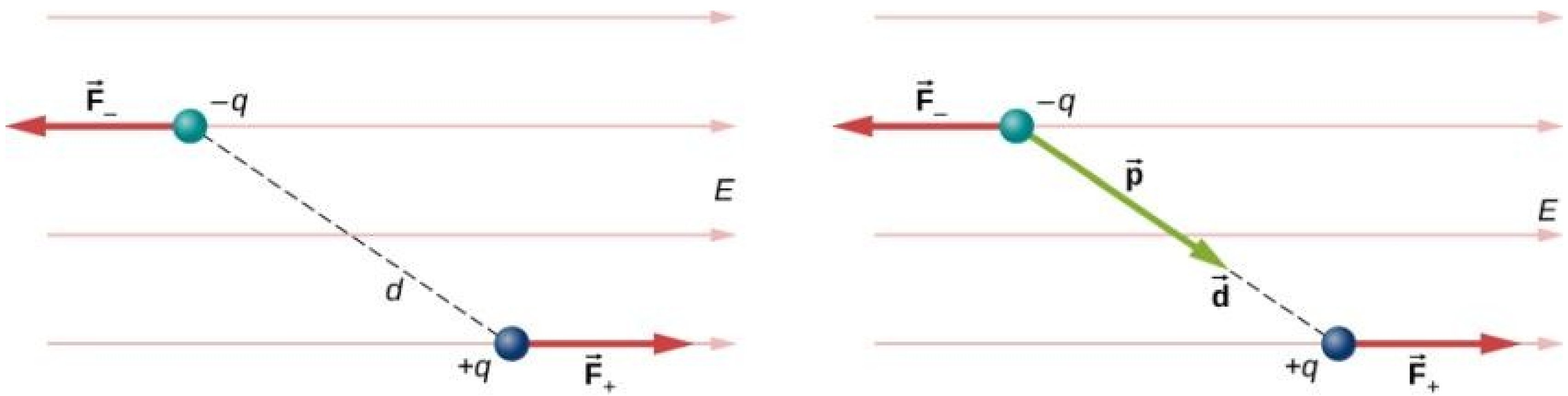
Three typical electric field diagrams.

a) A dipole.

b) Two identical charges.

c) Two charges with opposite signs and different magnitudes. Can you tell from the diagram which charge has the larger magnitude?

FIGURE 5.32

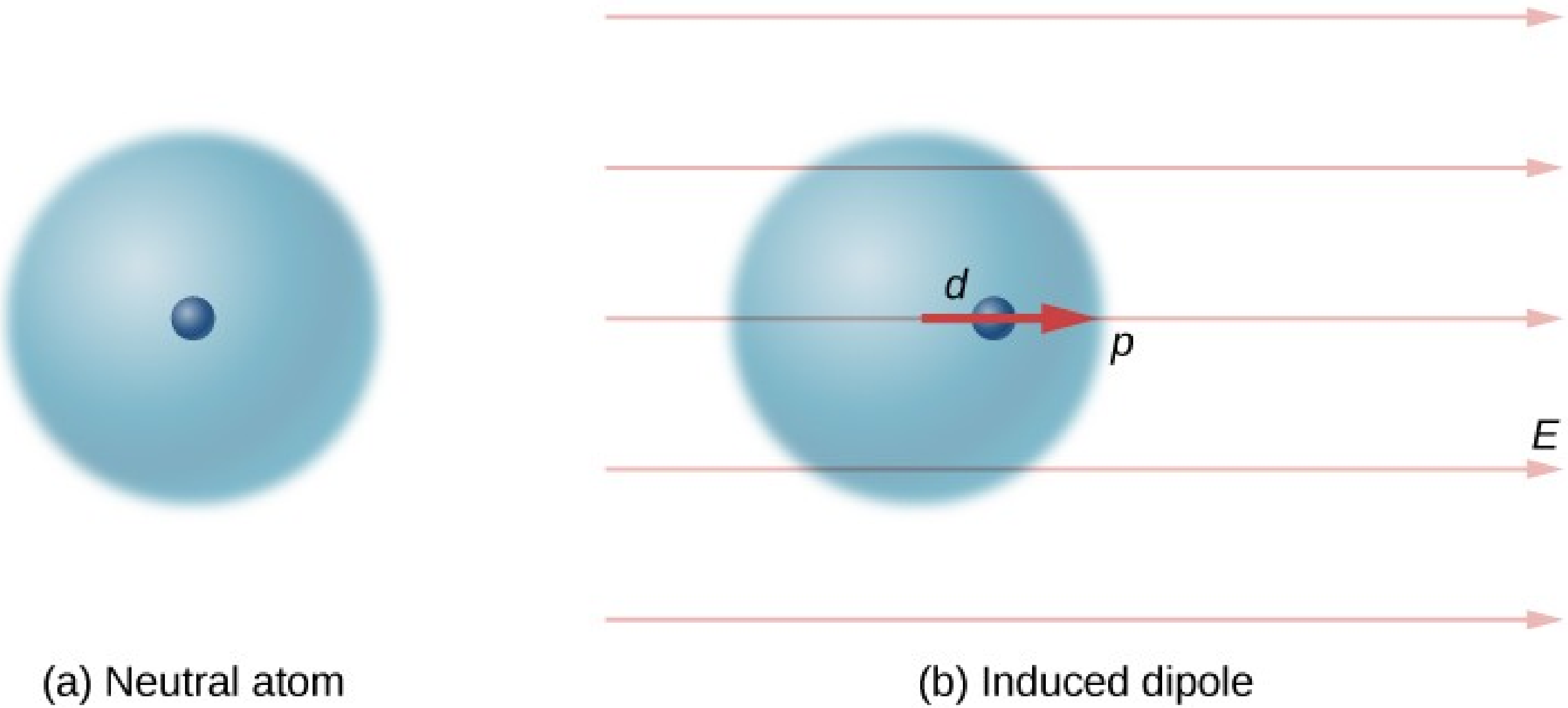


A dipole in an external electric field.

a) The net force on the dipole is zero, but the net torque is not. As a result, the dipole rotates, becoming aligned with the external field.

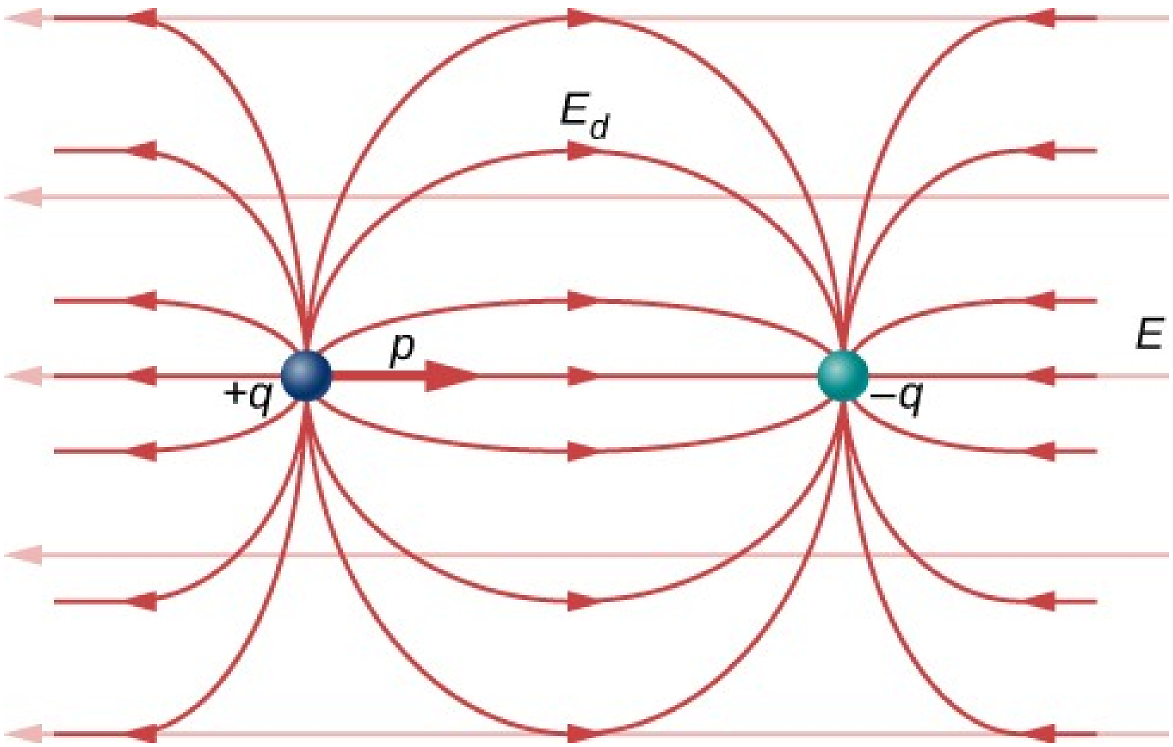
b) The dipole moment is a convenient way to characterize this effect. The points in the same direction as .

FIGURE 5.33



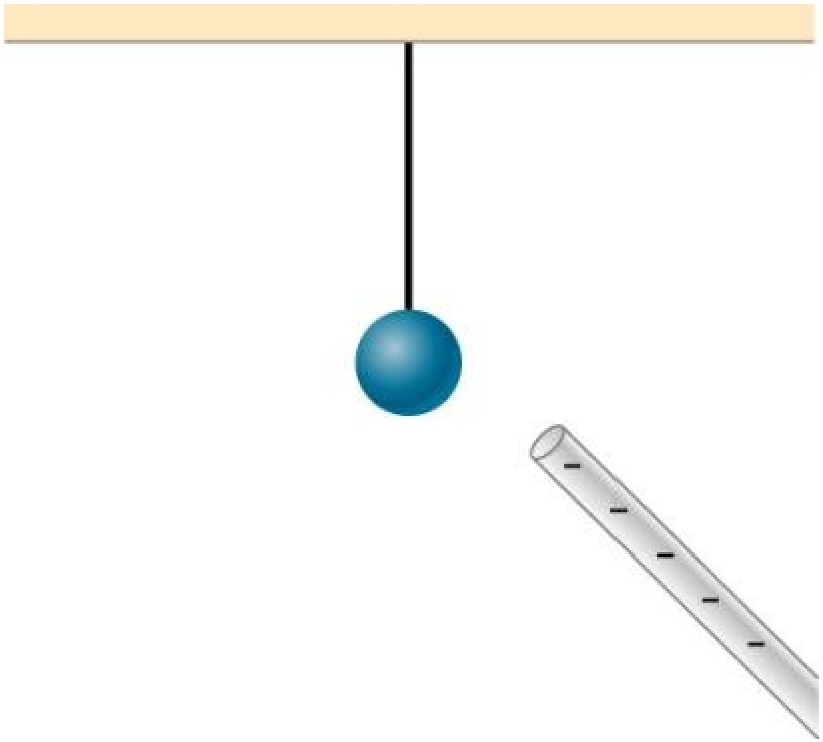
A dipole is induced in a neutral atom by an external electric field. The induced dipole moment is aligned with the external field.

