room? What might happen if the personnel wore shoes with rubber soles?

5. (a) Would life be different if the electron were positively charged and the proton were negatively charged? (b) Does the choice of signs have any bearing on physical and chemical interactions? Explain your answers.

6. If a suspended object A is attracted to a charged object B, can we conclude that A is charged? Explain.

7. Explain how a positively charged object can be used to leave another metallic object with a net negative charge. Discuss the motion of charges during the process.

8. Consider point A in Figure CQ15.8 located an arbitrary distance from two point charges in otherwise empty space. (a) Is it possible for an electric field to exist at point A in empty space? (b) Does charge exist at this point? (c) Does a force exist at this point?

Figure CQ15.8

9. A student stands on a thick piece of insulating material, places her hand on top of a Van de Graaff generator, and then turns on the generator. Does she receive a shock?

10. In fair weather, there is an electric field at the surface of the Earth, pointing down into the ground. What is the sign of the electric charge on the ground in this situation?

11. A charged comb often attracts small bits of dry paper that then fly away when they touch the comb. Explain why that occurs.

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

13. There are great similarities between electric and gravitational fields. A room can be electrically shielded so that there are no electric fields in the room by surrounding it with a conductor. Can a room be gravitationally shielded? Explain.

14. A spherical surface surrounds a point charge q. Describe what happens to the total flux through the surface if (a) the charge is tripled, (b) the volume of the sphere is doubled, (c) the surface is changed to a cube, (d) the charge is moved to another location inside the surface, and (e) the charge is moved outside the surface.

15. If more electric field lines leave a Gaussian surface than enter it, what can you conclude about the net charge enclosed by that surface?

16. A student who grew up in a tropical country and is studying in the United States may have no experience with static electricity sparks and shocks until his or her first American winter. Explain.

■ PROBLEMS

15.3 Coulomb's Law

1. **Q|C** A 7.50-nC charge is located 1.80 m from a 4.20-nC charge. (a) Find the magnitude of the electrostatic force that one particle exerts on the other. (b) Is the force attractive or repulsive?

2. A charged particle A exerts a force of 2.62 N to the right on charged particle B when the particles are 13.7 mm apart. Particle B moves straight away from A to make the distance between them 17.7 mm. What vector force does particle B then exert on A?

3. **Q|C** Two metal balls A and B of negligible radius are floating at rest on Space Station Freedom between two metal bulkheads, connected by a taut nonconducting thread of length 2.00 m. Ball A carries charge q, and ball B carries charge $2q$. Each ball is 1.00 m away from

a bulkhead. (a) If the tension in the string is 2.50 N, what is the magnitude of q? (b) What happens to the system as time passes? Explain.

4. A small sphere of mass $m = 7.50$ g and charge $q_1 = 32.0$ nC is attached to the end of a string and hangs vertically as in Figure P15.4. A second charge of equal mass and charge $q_2 = -58.0$ nC is located below the first charge a distance $d = 2.00$ cm below the first charge as in Figure P15.4. (a) Find the tension in the string. (b) If the string can withstand a maximum tension of 0.180 N, what is the smallest value d can have before the string breaks?

Figure P15.4

5. The nucleus of ^{8}Be, which consists of 4 protons and 4 neutrons, is very unstable and spontaneously breaks into two alpha particles (helium nuclei, each consisting of 2 protons and 2 neutrons). (a) What is the force between the two alpha particles when they are 5.00×10^{-15} m apart, and (b) what is the initial magnitude of the acceleration of the alpha particles due to this force? Note that the mass of an alpha particle is 4.002 6 u.

6. **BIO** A molecule of DNA (deoxyribonucleic acid) is 2.17 μm long. The ends of the molecule become singly ionized: negative on one end, positive on the other. The helical molecule acts like a spring and compresses 1.00% upon becoming charged. Determine the effective spring constant of the molecule.

