Due: Friday Oct. 1, 2004. 9:00 AM

ch. 19

51. • **IP** A uniform electric field of magnitude 6.00×10^3 N/C points upward. An empty, closed shoe box has a top and bottom that are 35.0 cm by 25.0 cm, vertical ends that are 25.0 cm by 20.0 cm, and vertical sides that are 20.0 cm by 35.0 cm. **(a)** Which side of the box has the greatest positive electric flux? Which side has the greatest negative electric flux? Which sides have zero electric flux? **(b)** Calculate the electric flux through each of the six sides of the box.

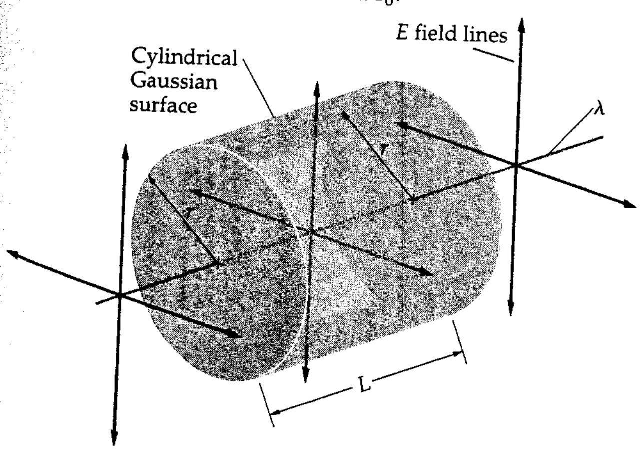
52. • BIO Nerve cells are long, thin cylinders along which electrical disturbances (nerve impulses) travel. The cell membrane of a typical nerve cell consists of an inner and an outer wall separated by a distance of 0.10 μm. The electric field within the cell membrane is 7.0×10^5 N/C. Approximating the cell membrane as a parallel-plate capacitor, determine the magnitude of the charge density on the inner and outer cell walls.

53. •• The electric flux through each of the six sides of a rectangular box are as follows: $\Phi_1 = +150.0\ \mathrm{N \cdot m^2/C}$; $\Phi_2 = +250.0\ \mathrm{N \cdot m^2/C}$; $\Phi_3 = -350.0\ \mathrm{N \cdot m^2/C}$; $\Phi_4 = +175.0\ \mathrm{N \cdot m^2/C}$; $\Phi_5 = -100.0\ \mathrm{N \cdot m^2/C}$; $\Phi_6 = +450.0\ \mathrm{N \cdot m^2/C}$. How much charge is in this box?

54. •• Consider a spherical Gaussian surface and three charges: $q_1 = 1.65\ \mu$C, $q_2 = -2.32\ \mu$C, and $q_3 = 3.71\ \mu$C. Find the electric flux through the Gaussian surface if it completely encloses **(a)** only charges q_1 and q_2, **(b)** only charges q_2 and q_3, and **(c)** all three charges. **(d)** Suppose a fourth charge, Q, is added to the situation described in part (c). Find the sign and magnitude of Q required to give zero electric flux through the surface.

55. ••• A thin wire of infinite extent has a charge per unit length of λ. Using the cylindrical Gaussian surface shown in **Figure 19–34**, show that the electric field produced by this wire at a radial distance r has a magnitude given by

$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$



▲ **FIGURE 19–34** Problems 55 and 62

General Problems

56. • A proton is released from rest in a uniform electric field of magnitude 1.08×10^5 N/C. Find the speed of the proton after it has traveled **(a)** 1.00 cm and **(b)** 10.0 cm.

57. • BIO Honeybees actively foraging in the field have been found to be electrically charged, due largely to air resistance as they fly. The charge carried by a bee, which can be as great as 93 pC, is thought to play a significant role in pollination—the bee can detach grains of pollen from a distance, like a charged comb attracting bits of paper. Given that the force required to detach pollen from an avocado stigma is 4.0×10^{-10} N, find the maximum distance at which the electrostatic force between a bee and a grain of pollen is sufficient to detach the pollen. Treat the bee and pollen as point charges, and assume that the pollen has a charge opposite in sign and equal in magnitude to the bee.

▲ A honeybee with static cling (Problem 57)

58. • A point charge at the origin of a coordinate system produces the electric field $\vec{E} = (36{,}000\ \mathrm{N/C})\hat{x}$ on the x axis at the location $x = -0.50$ m. Determine the sign and magnitude of the charge.

59. •• A small object of mass 0.025 kg and charge 3.1 μC hangs from the ceiling by a thread. A second small object, with a charge of 4.2 μC, is placed 1.5 m vertically below the first charge. Find **(a)** the electric field at the position of the upper charge due to the lower charge and **(b)** the tension in the thread.

60. •• **IP** Consider a system of three point charges on the x axis. Charge 1 is at $x = 0$, charge 2 is at $x = 0.20$ m, and charge 3 is at $x = 0.40$ m. In addition, the charges have the following values; $q_1 = -19\ \mu$C, $q_2 = q_3 = +19\ \mu$C. **(a)** The electric field vanishes at some point on the x axis between $x = 0.20$ m and $x = 0.40$ m. Is the point of zero field (i) at $x = 0.30$ m, (ii) to the left of $x = 0.30$ m or (iii) to the right of $x = 0.30$ m? Explain. **(b)** Find the point where $E = 0$ between $x = 0.20$ m and $x = 0.40$ m.

