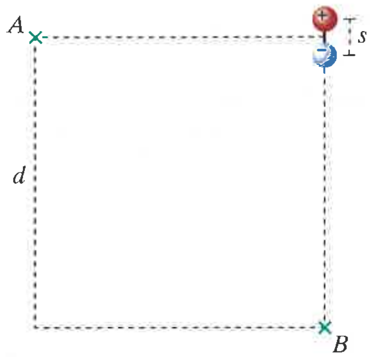

Figure 13.59

Q10 Which of these statements about a dipole are correct? Select all that are true. (1) At a distance d from a dipole, where $d \gg s$ (the separation between the charges), the magnitude of the electric field due to the dipole is proportional to $1/d^3$. (2) A dipole consists of two particles whose charges are equal in magnitude but opposite in sign. (3) The net electric field due to a dipole is zero, since the contribution of the negative charge cancels out the contribution of the positive charge. (4) At a distance d from a dipole, where $d \gg s$ (the separation between the charges), the magnitude of the electric field due to the dipole is proportional to $1/d^2$. (5) The electric field at any location in space, due to a dipole, is the vector sum of the electric field due to the positive charge and the electric field due to the negative charge.

Q11 If we triple the distance d, by what factor is the force on the point charge due to the dipole in Figure 13.60 reduced? (Note that the factor is smaller than one if the force is reduced and larger than one if the force is increased.)

Q12 If the charge of the point charge in Figure 13.60 were $-9Q$ (instead of Q): **(a)** By what factor would the magnitude of the force on the point charge due to the dipole change? Express your answer as the ratio (magnitude of new force / magnitude of Fv). **(b)** Would the direction of the force change?

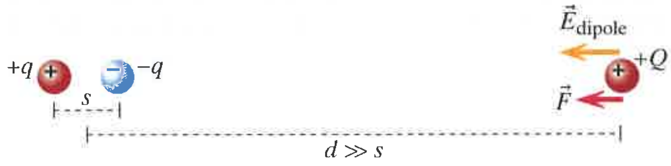

Figure 13.60

Q13 The distance between the dipole and the point charge in Figure 13.60 is d. If the distance between them were changed to $0.5d$, by what factor would the force on the point charge due to the dipole change? Express your answer as the ratio (magnitude of new force / magnitude of Fv).

Q14 Draw a diagram like the one in Figure 13.61.

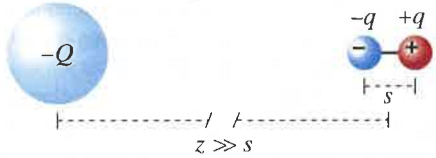

Figure 13.61

On your diagram, draw vectors showing: **(a)** the electric field of the dipole at the location of the negatively charged ball, **(b)** the net force on the ball due to the dipole, **(c)** the electric field of the ball at the center of the dipole, **(d)** the net force on the dipole due to the ball.

Q15 If the distance between the ball and the dipole in Figure 13.61 were doubled, what change would there be in the force on the ball due to the dipole?

PROBLEMS

Section 13.3

•P16 An electron in a region in which there is an electric field experiences a force of magnitude 3.8×10^{-16} N. What is the magnitude of the electric field at the location of the electron?

•P17 The electric field at a particular location is measured to be $\langle 0, -280, 0 \rangle$ N/C. What force would a positron experience if placed at this particular location?

•P18 An electron in a region in which there is an electric field experiences a force of magnitude 3.7×10^{-16} N. What is the magnitude of the electric field at the location of the electron?

•P19 If the particle in Figure 13.62 is a proton, and the electric field $\vec{E}_1$ has the value $\langle 2 \times 10^4, 2 \times 10^4, 0 \rangle$ N/C, what is the force $\vec{F}_2$ on the proton?

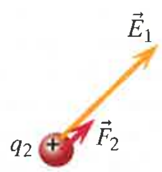

Figure 13.62

•P20 An electron in a region in which there is an electric field experiences a force of $\langle 8.0 \times 10^{-17}, -3.2 \times 10^{-16}, -4.8 \times 10^{-16} \rangle$ N. What is the electric field at the location of the electron?