7. A small sphere of charge 0.800 μC hangs from the end of a spring as in Figure P15.7a. When another small sphere of charge -0.600 μC is held beneath the first sphere as in Figure P15.7b, the spring stretches by $d = 3.50$ cm from its original length and reaches a new equilibrium position with a separation between the charges of $r = 5.00$ cm. What is the force constant of the spring?
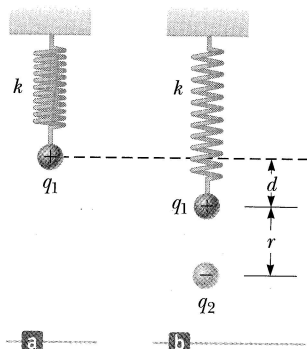
Figure P15.7

8. **S** Four point charges are at the corners of a square of side a as shown in Figure P15.8. Determine the magnitude and direction of the resultant electric force on q, with k_e, q, and a left in symbolic form.
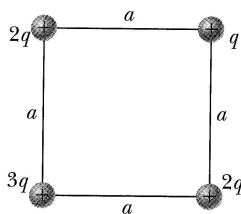
Figure P15.8

9. Two small identical conducting spheres are placed with their centers 0.30 m apart. One is given a charge of 12×10^{-9} C, the other a charge of -18×10^{-9} C. (a) Find the electrostatic force exerted on one sphere by the other. (b) The spheres are connected by a conducting wire. Find the electrostatic force between the two after equilibrium is reached, where both spheres have the same charge.

10. Calculate the magnitude and direction of the Coulomb force on each of the three charges shown in Figure P15.10.
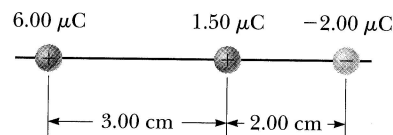
Figure P15.10 Problems 10 and 18.

11. **M** Three charges are arranged as shown in Figure P15.11. Find the magnitude and direction of the electrostatic force on the charge at the origin.
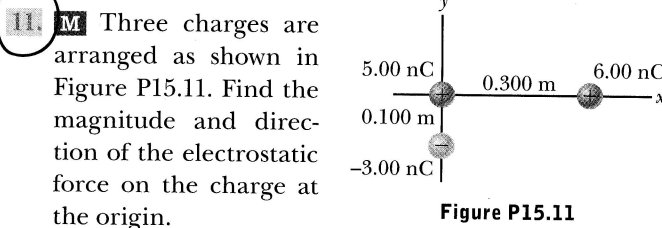
Figure P15.11

12. A positive charge $q_1 = 2.70$ μC on a frictionless horizontal surface is attached to a spring of force constant k as in Figure P15.12. When a charge of $q_2 = -8.60$ μC is placed 9.50 cm away from the positive charge, the spring stretches by 5.00 mm, reducing the distance between charges to $d = 9.00$ cm. Find the value of k.
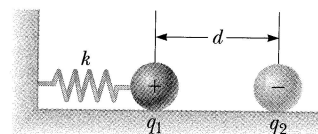
Figure P15.12

13. Three point charges are located at the corners of an equilateral triangle as in Figure P15.13. Find the magnitude and direction of the net electric force on the 2.00 μC charge.
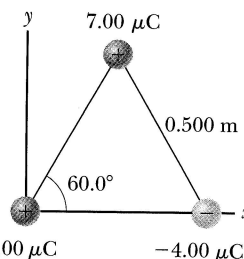
Figure P15.13 Problems 13 and 24.

14. Two identical metal blocks resting on a frictionless horizontal surface are connected by a light metal spring having constant $k = 100$ N/m and unstretched length $L_i = 0.400$ m as in Figure P15.14a. A charge Q is slowly placed on each block causing the spring to stretch to an equilibrium length $L = 0.500$ m as in Figure P15.14b. Determine the value of Q, modeling the blocks as charged particles.

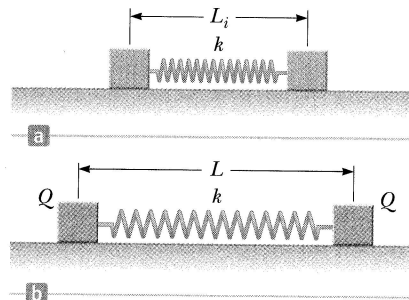**Figure P15.14**

15. Two small metallic spheres, each of mass $m = 0.20$ g, are suspended as pendulums by light strings from a common point as shown in Figure P15.15. The spheres are given the same electric charge, and it is found that they come to equilibrium when each string is at an angle of $\theta = 5.0°$ with the vertical. If each string has length $L = 30.0$ cm, what is the magnitude of the charge on each sphere?
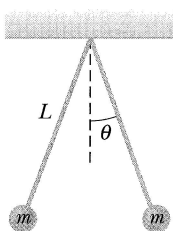
Figure P15.15