FIGURE 5.34



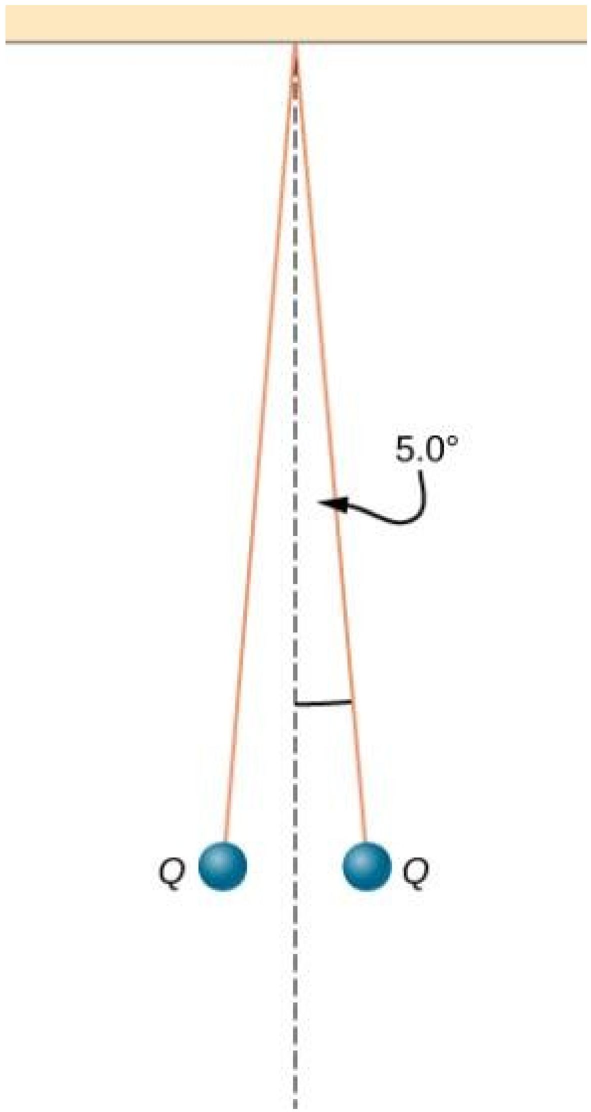
The net electric field is the vector sum of the field of the dipole plus the external field.

EXERCISE 9



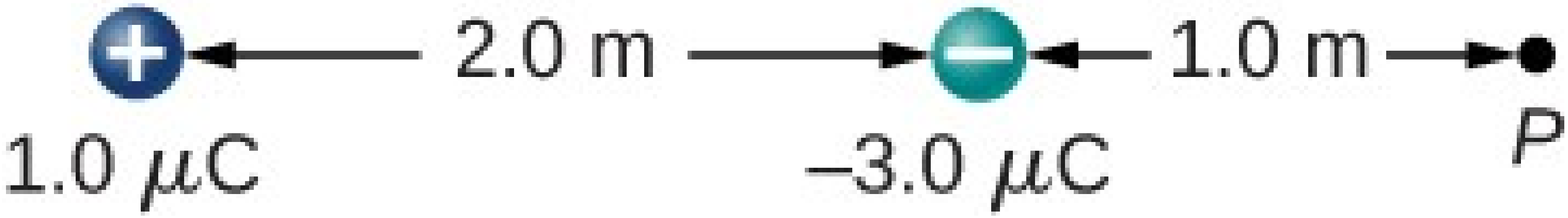
Does the uncharged conductor shown below experience a net electric force?

EXERCISE 55

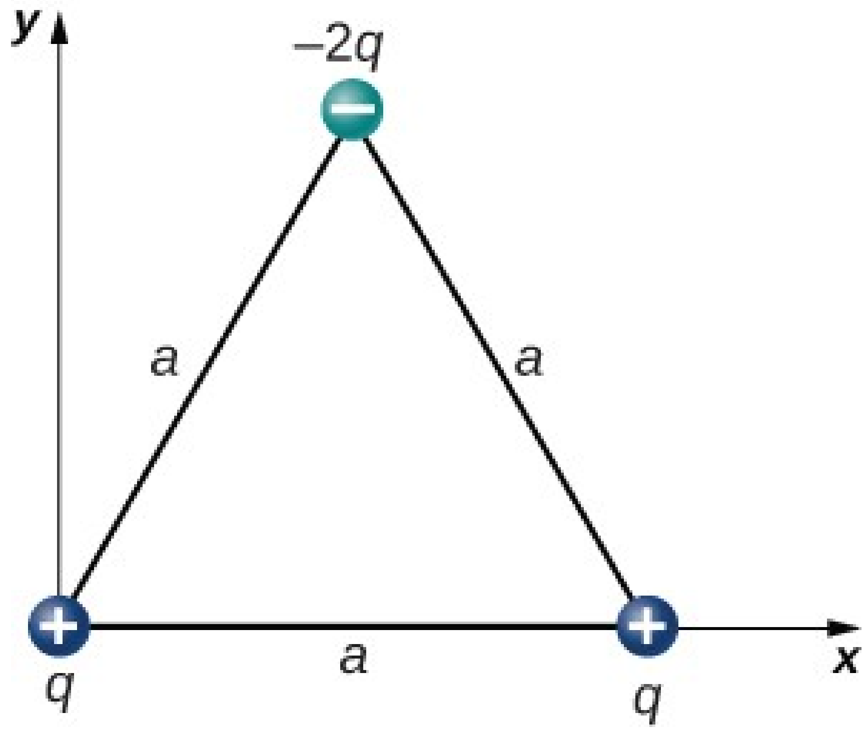


Does the uncharged conductor shown below experience a net electric force?

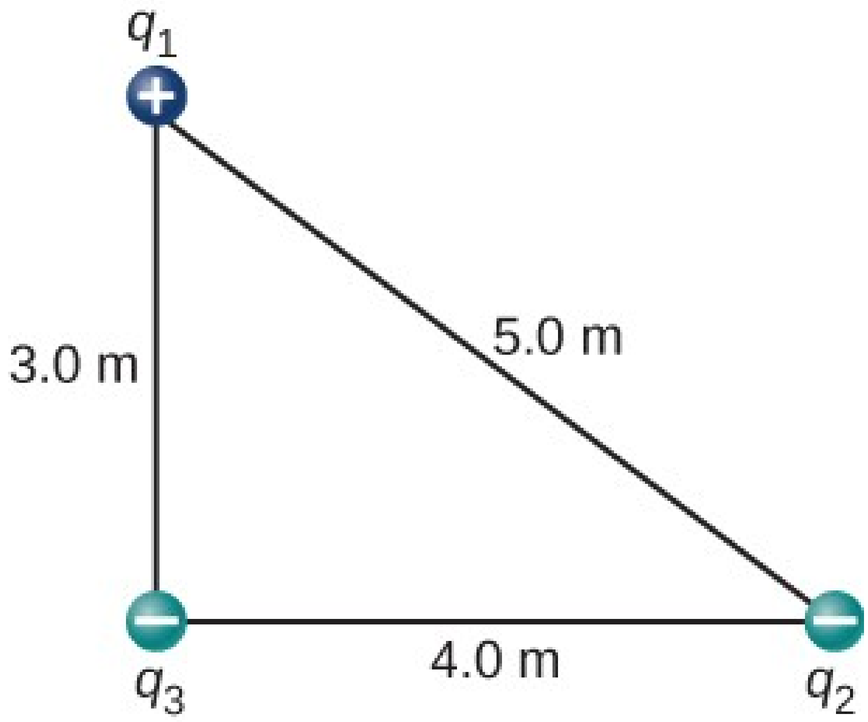
EXERCISE 59



EXERCISE 60



EXERCISE 62



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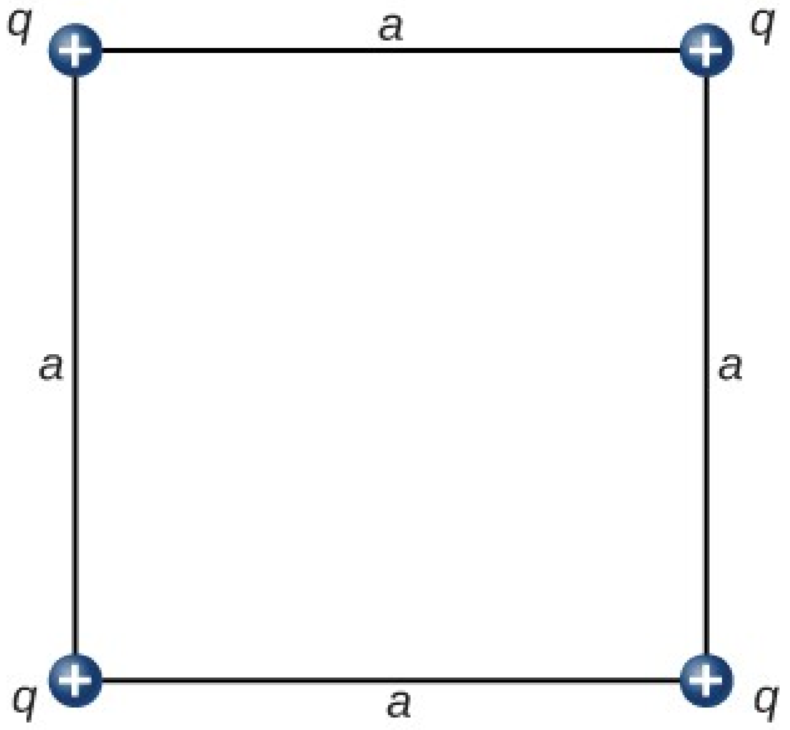