••P21 In the region shown in Figure 13.63 there is an electric field due to a point charge located at the center of the dashed circle. The arrows indicate the magnitude and direction of the electric field at the locations shown.

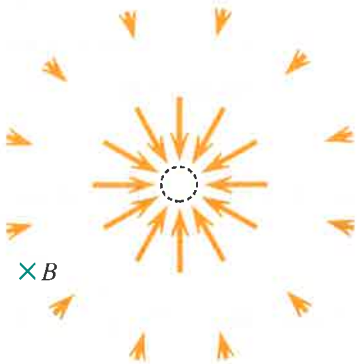

Figure 13.63

(a) What is the sign of the source charge? **(b)** Now a particle whose charge is -7×10^{-9} C is placed at location B. What is the direction of the electric force on the -7×10^{-9} C charge? **(c)** The electric field at location B has the value $\langle 2000, 2000, 0 \rangle$ N/C. What is the unit vector in the direction of $\vec{E}$ at this location? **(d)** What is the electric force on the -7×10^{-9} C charge? **(e)** What is the unit vector in the direction of this electric force?

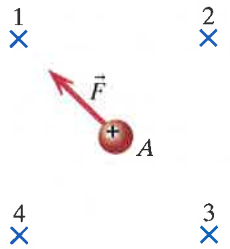

Figure 13.64

••P22 In the region shown in Figure 13.64 there is an electric field due to charged objects not shown in the diagram. A tiny glass ball with a charge of 5×10^{-9} C placed at location A experiences a force of $\langle 4 \times 10^{-5}, -4 \times 10^{5}, 0 \rangle$ N, as shown in the figure. **(a)** Which arrow in Figure 13.65 best indicates the direction of the electric field at location A? **(b)** What is the electric field at location A? **(c)** What is the magnitude of this electric field? **(d)** Now the glass ball is moved very far away. A tiny plastic ball with charge -6×10^{-9} C is placed at location A. Which arrow in Figure 13.65 best indicates the direction of the electric force on the negatively charged plastic ball? **(e)** What is the force on the negative plastic ball? **(f)** You discover that the source of the electric field at location A is a negatively charged particle. Which of the numbered locations in Figure 13.64 shows the location of this negatively charged particle, relative to location A?

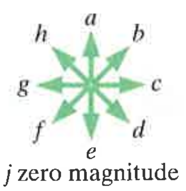

Figure 13.65

••P23 An electron is observed to accelerate in the $+z$ direction with an acceleration of 1.6×10^{16} m/s^2. Explain how to use the definition of electric field to determine the electric field at this location, and give the direction and magnitude of the field.

••P24 An object falling in a vacuum near a planet has a charge of -4×10^{-8} C and a mass of 0.3 kg. In this region of space there is an electric field $\langle 2 \times 10^{7}, 0, 0 \rangle$ N/C and a gravitational field $\langle 0, 5, 0 \rangle$ N/kg. What is the net force acting on the object?

••P25 A proton is observed to have an instantaneous acceleration of 9×10^{11} m/s^2. What is the magnitude of the electric field at the proton's location?

Section 13.4

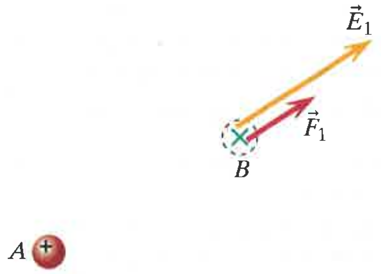

Figure 13.66

•P26 In Figure 13.66 a proton at location A makes an electric field $\vec{E}_1$ at location B. A different proton, placed at location B, experiences a force $\vec{F}_1$.

Now the proton at B is removed and replaced by a lithium nucleus, containing three protons and four neutrons. **(a)** Now what is the value of the electric field at location B due to the proton? **(b)** What is the force on the lithium nucleus? **(c)** The lithium nucleus is removed, and an electron is placed at location B. Now what is the value of the electric field at location B due to the proton? **(d)** What is the magnitude of the force on the electron? **(e)** Which arrow in Figure 13.65 best indicates the direction of the force on the electron due to the electric field?