16. GP Particle A of charge 3.00×10^{-4} C is at the origin, particle B of charge -6.00×10^{-4} C is at (4.00 m, 0) and particle C of charge 1.00×10^{-4} C is at (0, 3.00 m). (a) What is the x-component of the electric force exerted by A on C? (b) What is the y-component of the force exerted by A on C? (c) Find the magnitude of the force exerted by B on C. (d) Calculate the x-component of the force exerted by B on C. (e) Calculate the y-component of the force exerted by B on C. (f) Sum the two x-components to obtain the resultant x-component of the electric force acting on C. (g) Repeat part (f) for the y-component. (h) Find the magnitude and direction of the resultant electric force acting on C.

15.4 The Electric Field

17. A small object of mass 3.80 g and charge -18 μC is suspended motionless above the ground when immersed in a uniform electric field perpendicular to the ground. What is the magnitude and direction of the electric field?

18. (a) Determine the electric field strength at a point 1.00 cm to the left of the middle charge shown in Figure P15.10. (b) If a charge of -2.00 μC is placed at this point, what are the magnitude and direction of the force on it?

19. An electric field of magnitude 5.25×10^5 N/C points due south at a certain location. Find the magnitude and direction of the force on a -6.00 μC charge at this location.

20. An electron is accelerated by a constant electric field of magnitude 300 N/C. (a) Find the acceleration of the electron. (b) Use the equations of motion with constant acceleration to find the electron's speed after 1.00×10^{-8} s, assuming it starts from rest.

21. A small block of mass m and charge Q is placed on an insulated, frictionless, inclined plane of angle θ as in Figure P15.21. An electric field is applied parallel to the incline. (a) Find an expression for the magnitude of the electric field that enables the block to remain at rest. (b) If $m = 5.40$ g, $Q = -7.00$ μC, and
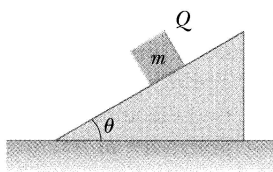
Figure P15.21

$\theta = 25.0°$, determine the magnitude and direction of the electric field that enables the block to remain at rest on the incline.

22. A small sphere of charge $q = +68$ μC and mass $m = 5.8$ g is attached to a light string and placed in a uniform electric field $\vec{E}$ that makes an angle $\theta = 37°$ with the horizontal. The opposite end of the string is attached to a wall and the sphere is in static equilibrium when the string is horizontal as in Figure P15.22. (a) Construct a free body diagram for the sphere. Find (b) the magnitude of the electric field and (c) the tension in the string.
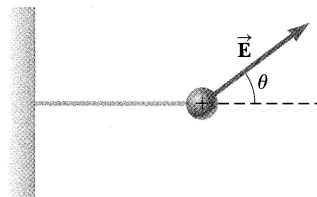
Figure P15.22

23. M A proton accelerates from rest in a uniform electric field of 640 N/C. At some later time, its speed is 1.20×10^6 m/s. (a) Find the magnitude of the acceleration of the proton. (b) How long does it take the proton to reach this speed? (c) How far has it moved in that interval? (d) What is its kinetic energy at the later time?

24. QC (a) Find the magnitude and direction of the electric field at the position of the 2.00 μC charge in Figure P15.13. (b) How would the electric field at that point be affected if the charge there were doubled? Would the magnitude of the electric force be affected?

25. S Two equal positive charges are at opposite corners of a trapezoid as in Figure P15.25. Find symbolic expressions for the components of the electric field at the point P.
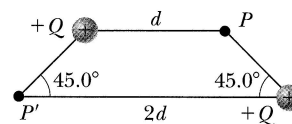
Figure P15.25

26. Three point charges are located on a circular arc as shown in Figure P15.26. (a) What is the total electric field at P, the center of the arc? (b) Find the electric force that would be exerted on a -5.00-nC charge placed at P.
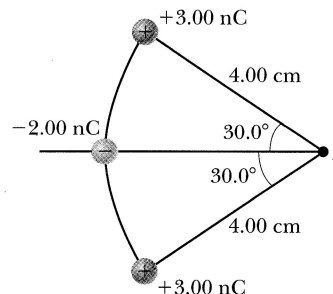
Figure P15.26