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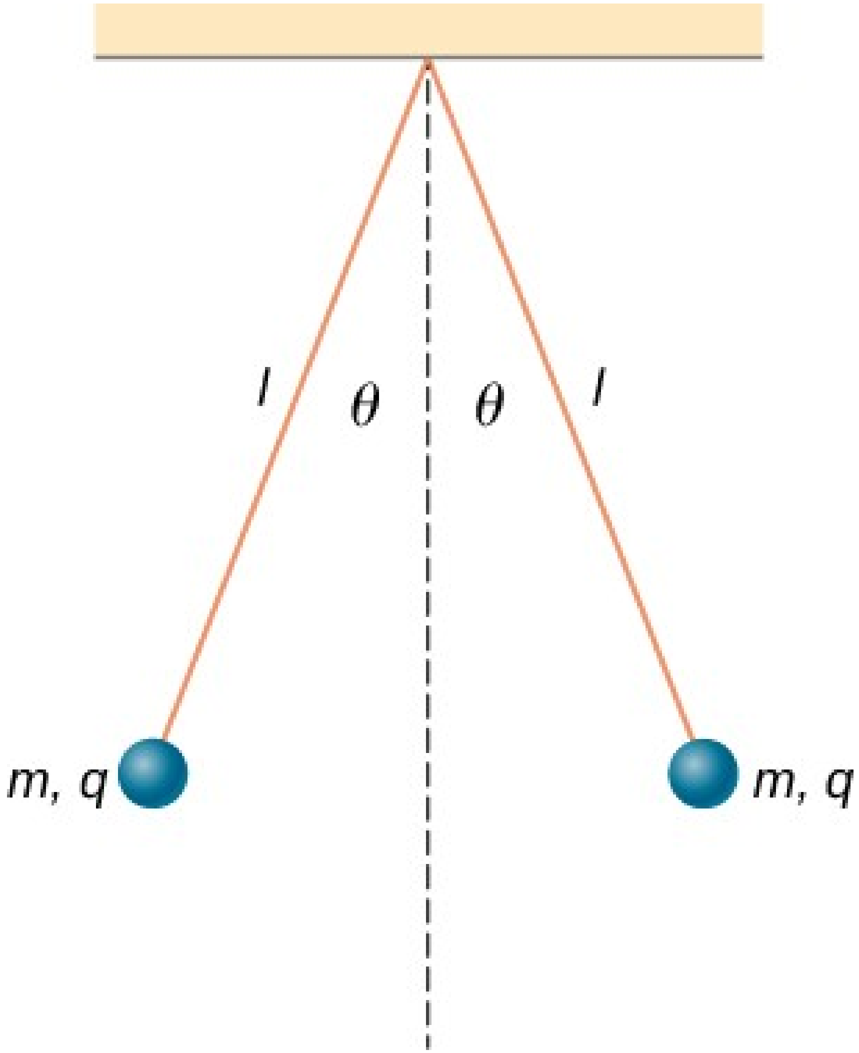
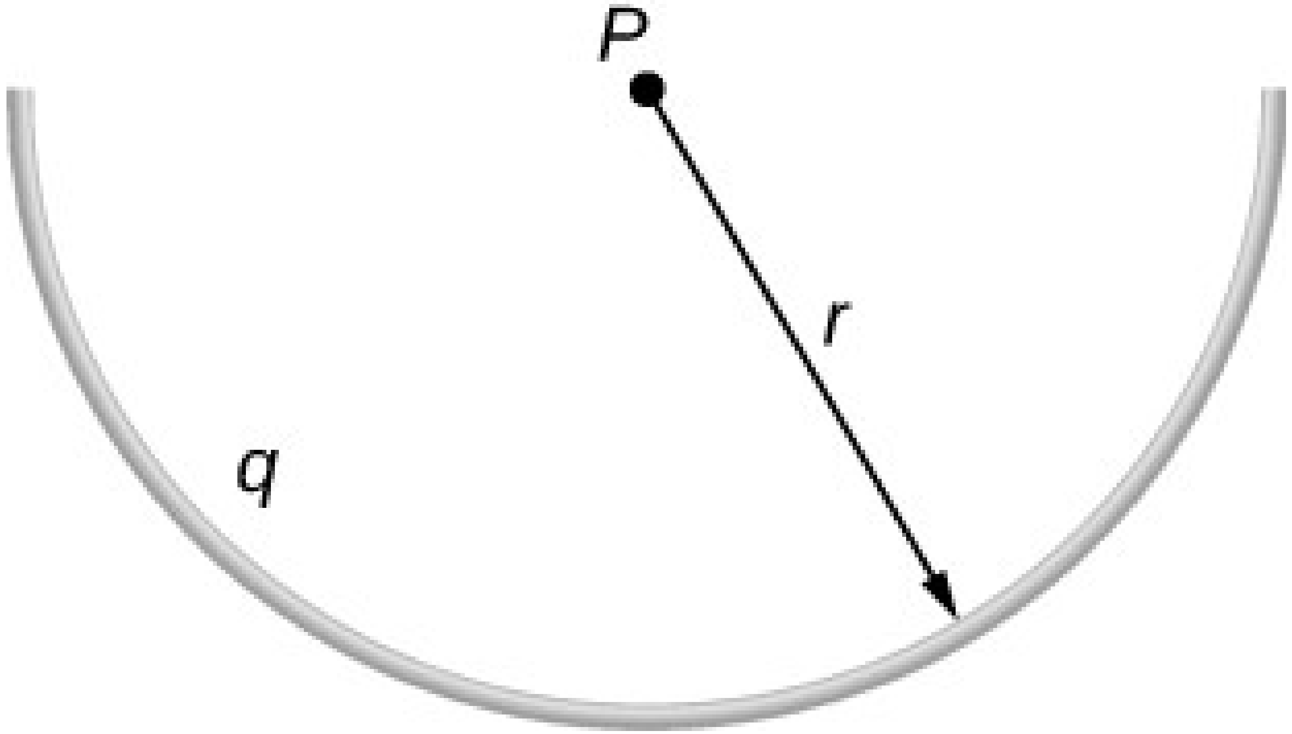
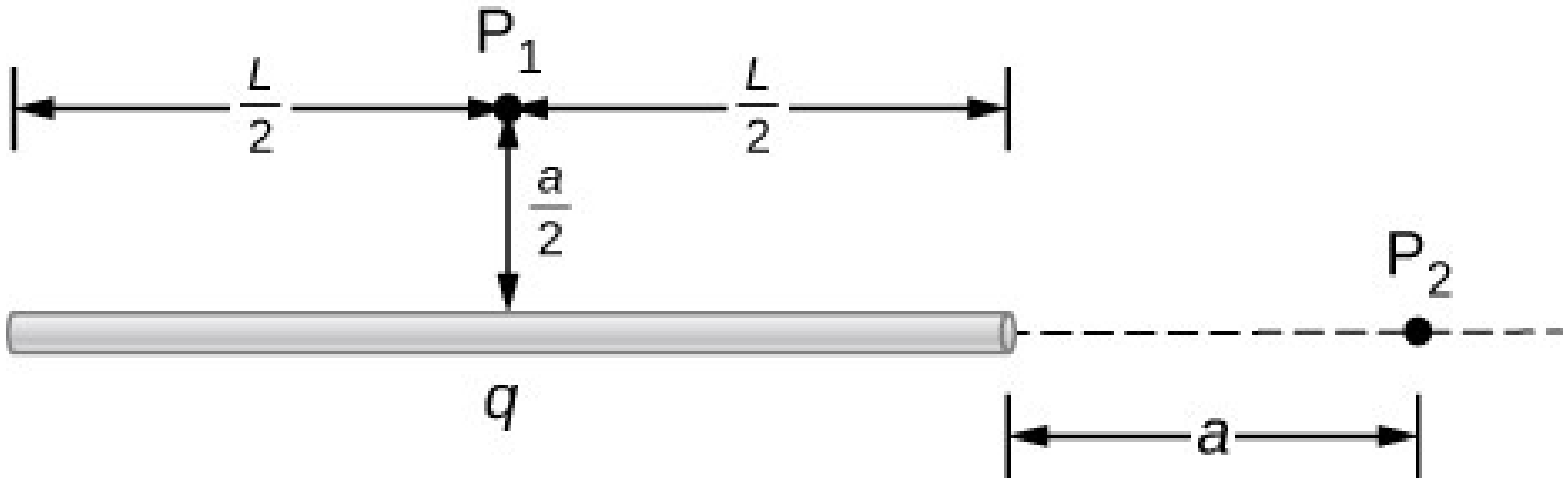