•P27 You want to calculate the electric field at location $\langle 0.5, -0.1, -0.5 \rangle$ m, due to a particle with charge +9 nC located at $\langle -0.6, -0.7, -0.2 \rangle$ m. **(a)** What is the source location? **(b)** What is the observation location? **(c)** What is the vector $\vec{r}$ that points from the source location to the observation location? **(d)** What is $|\vec{r}|$? **(e)** What is the vector $\hat{r}$? **(f)** What is the value of $\dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{|\vec{r}|^2}$? **(g)** Finally, what is the electric field, expressed as a vector?

•P28 A particle with charge +5 nC (a nanocoulomb is 1×10^{-9} C) is located at the origin. What is the electric field due to this particle at a location $\langle 0.4, 0, 0 \rangle$ m?

•P29 What is the electric field at a location $\langle -0.1, -0.1, 0 \rangle$ m, due to a particle with charge +4 nC located at the origin?

•P30 In a hydrogen atom in its ground state, the electron is on average a distance of about 0.5×10^{-10} m from the proton. What is the magnitude of the electric field due to the proton at this distance from the proton?

•P31 A sphere with radius 1 cm has a charge of 2×10^{-9} C spread out uniformly over its surface. What is the magnitude of the electric field due to the sphere at a location 4 cm from the center of the sphere?

•P32 A sphere with radius 2 cm is placed at a location near a point charge. The sphere has a charge of -9×10^{-10} C spread uniformly over its surface. The electric field due to the point charge has a magnitude of 470 N/C at the center of the sphere. What is the magnitude of the force on the sphere due to the point charge?

•P33 What are the magnitude and direction of the electric field $\vec{E}$ at location $\langle 20, 0, 0 \rangle$ cm if there is a negative point charge of 1 nC (1×10^{-9} C) at location $\langle 40, 0, 0 \rangle$ cm? Include units.

•P34 A sphere with radius 2 cm is placed at a location near a point charge. The sphere has a charge of -8×10^{-10} C spread uniformly over its surface. The electric field due to the point charge has a magnitude of 500 N/C at the center of the sphere. What is the magnitude of the force on the sphere due to the point charge?

••P35 An electron is located at $\langle 0.8, 0.7, -0.8 \rangle$ m. You need to find the electric field at location $\langle 0.5, 1, -0.5 \rangle$ m, due to the electron. **(a)** What is the source location? **(b)** What is the observation location? **(c)** What is the vector $\vec{r}$? **(d)** What is $|\vec{r}|$? **(e)** What is the vector $\hat{r}$? **(f)** What is the value of $\frac{1}{4\pi\varepsilon_0}\frac{q}{|\vec{r}|^2}$? **(g)** Finally, what is the electric field at the observation location, expressed as a vector?

••P36 A charged particle located at the origin creates an electric field of $\langle -1.2 \times 10^3, 0, 0 \rangle$ N/C at a location $\langle 0.12, 0, 0 \rangle$ m. What is the particle's charge?

••P37 At a particular location in the room there is an electric field $= \langle 1000, 0, 0 \rangle$ N/C. Where would you place a single negative point particle of charge 1 μC in order to produce this electric field?

••P38 The electric field at a location C points north, and the magnitude is 1×10^6 N/C. Give numerical answers to the following questions: **(a)** Where relative to C should you place a single proton to produce this field? **(b)** Where relative to C should you place a single electron to produce this field? **(c)** Where should you place a proton and an electron, at equal distances from C, to produce this field?

••P39 You want to create an electric field $= \langle 0, 4104, 0 \rangle$ N/C at location $\langle 0, 0, 0 \rangle$. **(a)** Where would you place a proton to produce this field at the origin? **(b)** Instead of a proton, where would you place an electron to produce this field at the origin? (*Hint:* This problem will be much easier if you draw a diagram.)