27. In Figure P15.27 determine the point (other than infinity) at which the total electric field is zero.
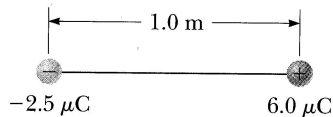

Figure P15.27

28. Three charges are at the corners of an equilateral triangle, as shown in Figure P15.28. Calculate the electric field at a point midway between the two charges on the x-axis.
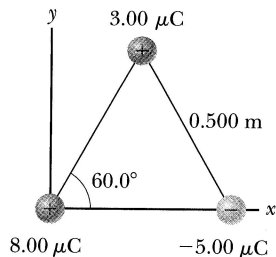

Figure P15.28

29. Three identical charges ($q = -5.0 \, \mu C$) lie along a circle of radius 2.0 m at angles of 30°, 150°, and 270°, as shown in Figure P15.29. What is the resultant electric field at the center of the circle?
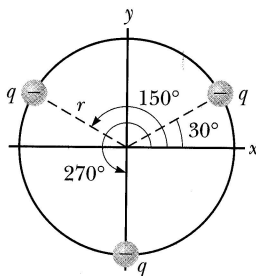
Figure P15.29

15.5 Electric Field Lines

15.6 Conductors in Electrostatic Equilibrium

30. Figure P15.30 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?

31. (a) Sketch the electric field lines around an isolated point charge $q > 0$. (b) Sketch the electric field pattern around an isolated negative point charge of magnitude $-2q$.

Figure P15.30

32. (a) Sketch the electric field pattern around two positive point charges of magnitude 1 μC placed close together. (b) Sketch the electric field pattern around two negative point charges of $-2 \, \mu C$, placed close together. (c) Sketch the pattern around two point charges of $+1 \, \mu C$ and $-2 \, \mu C$, placed close together.

33. Two point charges are a small distance apart. (a) Sketch the electric field lines for the two if one has a charge four times that of the other and both charges are positive. (b) Repeat for the case in which both charges are negative.
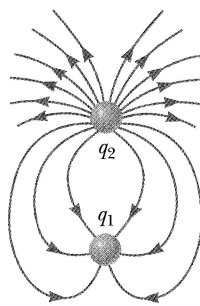
34. **S** Three equal positive charges are at the corners of an equilateral triangle of side a as in Figure P15.34. Assume the three charges together create an electric field. (a) Sketch the electric field lines in the plane of the charges. (b) Find the location of one point (other than ∞) where the electric field is zero. What are (c) the magnitude and (d) the direction of the electric field at P due to the two charges at the base?
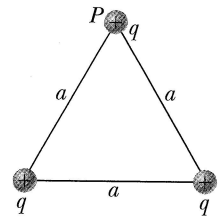

Figure P15.34

35. Refer to Figure 15.20. The charge lowered into the center of the hollow conductor has a magnitude of 5 μC. Find the magnitude and sign of the charge on the inside and outside of the hollow conductor when the charge is as shown in (a) Figure 15.20a, (b) Figure 15.20b, (c) Figure 15.20c, and (d) Figure 15.20d.

15.8 The Van de Graaff Generator

36. The dome of a Van de Graaff generator receives a charge of 2.0×10^{-4} C. Find the strength of the electric field (a) inside the dome, (b) at the surface of the dome, assuming it has a radius of 1.0 m, and (c) 4.0 m from the center of the dome. *Hint:* See Section 15.6 to review properties of conductors in electrostatic equilibrium. Also, use that the points on the surface are outside a spherically symmetric charge distribution; the total charge may be considered to be located at the center of the sphere.

37. If the electric field strength in air exceeds 3.0×10^6 N/C, the air becomes a conductor. Using this fact, determine the maximum amount of charge that can be carried by a metal sphere 2.0 m in radius. (See the hint in Problem 36.)