EXERCISE 83

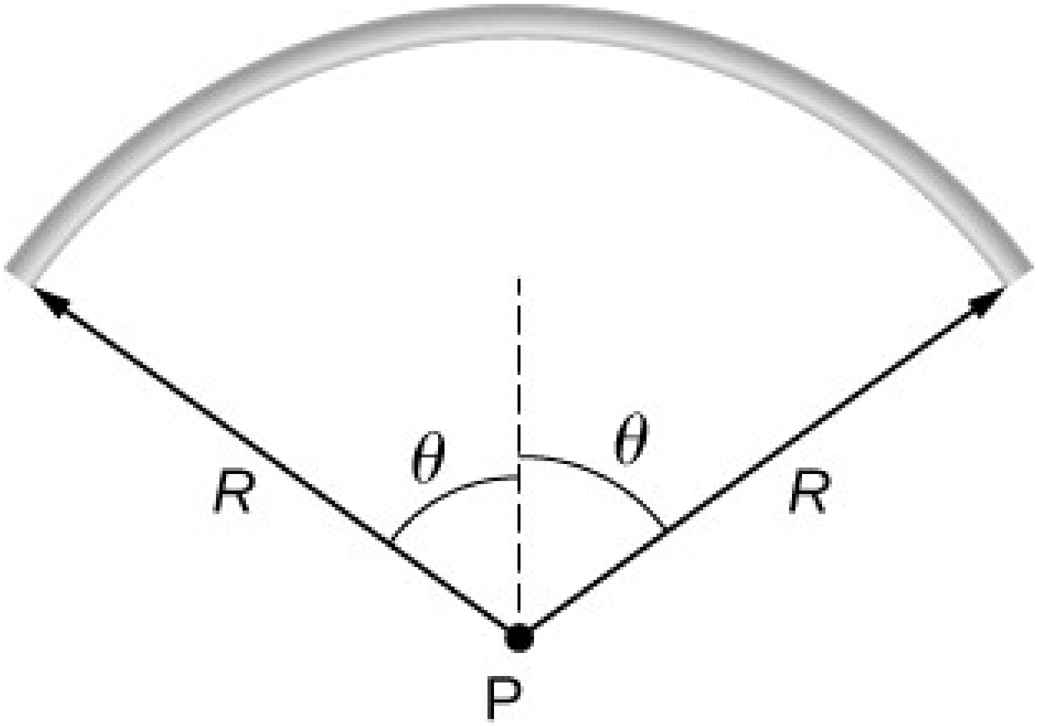
EXERCISE 84



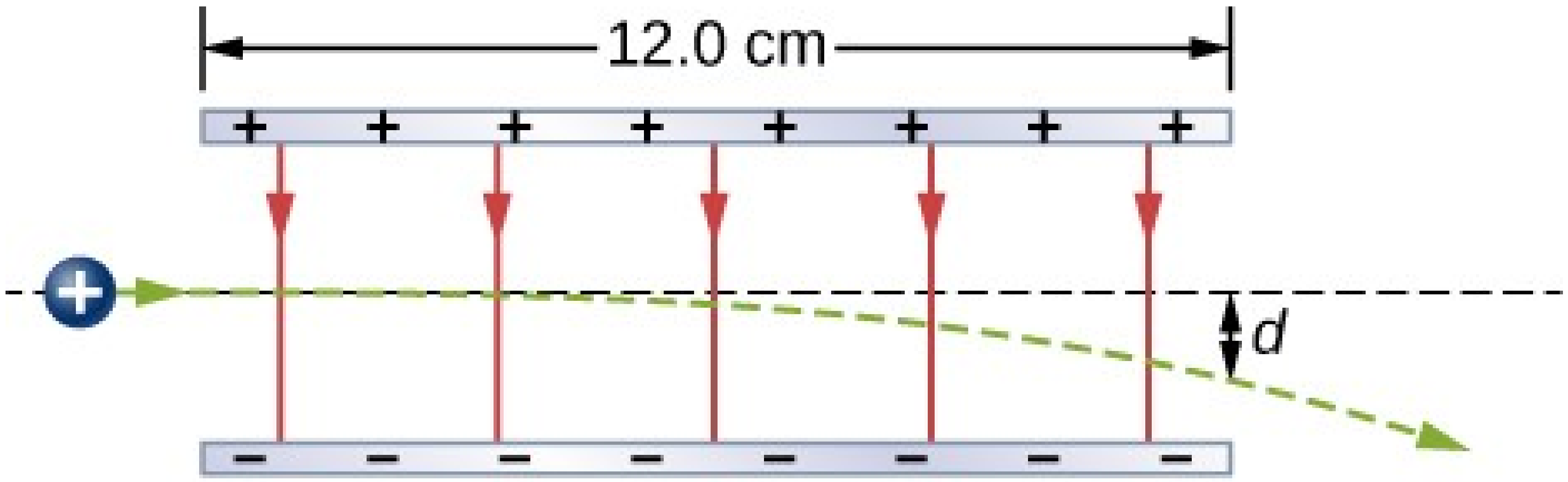
EXERCISE 87



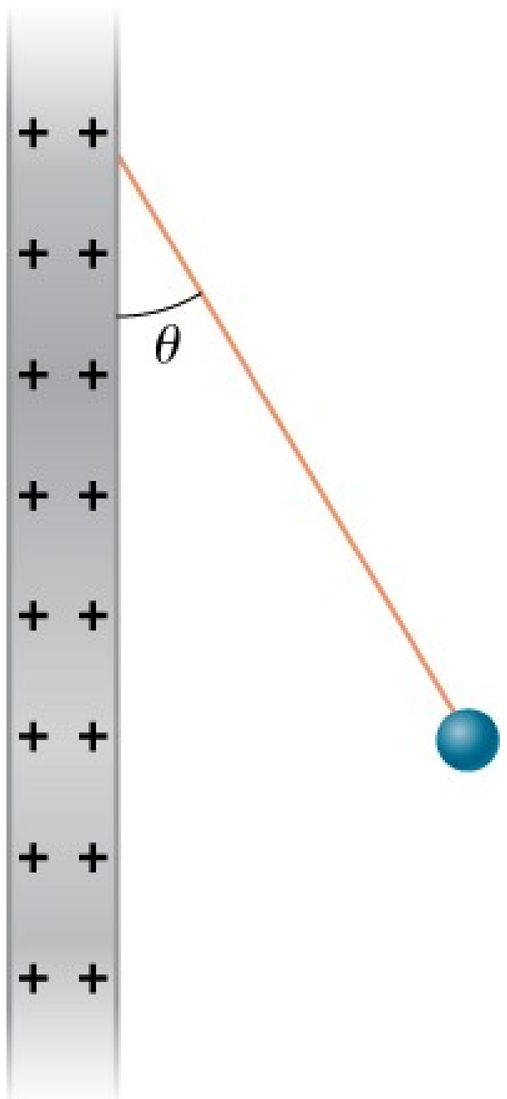
EXERCISE 90



EXERCISE 94



EXERCISE 95



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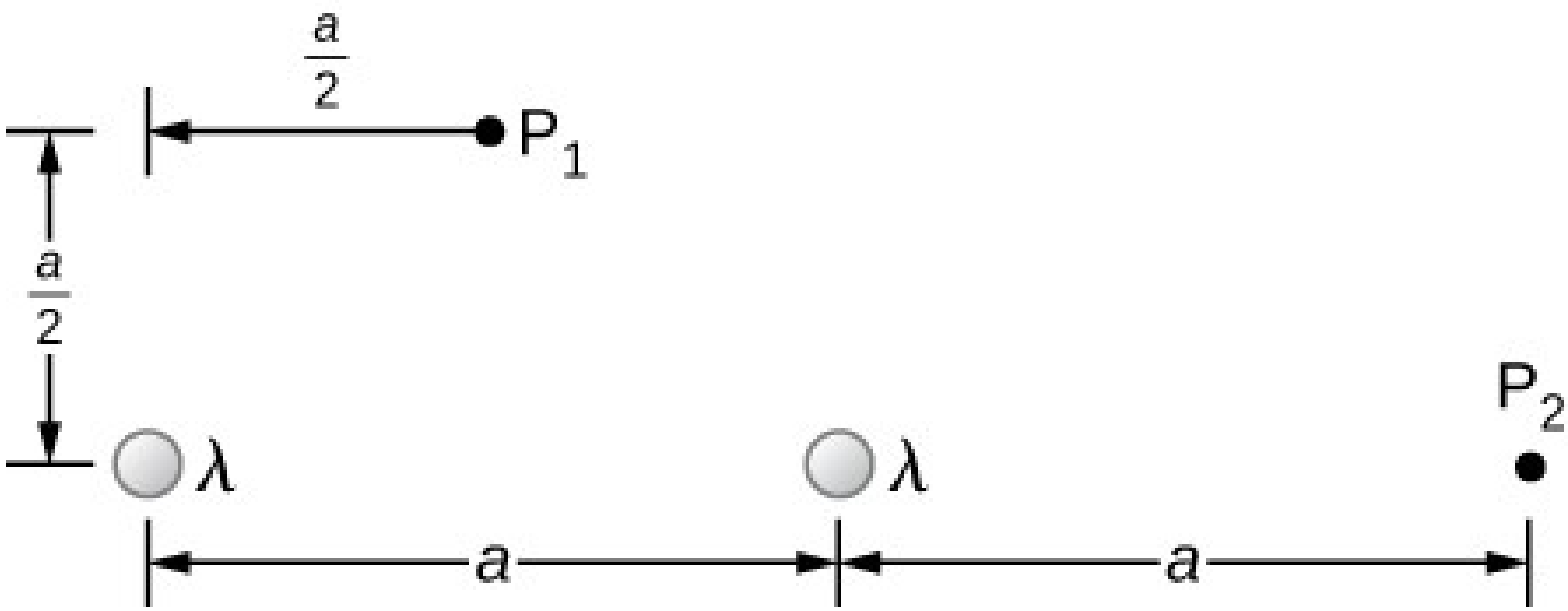
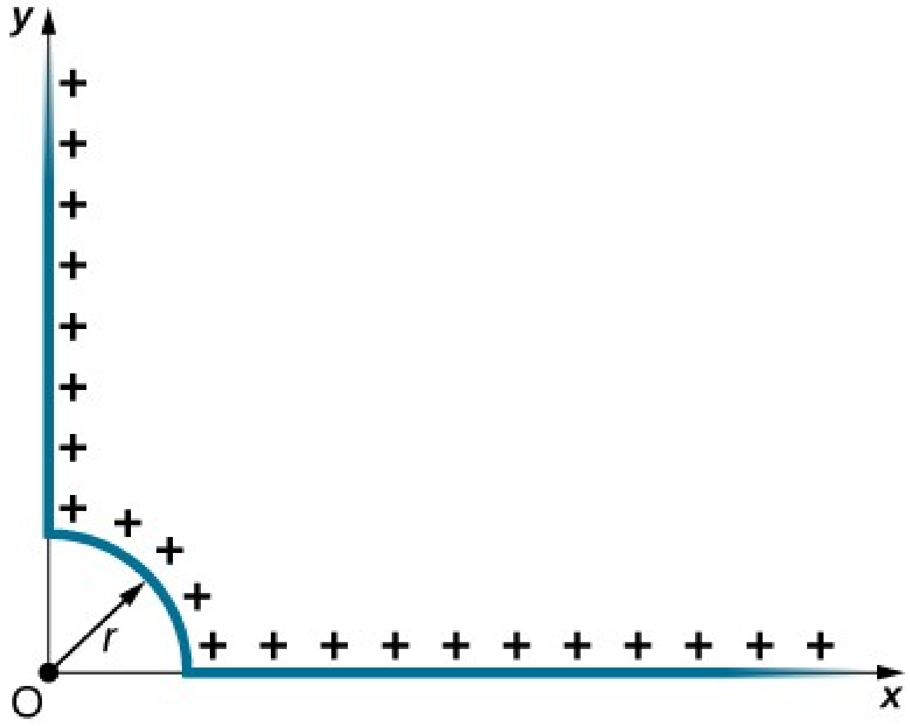
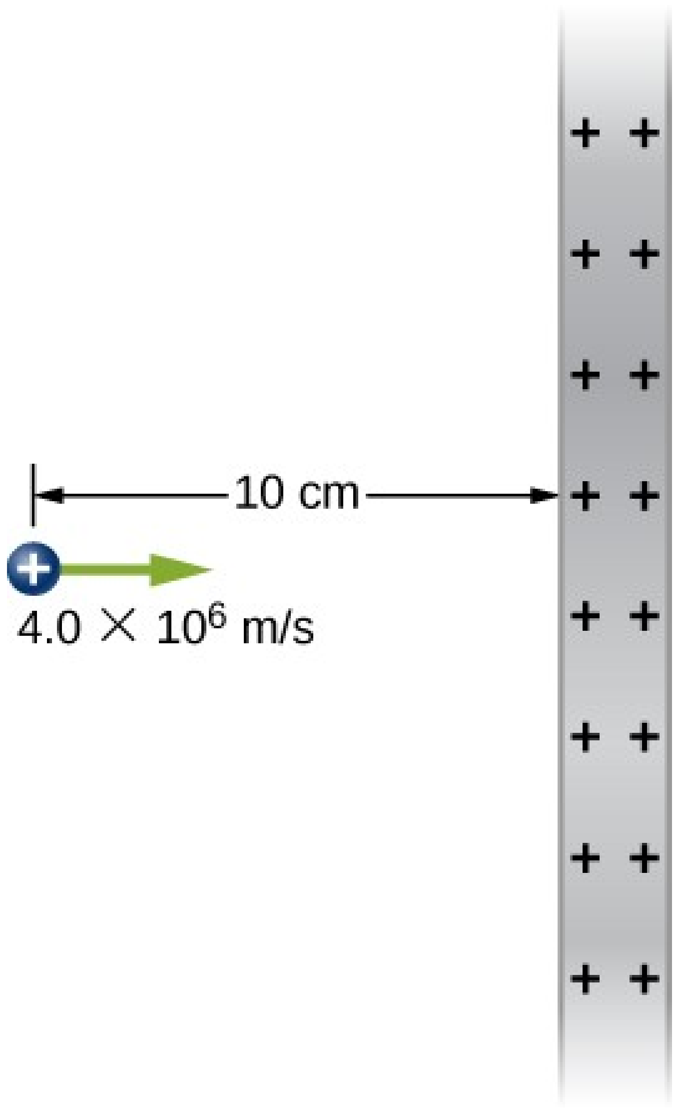