••P40 A π^- ("pi-minus") particle, which has charge $-e$, is at location $\langle 7 \times 10^{-9}, -4 \times 10^{-9}, -5 \times 10^{-9} \rangle$ m. **(a)** What is the electric field at location $\langle -5 \times 10^{-9}, 5 \times 10^{-9}, 4 \times 10^{-9} \rangle$ m, due to the π^- particle? **(b)** At a particular moment an antiproton (same mass as the proton, charge $-e$) is at the observation location. At this moment what is the force on the antiproton, due to the π^-?

••P41 What is the electric field at a location $\vec{b} = \langle -0.1, -0.1, 0 \rangle$ m, due to a particle with charge +3 nC located at the origin?

••P42 At a particular location in the room there is an electric field $\vec{E} = \langle 1000, 0, 0 \rangle$ N/C. Figure out where to place a single positive point particle, and how much charge it should have, in order to produce this electric field (there are many possible answers!). Do the same for a single negatively charged point particle. Be sure to draw diagrams to explain the geometry of the situation.

••P43 Where must an electron be to create an electric field of $\langle 0, 160, 0 \rangle$ N/C at a location in space? Calculate its displacement from the observation location and show its location on a diagram.

••P44 The electric field at a location C points west, and the magnitude is 2×10^6 N/C. Give numerical answers to the following questions: **(a)** Where relative to C should you place a single proton to produce this field? **(b)** Where relative to C should you place a single electron to produce this field? **(c)** Where should you place a proton and an electron, at equal distances from C, to produce this field?

••P45 A lithium nucleus consisting of three protons and four neutrons accelerates to the right due to electric forces, and the initial magnitude of the acceleration is 3×10^{13} m/s/s. **(a)** What is the direction of the electric field that acts on the lithium nucleus? **(b)** What is the magnitude of the electric field that acts on the lithium nucleus? Be quantitative (that is, give a number). **(c)** If this acceleration is due solely to a single helium nucleus (two protons and two neutrons), where is the helium nucleus initially located? Be quantitative (that is, give a number).

Section 13.5

••P46 (a) On a clear and carefully drawn diagram, place a helium nucleus (consisting of two protons and two neutrons) and a proton in such a way that the electric field due to these charges is zero at a location marked ×, a distance 1×10^{-10} m from the helium nucleus. Explain briefly but carefully, and use diagrams to help in the explanation. Be quantitative about the relative distances. **(b)** On a clear and carefully drawn diagram, place a helium nucleus and an electron in such a way that the electric field due to these charges is zero at a location marked ×. Explain briefly but carefully, and use diagrams to help in the explanation. Be quantitative about the relative distances.

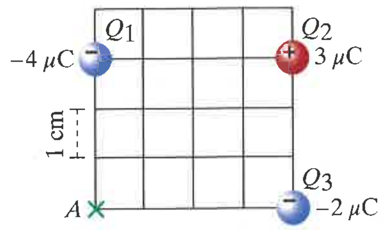

Figure 13.67

••P47 At a particular moment, three charged particles are located as shown in Figure 13.67. $Q_1 = -4\,\mu$C, $Q_2 = +3\,\mu$C, and $Q_3 = -2\,\mu$C. Your answers to the following questions should be vectors. (Recall that $1\,\mu\text{C} = 1 \times 10^{-6}$ C.) **(a)** Find the electric field at the location of Q_3, due to Q_1. **(b)** Find the electric field at the location of Q_3, due to Q_2. **(c)** Find the net electric field at the location of Q_3. **(d)** Find the net force on Q_3. **(e)** Find the electric field at location A due to Q_1. **(f)** Find the electric field at location A due to Q_2. **(g)** Find the electric field at location A due to Q_3. **(h)** What is the net electric field at location A? **(i)** If a particle with charge −3 nC were placed at location A, what would be the force on this particle?