38. In the Millikan oil-drop experiment illustrated in Figure 15.21, an atomizer (a sprayer with a fine nozzle) is used to introduce many tiny droplets of oil between two oppositely charged parallel metal plates. Some of the droplets pick up one or more excess electrons. The charge on the plates is adjusted so that the electric force on the excess electrons exactly balances the weight of the droplet. The idea is to look for a droplet that has the smallest electric force and assume it has only one excess electron. This strategy lets the observer measure the charge on the electron. Suppose we are using an electric field of 3×10^4 N/C. The charge on one electron is about 1.6×10^{-19} C. Estimate the radius of an oil drop of density 858 kg/m³ for which its weight could be balanced by the electric force of this field on one electron. (Problem 38 is courtesy of E. F. Redish. For more problems of this type, visit www.physics.umd .edu/perg/.)

39. A Van de Graaff generator is charged so that a proton at its surface accelerates radially outward at 1.52×10^{12} m/s². Find (a) the magnitude of the electric force on the proton at that instant and (b) the magni-

tude and direction of the electric field at the surface of the generator.

15.9 Electric Flux and Gauss's Law

40. A uniform electric field of magnitude $E = 435$ N/C makes an angle of $\theta = 65.0°$ with a plane surface of area $A = 3.50$ m^2 as in Figure P15.40. Find the electric flux through this surface.
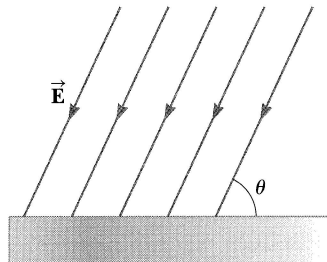

Figure P15.40

41. [M] An electric field of intensity 3.50 kN/C is applied along the x-axis. Calculate the electric flux through a rectangular plane 0.350 m wide and 0.700 m long if (a) the plane is parallel to the yz-plane, (b) the plane is parallel to the xy-plane, and (c) the plane contains the y-axis and its normal makes an angle of 40.0° with the x-axis.

42. [Q/C] The electric field everywhere on the surface of a charged sphere of radius 0.230 m has a magnitude of 575 N/C and points radially outward from the center of the sphere. (a) What is the net charge on the sphere? (b) What can you conclude about the nature and distribution of charge inside the sphere?

43. [S] Four closed surfaces, S_1 through S_4, together with the charges $-2Q$, Q, and $-Q$, are sketched in Figure P15.43. (The colored lines are the intersections of the surfaces with the page.) Find the electric flux through each surface.
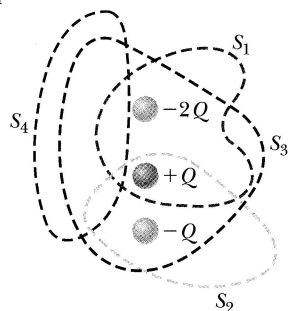
Figure P15.43

44. A charge $q = +5.80$ μC is located at the center of a regular tetrahedron (a four-sided surface) as in Figure P15.44. Find (a) the total electric flux through the tetrahedron and (b) the electric flux through one face of the tetrahedron.
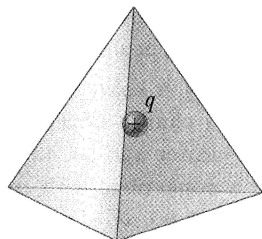

Figure P15.44

45. A point charge q is located at the center of a spherical shell of radius a that has a charge $-q$ uniformly distributed on its surface. Find the electric field (a) for all points outside the spherical shell and (b) for a point inside the shell a distance r from the center.

46. [Q/C] A charge of 1.70×10^2 μC is at the center of a cube of edge 80.0 cm. No other charges are nearby. (a) Find the flux through the whole surface of the cube. (b) Find the flux through each face of the cube. (c) Would your answers to parts (a) or (b) change if the charge were not at the center? Explain.

47. Suppose the conducting spherical shell of Figure 15.29 carries a charge of 3.00 nC and that a charge of -2.00 nC is at the center of the sphere. If $a = 2.00$ m and $b = 2.40$ m, find the electric field at (a) $r = 1.50$ m, (b) $r = 2.20$ m, and (c) $r = 2.50$ m. (d) What is the charge distribution on the sphere?

48. [S] A very large nonconducting plate lying in the xy-plane carries a charge per unit area of σ. A second such plate located at $z = 2.00$ cm and oriented parallel to the xy-plane carries a charge per unit area of -2σ. Find the electric field (a) for $z < 0$, (b) $0 < z < 2.00$ cm, and (c) $z > 2.00$ cm.