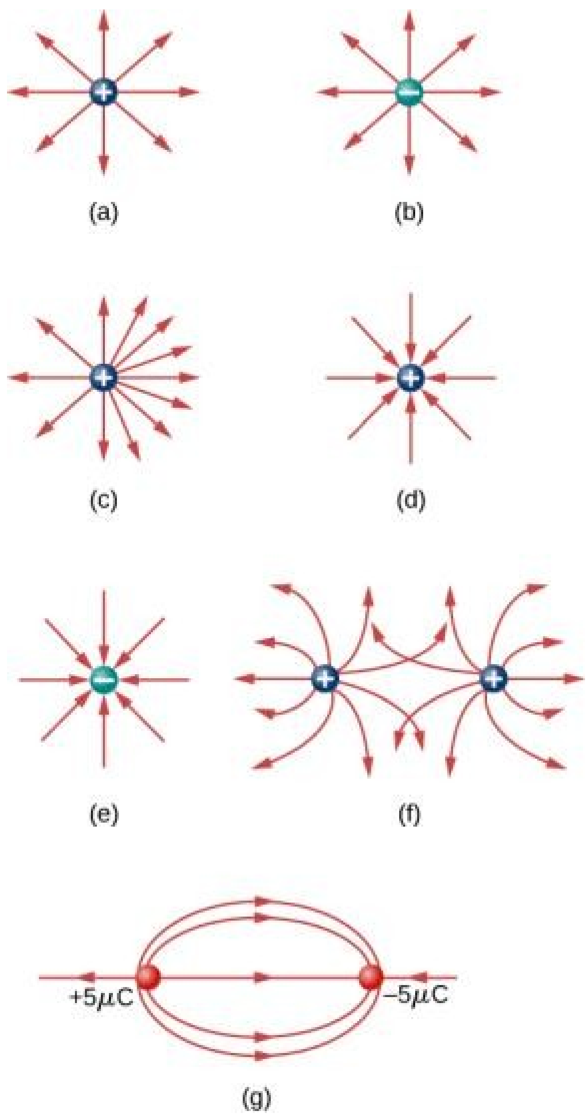
EXERCISE 97



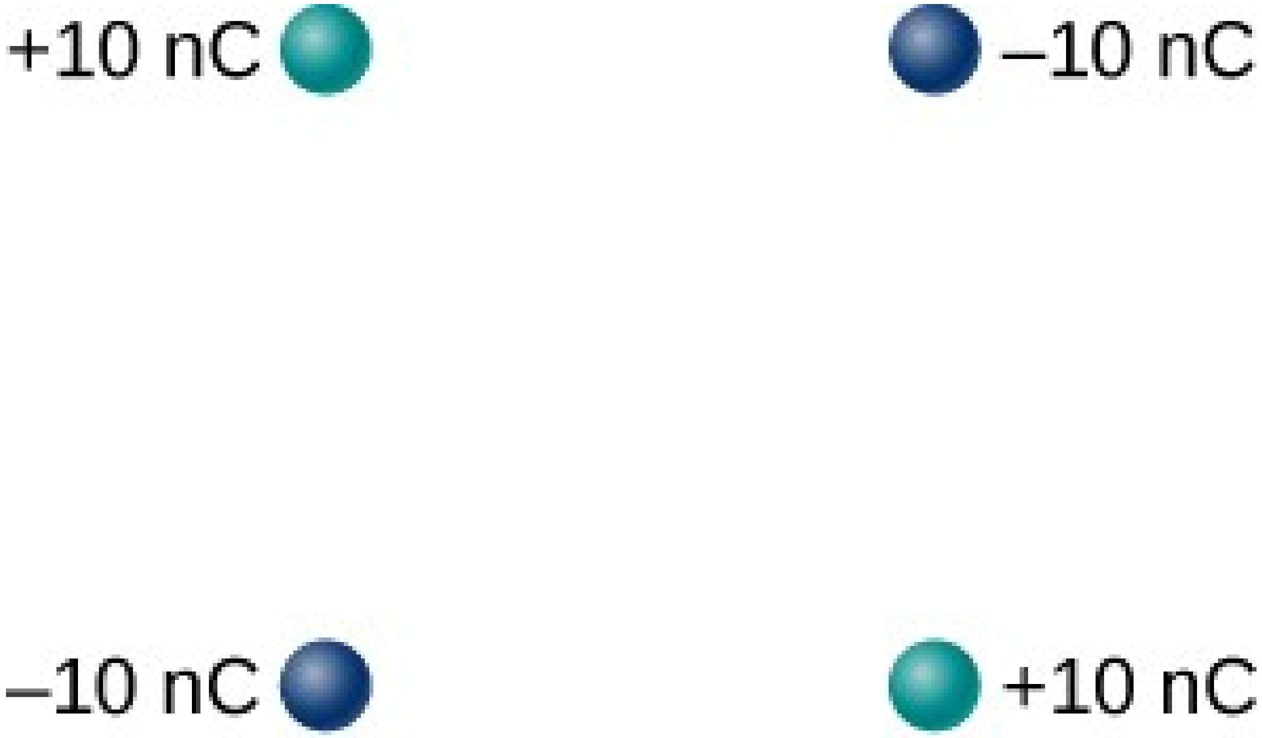
EXERCISE 98



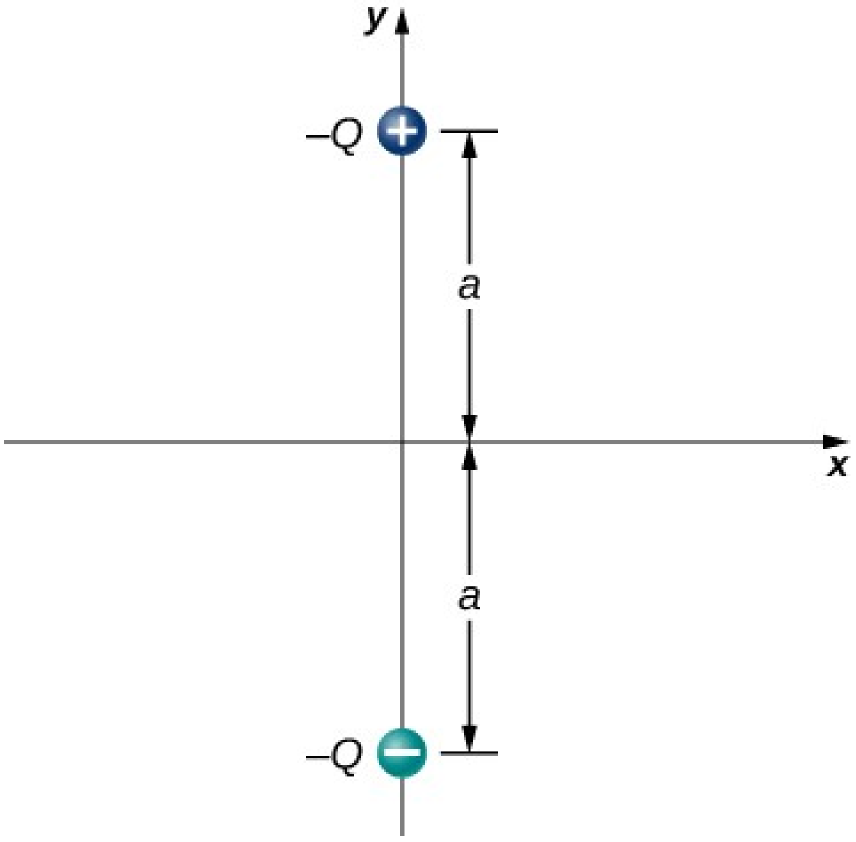
EXERCISE 100



EXERCISE 103



EXERCISE 105



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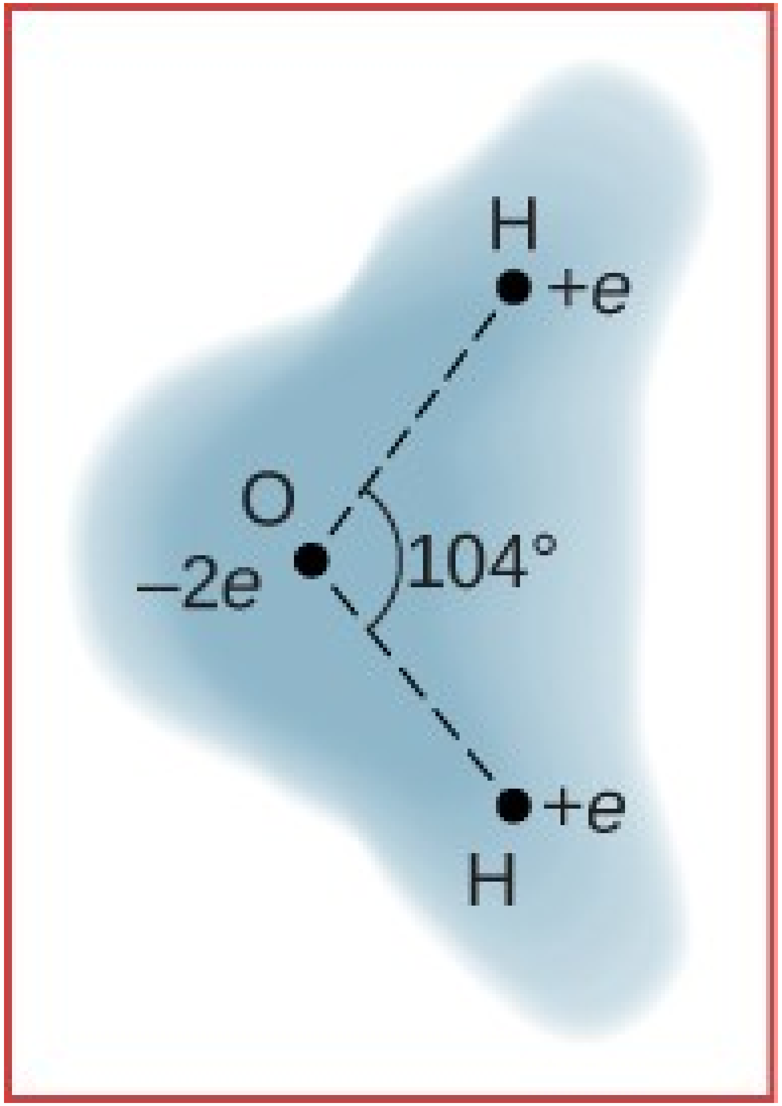