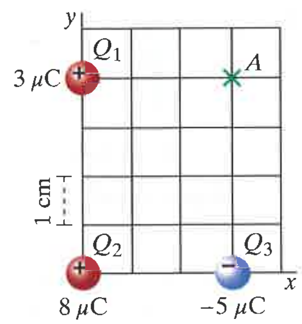

Figure 13.68

••P48 At a particular moment, one negative and two positive charges are located as shown in Figure 13.68. $Q_1 = +3\,\mu$C, $Q_2 = +8\,\mu$C, and $Q_3 = -5\,\mu$C. Your answers to each part of this problem should be vectors. (Recall that $1\,\mu\text{C} = 1 \times 10^{-6}$ C.) **(a)** Find the electric field at the location of Q_1, due to Q_2 and Q_3. **(b)** Use the electric field you calculated in part (a) to find the force on Q_1. **(c)** Find the electric field at location A, due to all three charges. **(d)** An alpha particle (He^{2+}, containing two protons and two neutrons) is released from rest at location A.

Use your answer from the previous part to determine the initial acceleration of the alpha particle.

••P49 An Fe^{3+} ion is located 400 nm (400×10^{-9} m, about 4000 atomic diameters) from a Cl^- ion, as shown in Figure 13.69 (ions not shown to scale).

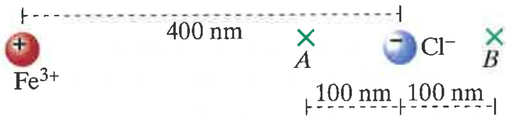

Figure 13.69

(a) Determine the magnitude and direction of the electric field $\vec{E}_A$ at location A, 100 nm to the left of the Cl^- ion. **(b)** Determine the magnitude and direction of the electric field $\vec{E}_B$ at location B, 100 nm to the right of the Cl^- ion. **(c)** If an electron is placed at location A, what are the magnitude and direction of the force on the electron?

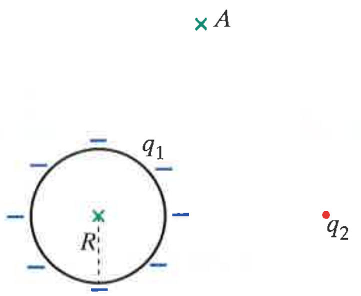

Figure 13.70

••P50 A hollow ball with radius $R = 2$ cm has a charge of $q_1 = -3$ nC spread uniformly over its surface, as shown in Figure 13.70. The center of the ball is at $\langle -3,0,0 \rangle$ cm. A point charge of $q_2 = 5$ nC is located at $\langle 4,0,0 \rangle$ cm. **(a)** What is the net electric field at location A, when $\vec{r}_A = \langle 0,6,0 \rangle$ cm? **(b)** Draw an arrow representing the net electric field at that location. Make sure that the arrow you drew makes sense.

••P51 Three nested hollow spheres have the same center. The innermost sphere has a radius of 2 cm and carries a uniformly distributed charge of 6 nC (1 nC = 1×10^{-9} C). The middle sphere has a radius of 5 cm and carries a uniformly distributed charge of -4 nC. The outermost sphere has a radius of 10 cm and carries a uniformly distributed charge of 8 nC. **(a)** What is the magnitude of the electric field at a distance of 1 cm from the center? **(b)** What is the magnitude of the electric field at a distance of 4 cm from the center? **(c)** What is the magnitude of the electric field at a distance of 9 cm from the center?

Section 13.6

•P52 A dipole is located at the origin and is composed of charged particles with charge $+e$ and $-e$, separated by a distance 6×10^{-10} m along the x axis. The charge $+e$ is on the $+x$ axis. Calculate the electric field due to this dipole at a location $\langle 0, -5 \times 10^{-8}, 0 \rangle$ m.

•P53 A dipole is located at the origin and is composed of charged particles with charge $+e$ and $-e$, separated by a distance 2×10^{-10} m along the x axis. Calculate the magnitude of the electric field due to this dipole at a location $\langle 0, 3 \times 10^{-8}, 0 \rangle$ m.

•P54 The dipole moment of the HF (hydrogen fluoride) molecule has been measured to be 6.3×10^{-30} C·m. If we model the dipole as having charges of $+e$ and $-e$ separated by a distance s, what is s? Is this plausible?

••P55 A dipole is located at the origin and is composed of charged particles with charge $+e$ and $-e$, separated by a distance 6×10^{-10} m along the y axis. The $+e$ charge is on the $-y$ axis. Calculate the force on a proton due to this dipole at a location $\langle 0, 4 \times 10^{-8}, 0 \rangle$ m.