Additional Problems

49. In deep space two spheres each of radius 5.00 m are connected by a 3.00×10^2 m nonconducting cord. If a uniformly distributed charge of 35.0 mC resides on the surface of each sphere, calculate the tension in the cord.

50. [Q/C] A nonconducting, thin plane sheet of charge carries a uniform charge per unit area of 5.20 μC/m^2 as in Figure 15.30. (a) Find the electric field at a distance of 8.70 cm from the plate. (b) Explain whether your result changes as the distance from the sheet is varied.

51. Three point charges are aligned along the x-axis as shown in Figure P15.51. Find the electric field at the position $x = +2.0$ m, $y = 0$.
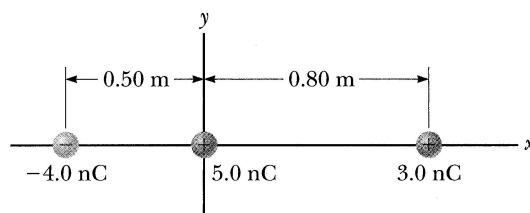

Figure P15.51

52. [M] A small plastic ball of mass $m = 2.00$ g is suspended by a string of length $L = 20.0$ cm in a uniform electric field, as shown in Figure P15.52. If the ball is in
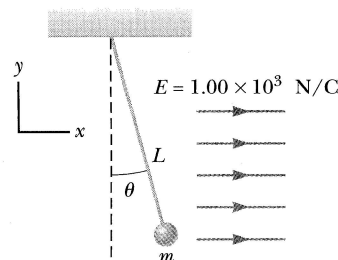

Figure P15.52

equilibrium when the string makes a $\theta = 15.0°$ angle with the vertical as indicated, what is the net charge on the ball?

53. (a) Two identical point charges $+q$ are located on the y-axis at $y = +a$ and $y = -a$. What is the electric field along the x-axis at $x = b$? (b) A circular ring of charge of radius a has a total positive charge Q distributed uniformly around it. The ring is in the $x = 0$ plane with its center at the origin. What is the electric field along the x-axis at $x = b$ due to the ring of charge? *Hint:* Consider the charge Q to consist of many pairs of identical point charges positioned at the ends of diameters of the ring.

54. **S** The electrons in a particle beam each have a kinetic energy K. Find the magnitude of the electric field that will stop these electrons in a distance d, expressing the answer symbolically in terms of K, e, and d. Should the electric field point in the direction of the motion of the electron, or should it point in the opposite direction?

55. **S** A point charge $+2Q$ is at the origin and a point charge $-Q$ is located along the x-axis at $x = d$ as in Figure P15.55. Find symbolic expressions for the components of the net force on a third point charge $+Q$ located along the y-axis at $y = d$.
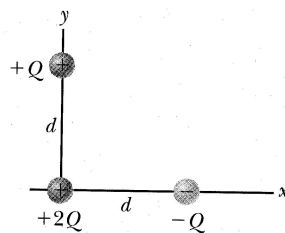

Figure P15.55

56. **Q|C** A 1.00-g cork ball having a positive charge of 2.00 mC is suspended vertically on a 0.500-m-long light string in the presence of a uniform downward-directed electric field of magnitude $E = 1.00 \times 10^5$ N/C as in Figure P15.56. If the ball is displaced slightly from the vertical, it oscillates like a simple pendulum. (a) Determine the period of the ball's oscillation. (b) Should gravity be included in the calculation for part (a)? Explain.
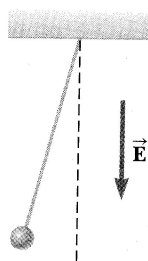

Figure P15.56

57. Two 2.0-g spheres are suspended by 10.0-cm-long light strings (Fig. P15.57). A uniform electric field is applied in the x-direction. If the spheres have charges of -5.0×10^{-8} C and $+5.0 \times 10^{-8}$ C, determine the electric field intensity that enables the spheres to be in equilibrium at $\theta = 10°$.
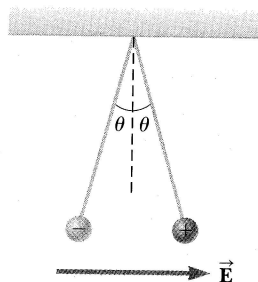

Figure P15.57

58. **Q|C** A point charge of magnitude 5.00 μC is at the origin of a coordinate system, and a charge of -4.00 μC is

at the point $x = 1.00$ m. There is a point on the x-axis, at x less than infinity, where the electric field goes to zero. (a) Show by conceptual arguments that this point cannot be located between the charges. (b) Show by conceptual arguments that the point cannot be at any location between $x = 0$ and negative infinity. (c) Show by conceptual arguments that the point must be between $x = 1.00$ m and $x =$ positive infinity. (d) Use the values given to find the point and show that it is consistent with your conceptual argument.