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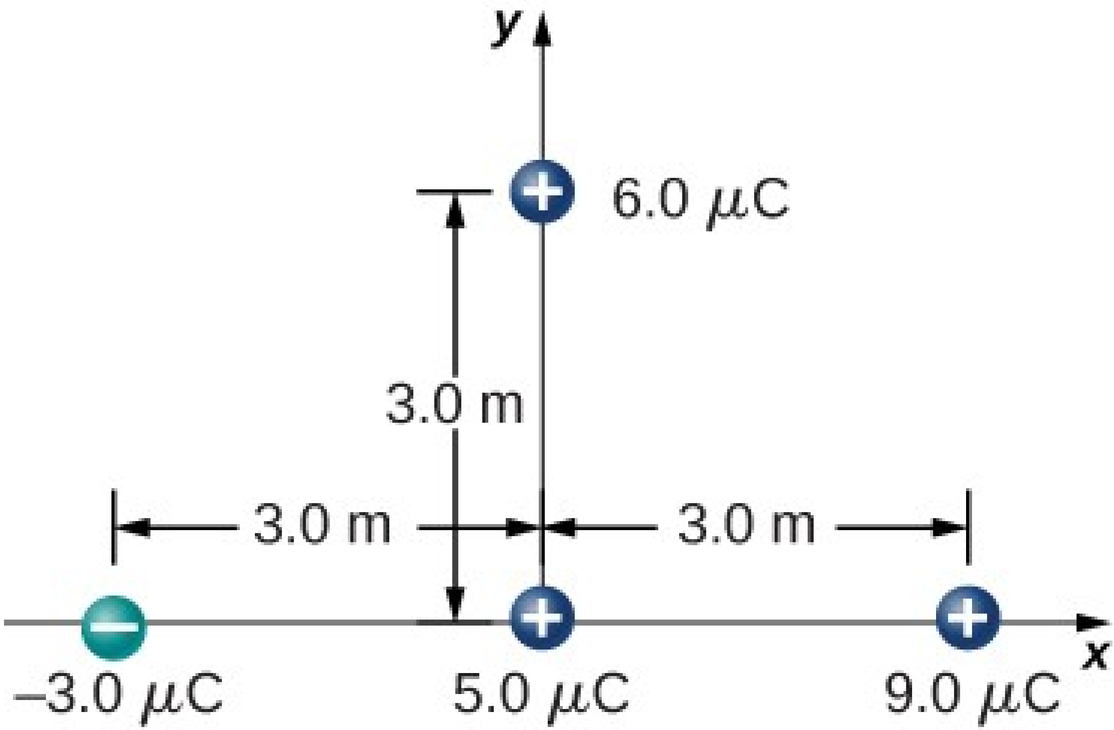
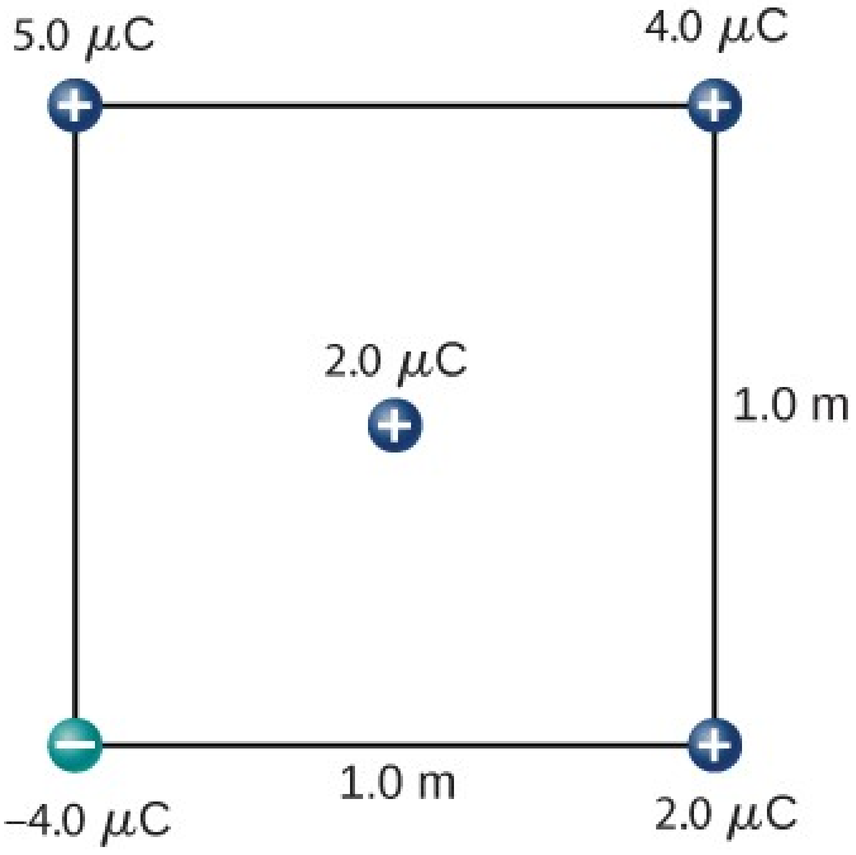


EXERCISE 110



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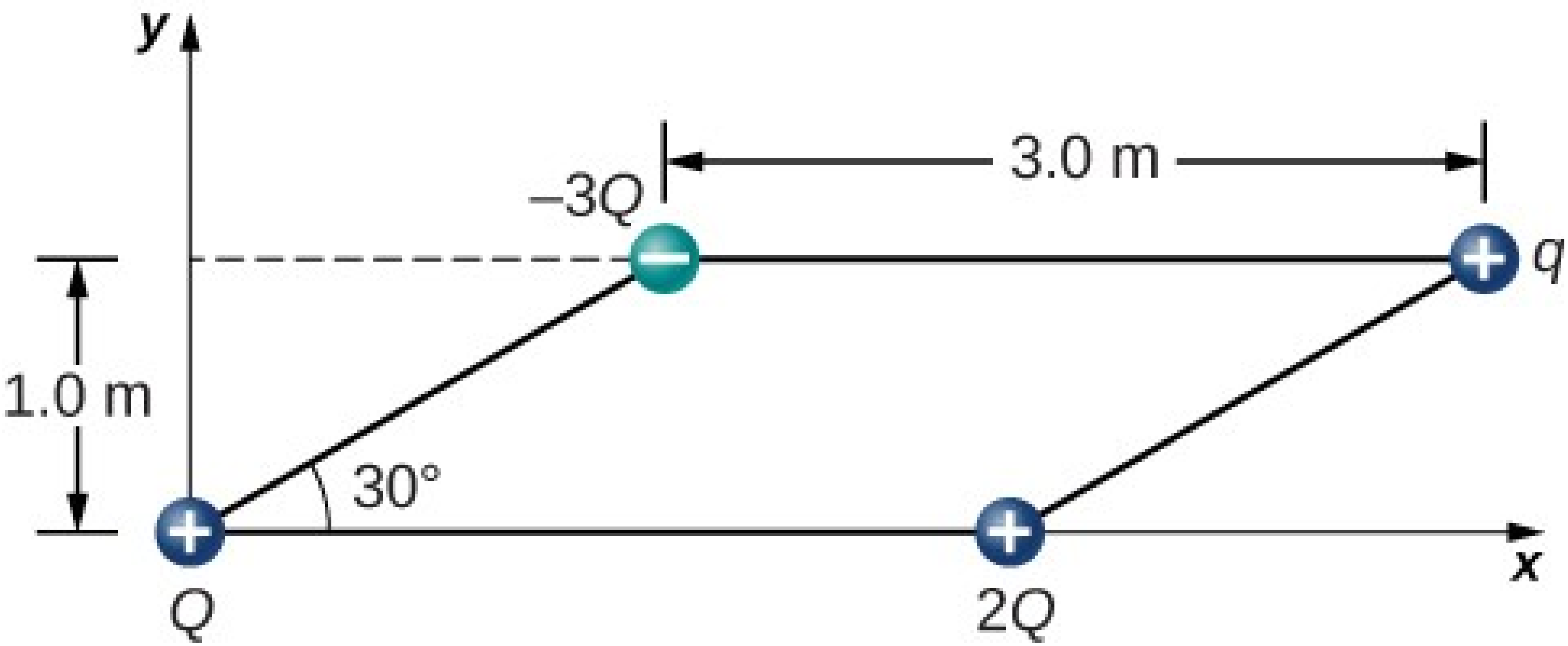
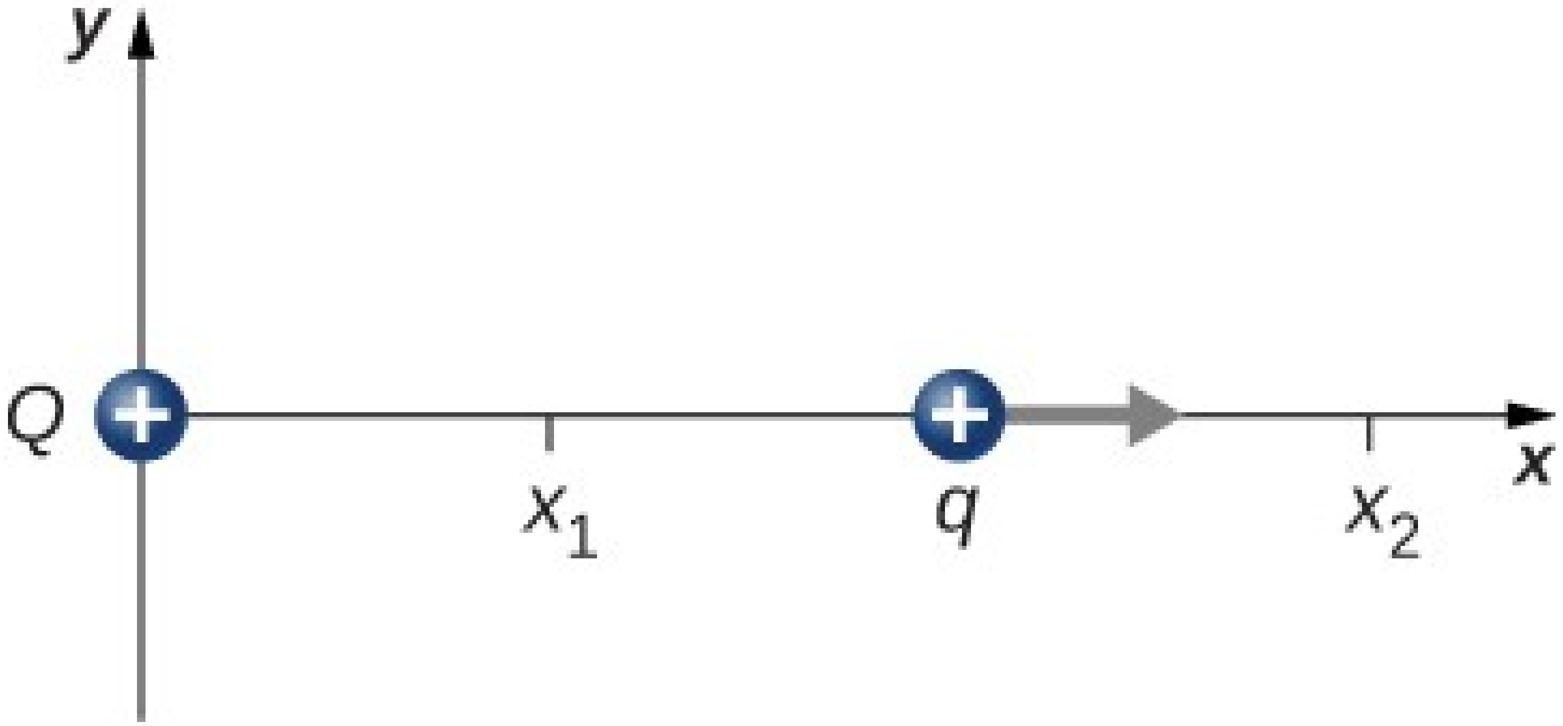
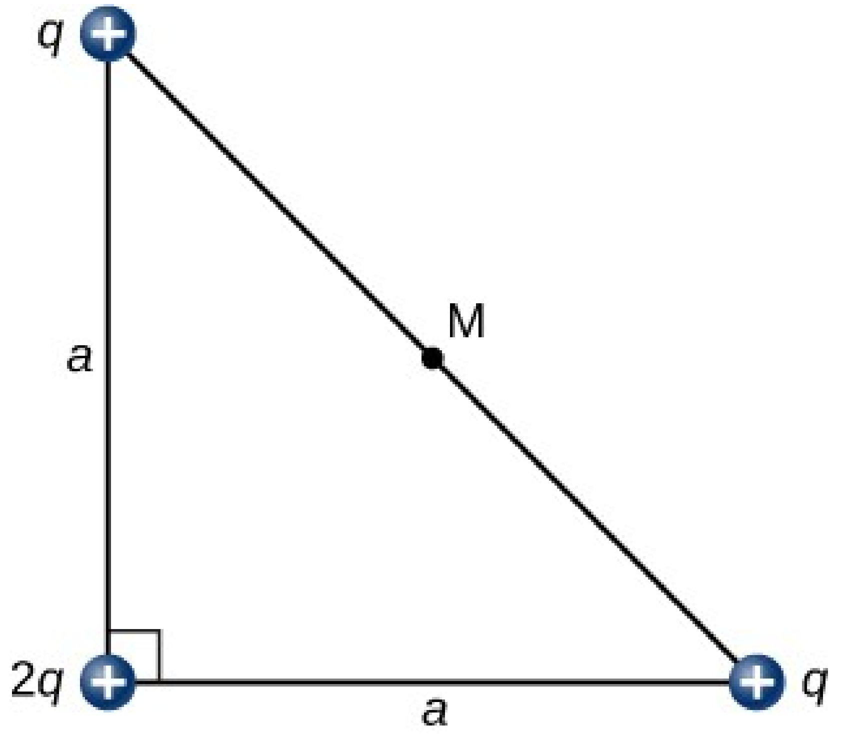