••P56 A dipole is located at the origin and is composed of charged particles with charge $+2e$ and $-2e$, separated by a distance 2×10^{-10} m along the y axis. The $+2e$ charge is on the $+y$ axis. Calculate the force on a proton at a location $\langle 0, 0, 3 \times 10^{-8} \rangle$ m due to this dipole.

•P57 A dipole consists of two charges +6 nC and −6 nC, held apart by a rod of length 3 mm, as shown in Figure 13.71. **(a)** What is the magnitude of the electric field due to the dipole at location A, 5 cm from the center of the dipole? **(b)** What is the magnitude of the electric field due to the dipole at location B, 5 cm from the center of the dipole?

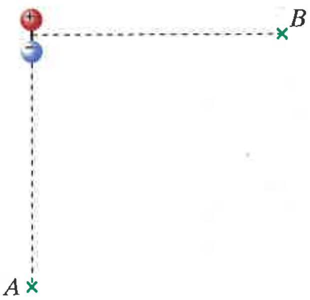

Figure 13.71

••P58 A dipole is centered at the origin and is composed of charged particles with charge $+2e$ and $-2e$, separated by a distance 7×10^{-10} m along the y axis. The $+2e$ charge is on the $-y$ axis, and the $-2e$ charge is on the $+y$ axis. **(a)** A proton is located at $\langle 0, 3 \times 10^{-8}, 0 \rangle$ m. What is the force on the proton due to the dipole? **(b)** An electron is located at $\langle -3 \times 10^{-8}, 0, 0 \rangle$ m. What is the force on the electron due to the dipole? (*Hint:* Make a diagram. One approach is to calculate magnitudes, and get directions from your diagram.)

••P59 Two dipoles are oriented as shown in Figure 13.72. Each dipole consists of two charges $+q$ and $-q$, held apart by a rod of length s, and the center of each dipole is a distance d from location A. If $q = 2$ nC, $s = 1$ mm, and $d = 8$ cm, what is the electric field at location A? (*Hint:* Draw a diagram and show the direction of each dipole's contribution to the electric field on the diagram.)

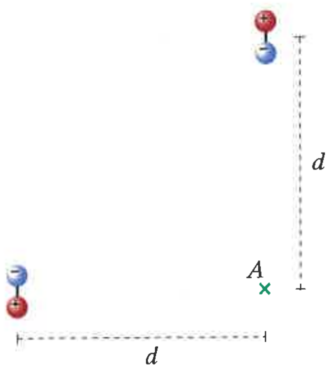

Figure 13.72

••P60 Two dipoles are oriented as shown in Figure 13.73. Each dipole consists of charges held apart by a short rod (not shown to scale). What is the electric field at location A? Start by drawing a diagram that shows the direction of each dipole's contribution to the electric field at location A.

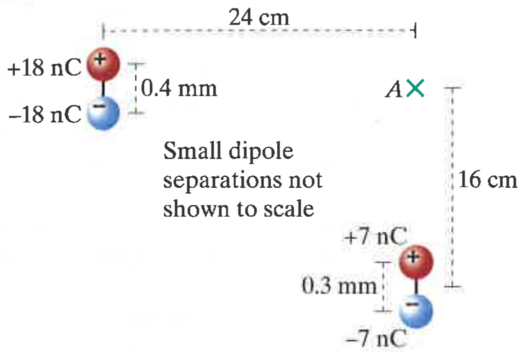

Figure 13.73

••P61 A charge of +1 nC (1×10^{-9} C) and a dipole with charges $+q$ and $-q$ separated by 0.3 mm contribute a net field at location A that is zero, as shown in Figure 13.74.

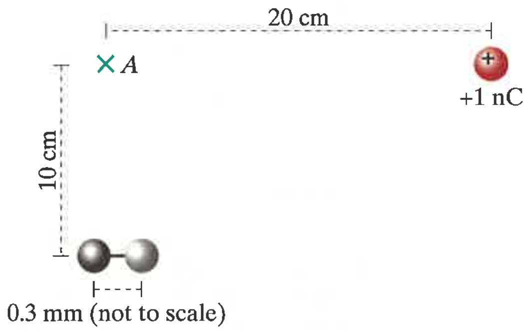

Figure 13.74

(a) Which end of the dipole is positively charged? **(b)** How large is the charge q?