59. Two hard rubber spheres, each of mass $m = 15.0$ g, are rubbed with fur on a dry day and are then suspended with two insulating strings of length $L = 5.00$ cm whose support points are a distance $d = 3.00$ cm from each other as shown in Figure P15.59. During the rubbing process, one sphere receives exactly twice the charge of the other. They are observed to hang at equilibrium,
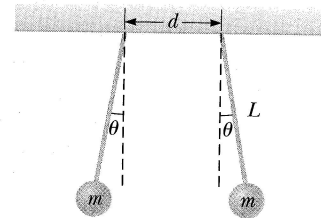

Figure P15.59

each at an angle of $\theta = 10.0°$ with the vertical. Find the amount of charge on each sphere.

60. Two small beads having positive charges $q_1 = 3q$ and $q_2 = q$ are fixed at the opposite ends of a horizontal insulating rod of length $d = 1.50$ m. The bead with charge q_1 is at the origin. As shown in Figure P15.60, a
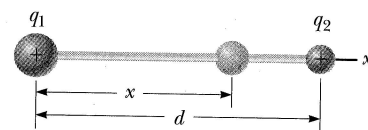

Figure P15.60

third small charged bead is free to slide on the rod. At what position x is the third bead in equilibrium?

61. **M** A solid conducting sphere of radius 2.00 cm has a charge of 8.00 μC. A conducting spherical shell of inner radius 4.00 cm and outer radius 5.00 cm is concentric with the solid sphere and has a charge of -4.00 μC. Find the electric field at (a) $r = 1.00$ cm, (b) $r = 3.00$ cm, (c) $r = 4.50$ cm, and (d) $r = 7.00$ cm from the center of this charge configuration.

62. Three identical point charges, each of mass $m = 0.100$ kg, hang from three strings, as shown in Figure P15.62. If the lengths of the left and right strings are

each $L = 30.0$ cm and if the angle θ is 45.0°, determine the value of q.

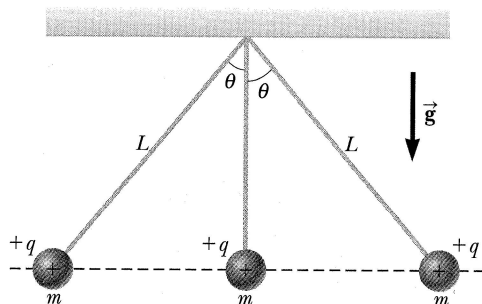**Figure P15.62**

63. Each of the electrons in a particle beam has a kinetic energy of 1.60×10^{-17} J. (a) What is the magnitude of the uniform electric field (pointing in the direction of the electrons' movement) that will stop these electrons in a distance of 10.0 cm? (b) How long will it take to stop the electrons? (c) After the electrons stop, what will they do? Explain.

64. Protons are projected with an initial speed $v_0 = 9\,550$ m/s into a region where a uniform electric field of magnitude $E = 720$ N/C is present (Fig. P15.64). The protons are to hit a target that lies a horizontal distance of 1.27 mm from the point where the protons are launched. Find (a) the two projection angles θ that will result in a hit and (b) the total duration of flight for each of the two trajectories.
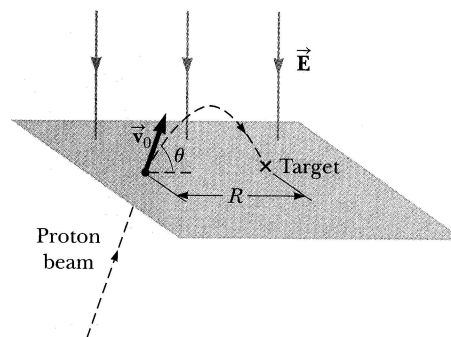

Figure P15.64