EXERCISE 112

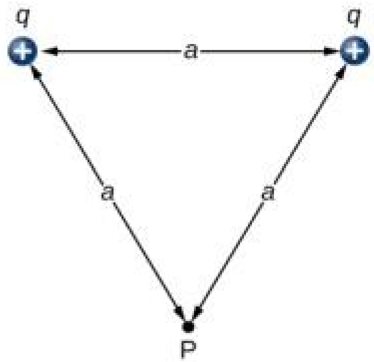


EXERCISE 114

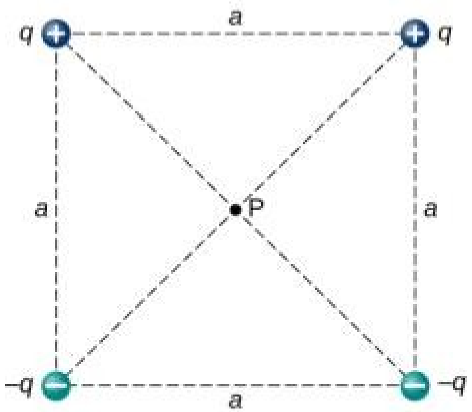


EXERCISE 115

(a)

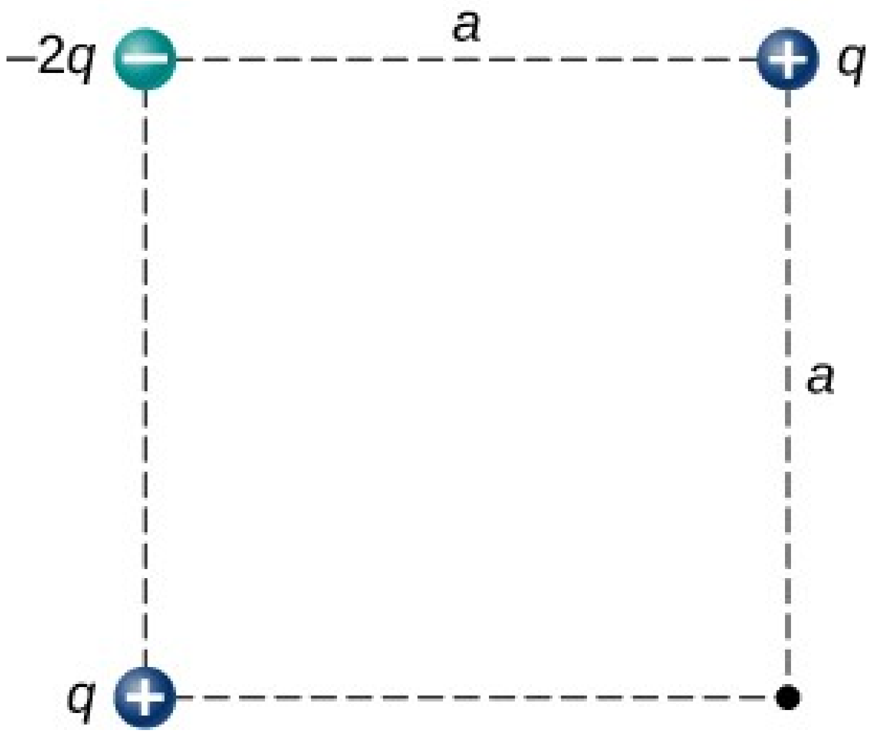


(b)

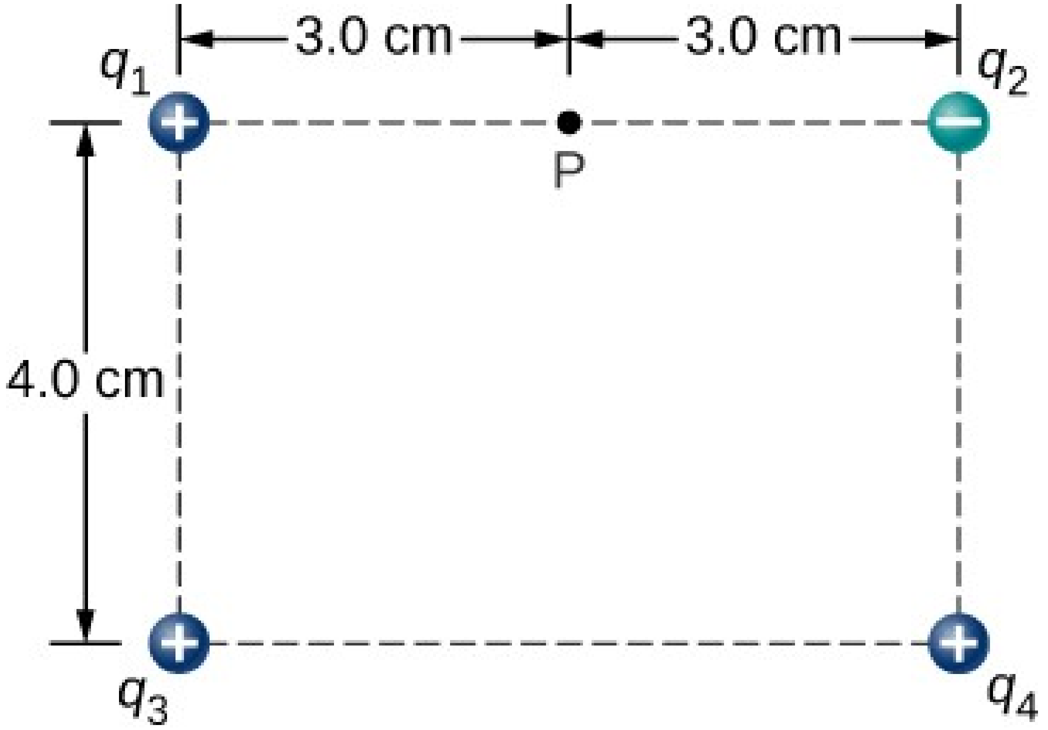


(c)