•••P62 A water molecule is asymmetrical, with one end positively charged and the other negatively charged. It has a dipole moment whose magnitude is measured to be 6.2×10^{-30} C·m. If the dipole moment is oriented perpendicular to an electric field whose magnitude is 4×10^{5} N/m, what is the magnitude of the torque on the water molecule? Also, show that the vector torque is equal to $\vec{p}\times\vec{E}$, where $\vec{p}$ is the dipole moment.

•••P63 Two identical permanent dipoles, each consisting of charges $+q$ and $-q$ separated by a distance s, are aligned along the x axis, a distance r from each other, where $r \gg s$ (Figure 13.75). Show all of the steps in your work, and briefly explain each step. **(a)** Draw a diagram showing all individual forces acting on each particle, and draw heavier vectors showing the net force on each dipole. **(b)** Show that the magnitude of the net force exerted on one dipole by the other dipole is this:

$$F \approx \frac{1}{4\pi\varepsilon_0}\frac{6q^2s^2}{r^4}$$

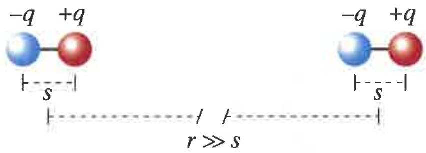

Figure 13.75

Section 13.8

••P64 You make repeated measurements of the electric field $\vec{E}$ due to a distant charge, and you find it is constant in magnitude and direction. At time $t = 0$ your partner moves the charge. The electric field doesn't change for a while, but at time $t = 45$ ns you observe a sudden change. How far away was the charge originally?

COMPUTATIONAL PROBLEMS

If you did not learn how to create 3D computational models using VPython in your previous physics course, you should work through the introductory materials from Chapter 1 that are available at `www.wiley.com/college/chabay`.

To install the free 3D programming environment VPython, go to vpython.org and (carefully) follow the instructions for your operating system (Windows, MacOS, or Linux). Note the instructions given there on how to zoom and rotate the "camera" when viewing a 3D scene you have created.

To use an `arrow` object to visualize an electric field, it is usually necessary to scale the length of the arrow in order to make it fit on the screen with the objects that produce or experience that field. Watch VPython Instructional Video 5: Scalefactors, at `vpython.org/video05.html` to learn how to do this. In general it may be helpful to print the magnitude of an electric field using `print(mag(E))` in order to decide on an appropriate scale factor.

More detailed and extended versions of some of these computational modeling problems may be found in the lab activities included in the *Matter & Interactions, 4th Edition*, resources for instructors.

•P65 In Section 13.9 there is a program to calculate the electric field of a single point charge at multiple observation locations. **(a)** Study this program and make sure you can explain every line of code. **(b)** Modify the program so that the magnitude of the electric field at each observation location is the same. (There is more than one way to do this.) **(c)** Add an additional circle of observation locations in the yz plane, centered on the point charge.

••P66 A particle with a charge of +3 nC is located at ⟨−0.04, 0, 0⟩ m. **(a)** Calculate the electric field at location ⟨−0.04, 0, 0.05⟩ m due to this particle, and create an arrow to visualize the field at the observation location. Try a scale factor of about 2×10^{-6}. **(b)** Add an arrow representing the electric field at location ⟨−0.04, 0, −0.05⟩ due to this particle. **(c)** Add two more arrows, each representing the electric field at a location 0.05 m from the particle in the $\pm y$ direction. **(d)** Add two more arrows, each representing the electric field at a location 0.05 m from the particle in the $\pm x$ direction.

••P67 Three charged spheres lie in the xz plane. Sphere a has a charge of +2 nC, and is located at $\langle -0.03, 0, 0.03\rangle$ m. Sphere b has a charge of +4 nC, and is located at $\langle 0.03, 0, 0.03\rangle$ m. Sphere c has a charge of −2 nC, and is located at $\langle 0, 0, -0.011\rangle$ m. Write a program to calculate and display (using an arrow) the electric field of these three charged spheres at location $\langle 0, 0.25, 0\rangle$ m.

••P68 The following code creates two objects representing a dipole oriented along the y axis. **(a)** Extend the program to calculate and display (using arrows) the electric field due to the dipole at 12 equally spaced observation locations located on a circle of radius 0.5 nm in the xy plane, centered on the dipole. **(b)** Add a second circle of arrows representing the electric field at observation locations in the yz plane.

```
from visual import *
scene.width = scene.height = 800
oofpez = 9e9
qe = 1.6e-19
sf = 5e-20
source_01 = sphere(pos=vector(0,0.1e-9,0),
              color=color.red,
              radius=0.5e-10)
q_01 = +qe
source_02 = sphere(pos=vector(0,-0.1e-9,0),
              color=color.blue,
              radius=0.5e-10)
q_02 = -qe
```

••P69 The following skeleton program creates objects representing a stationary source charge and a moving antiproton. **(a)** Complete the program so that the antiproton is affected by the net electric field at its current location. **(b)** Add two arrows, and use them to visualize the momentum of the antiproton, and the electric field at the location of the antiproton. These arrows should move with the antiproton.

```
from visual import *
scene.width = scene.height = 760
scene.range = 3e-8
oofpez = 9e9
qe = 1.6e-19
source = sphere(pos=vector(-0.5e-8,0,0),
             radius=5e-10,
             color=color.red)
source_q = qe
##antiproton
ap = sphere(pos=vector(0.5e-8,-1e-8,0),
             radius=5e-10,
             color=color.cyan,
             make_trail = True)
ap_q = -qe
ap_m = 1.7e-27
ap_p = ap_m * vector(0,5e3,0)
deltat = 1e-15
t=0

while t < 8e-12:
    rate(500)
    ## add your code here
    ap.pos = ap.pos + (ap_p/ap_m) * deltat
    t = t + deltat
```

•••P70 Start with the program you wrote in Problem P68 to calculate and display the electric field of a dipole. **(a)** Place a proton at location $\langle 0.3\times 10^{-9}, 0, 0\rangle$ m, and release it from rest. Compute and display the trajectory of the proton as it moves under the influence of the electric field of the dipole. You may wish to start with $\Delta t = 1\times 10^{-17}$ s. **(b)** Simultaneously compute and plot a graph showing the potential energy U, kinetic energy K, and $(K+U)$ vs. time for the entire system (dipole + proton). Your graph will be more useful as a computational diagnostic tool if you do not include the potential energy associated with the interaction of the pair of charges making up the dipole, which does not change. **(c)** Explain the shape of the K and U graphs.

•••P71 Write a computer program to calculate and plot a graph of the magnitude of the electric field of the dipole from Problem P68 at locations on the y axis as a function of distance from the center of the dipole. Vary y from 0.2 nm (0.2×10^{-9} m) to 0.5 nm from the center of the dipole. Do the calculation two different ways, and put both plots (in different colors) on the same axes: **(a)** Calculate the electric field exactly as the superposition of the fields due to the individual charges. **(b)** Calculate the electric field using the approximate equation for the dipole field derived in Section 13.6. **(c)** Comment on the validity of the approximate equation. How close to the dipole (compared to s, the dipole separation) do you have to get before the approximate equation no longer gives good results? What is your criterion for "good results"?

ANSWERS TO CHECKPOINTS

1 $\approx 1\times 10^{-10}$ m; protons and electrons
2 $\langle 0, -4.8\times 10^{-17}, 0\rangle$ N; $\langle 0,0,0\rangle$ N
3 $\langle 900, 0, 0\rangle$ N/C
4 2.8×10^{4} N/C
5 **(a)** 3.6×10^{4} N/C; **(b)** 7.2×10^{4} N/C
6 **(a)** 1/8; **(b)** three times bigger; **(c)** two times bigger, opposite direction
7 Its electric dipole moment would point horizontally, in the same direction as the applied electric field, with the + charge to the right.
8 3.2×10^{-19} C