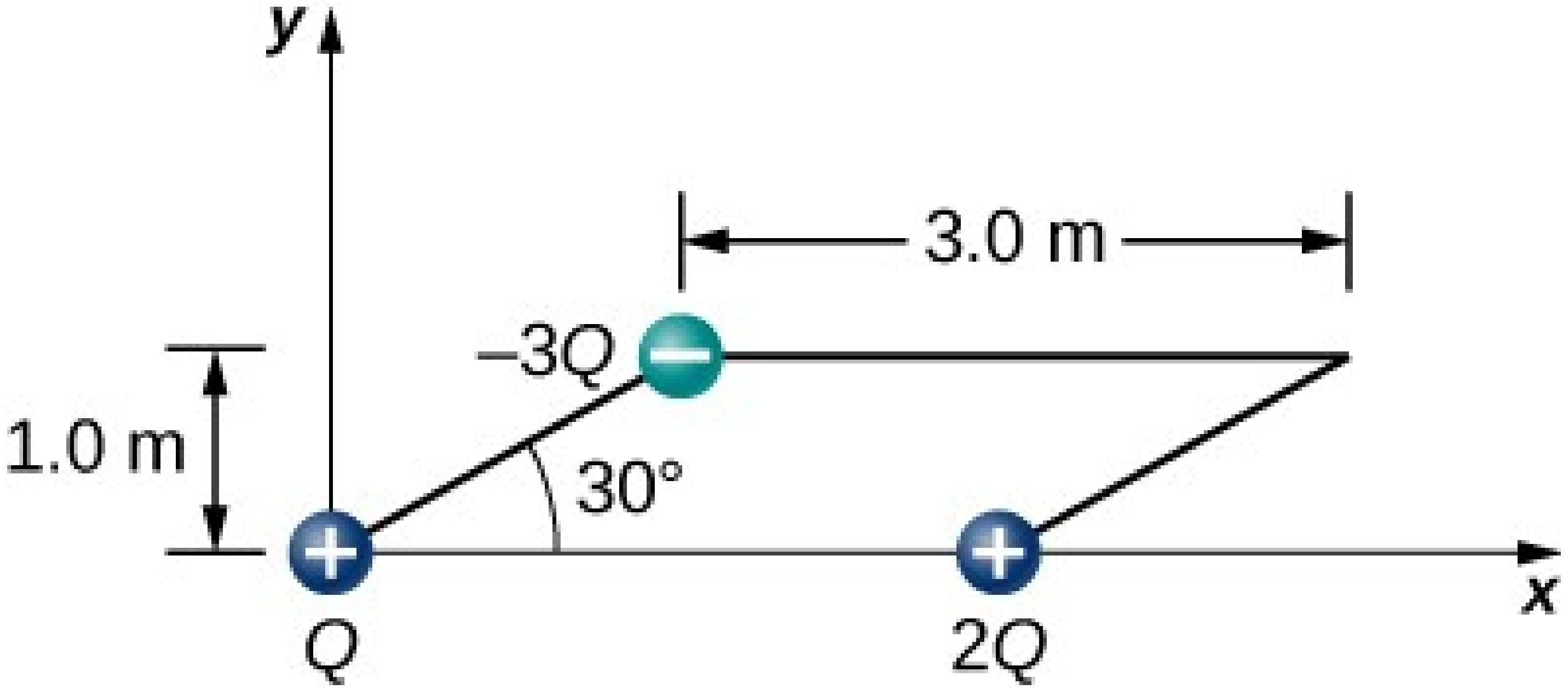
EXERCISE 116



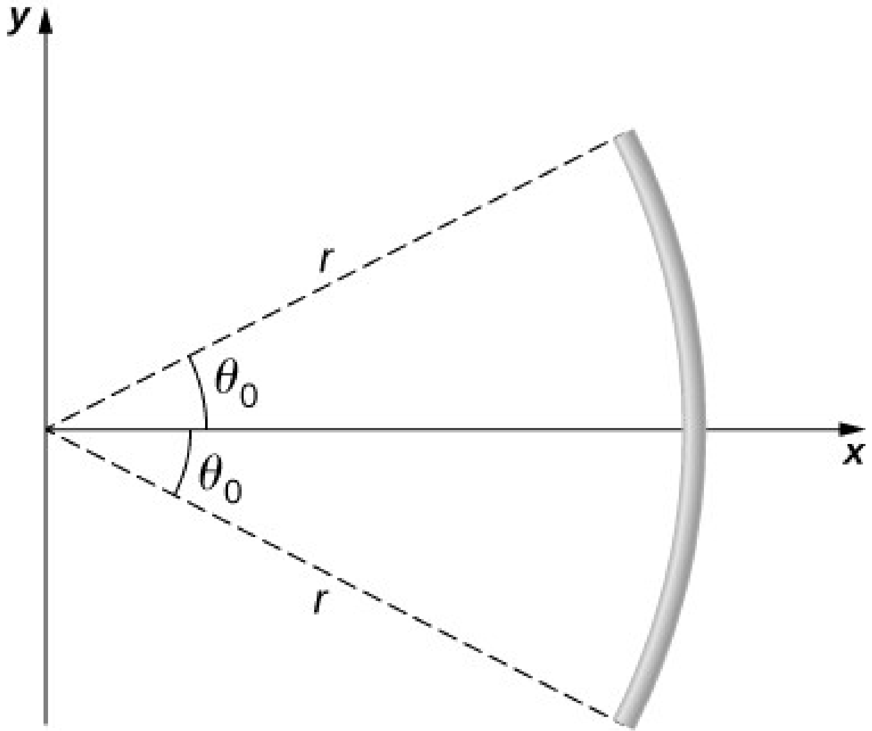
EXERCISE 117



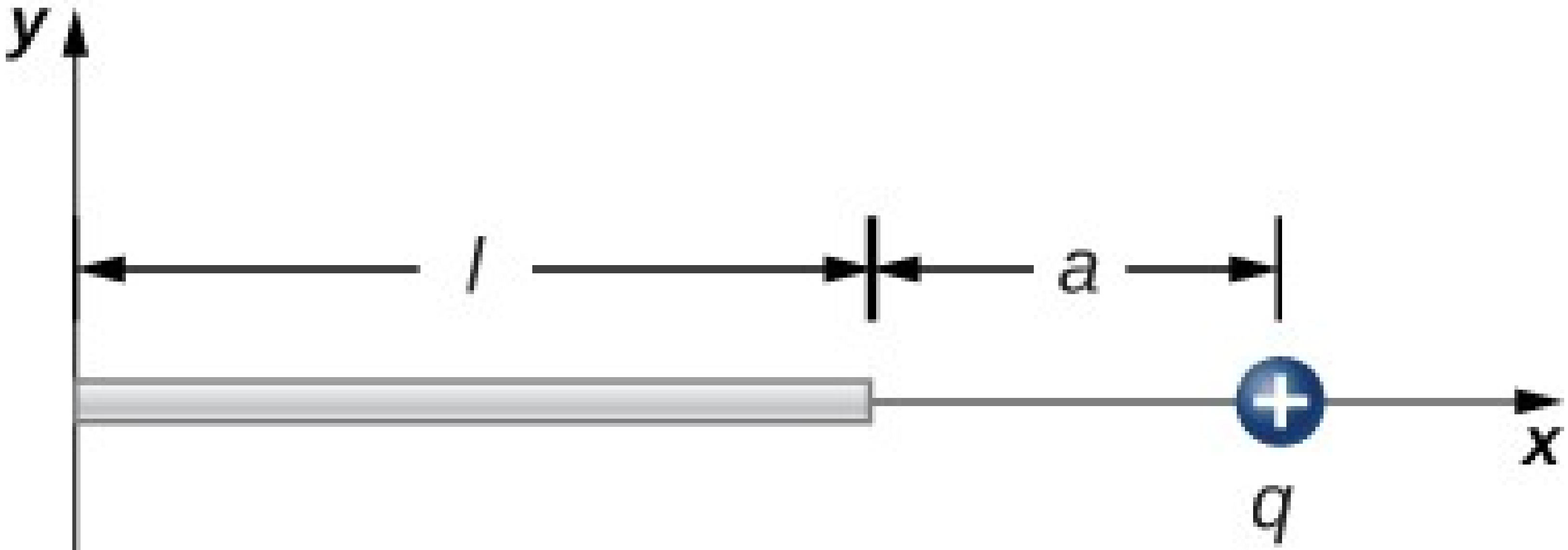
EXERCISE 118



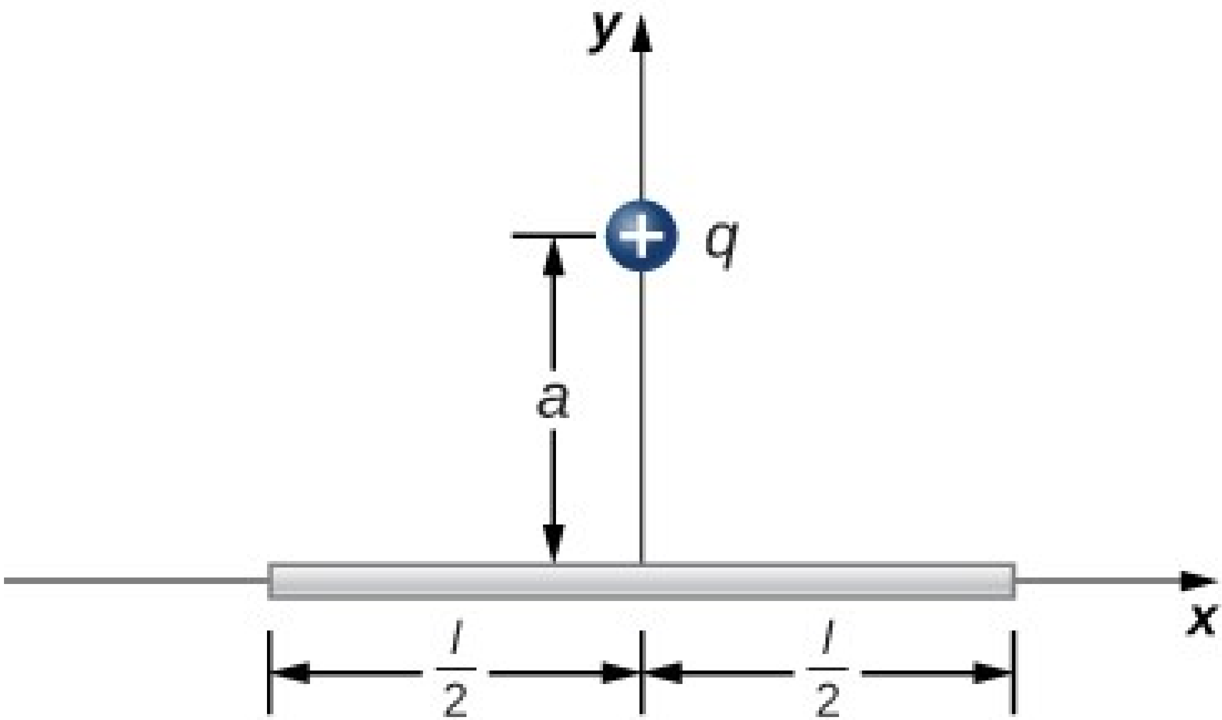
EXERCISE 122



EXERCISE 124



EXERCISE 125



EXERCISE 126