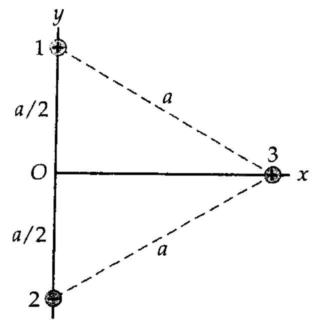
61. •• **IP** Consider the system of three point charges described in the previous problem. **(a)** The electric field vanishes at two different points on the x axis. One point is between $x = 0.20$ m and $x = 0.40$ m. Is the second point located to the left of charge 1 or to the right of charge 3? Explain. **(b)** Find the value of x at the second point where $E = 0$.

62. •• The electric field at a radial distance of 50.0 cm from a thin, charged wire has a magnitude of 25,400 N/C. **(a)** Using the result given in Problem 55, what is the magnitude of the charge per length on this wire? **(b)** At what distance from the wire is the magnitude of the electric field equal to $\frac{1}{2}$(25,400 N/C)?

63. •• A system consisting entirely of electrons and protons has a net charge of 1.84×10^{-15} C and a net mass of 4.56×10^{-23} kg. How many **(a)** electrons and **(b)** protons are in this system?

64. •• **IP** Three charges are placed at the vertices of an equilateral triangle of side $a = 0.63$ m, as shown in **Figure 19–35**. Charges 1 and 3 are $+7.3\ \mu$C; charge 2 is $-7.3\ \mu$C. **(a)** Find the magnitude and direction of the net force acting on charge 3. **(b)** If charge 3 is moved to the origin, will the net force acting on it there be greater than, less than, or equal to the net force found in part (a)? Explain. **(c)** Find the net force on charge 3 when it is at the origin.

65. •• **IP** Consider the system of three charges described in the previous problem and shown in Figure 19–35. **(a)** Do you expect the net force acting on charge 1 to have a magnitude greater than, less than, or the same as the magnitude of the net force acting on charge 2? Explain. **(b)** Find the magnitude of the net force acting on charge 1. **(c)** Find the magnitude of the net force acting on charge 2.



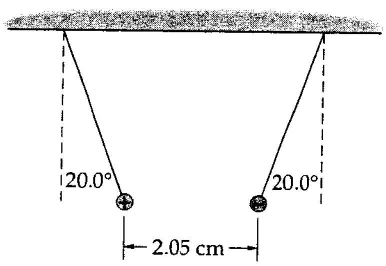
▲ **FIGURE 19–35** Problems 64 and 65

66. •• **IP BIO** The cell membrane in a nerve cell has a thickness of 0.12 μm. **(a)** Approximating the cell membrane as a parallel-plate capacitor with a surface charge density of 5.9×10^{-6} C/m^2, find the electric field within the membrane. **(b)** If the thickness of the membrane were doubled, would your answer to part (a) increase, decrease, or stay the same? Explain.

67. •• A square with sides of length L has a point charge at each of its four corners. Two corners that are diagonally opposite have charges equal to $+2.25$ μC; the other two diagonal corners have charges Q. Find the magnitude and sign of the charges Q such that each of the $+2.25$ μC charges experiences zero net force.

68. •• **IP** Suppose a charge $+Q$ is placed on the Earth, and another charge $+Q$ is placed on the Moon. **(a)** Find the value of Q needed to "balance" the gravitational attraction between the Earth and the Moon. **(b)** How would your answer to part (a) change if the distance between the Earth and the Moon were doubled? Explain.

69. •• Two small plastic balls hang from threads of negligible mass. Each ball has a mass of 0.12 g and a charge of magnitude q. The balls are attracted to each other, and the threads attached to the balls make an angle of 20.0° with the vertical, as shown in **Figure 19–36**. Find **(a)** the magnitude of the electric force acting on each ball, **(b)** the tension in each of the threads, and **(c)** the magnitude of the charge on the balls.



▲ **FIGURE 19–36** Problem 69

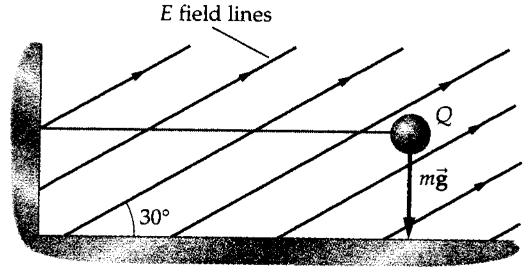
70. •• A small sphere with a charge of $+2.44$ μC is attached to a relaxed, horizontal spring whose force constant is 89.2 N/m. The spring extends along the x axis, and the sphere rests on a frictionless surface with its center at the origin. A point charge $Q = -8.55$ μC is now moved slowly from infinity to a point $x = d > 0$ on the x axis. This causes the small sphere to move to the position $x = 0.124$ m. Find d.

71. •• Twelve identical point charges q are equally spaced around the circumference of a circle of radius R. The circle is centered at the origin. One of the twelve charges, which happens to be on the positive x axis, is now moved to the center of the circle. Find **(a)** the direction and **(b)** the magnitude of the net electric force exerted on this charge.

72. •• **BIO** When a nerve impulse propagates along a nerve cell, the electric field within the cell membrane changes from 7.0×10^5 N/C in one direction to 3.0×10^5 N/C in the other direction. Approximating the cell membrane as a parallel-plate capacitor, find the magnitude of the change in charge density on the walls on the cell membrane.

73. •• **IP** The Earth produces an approximately uniform electric field at ground level. This electric field has a magnitude of 110 N/C and points radially inward, toward the center of the Earth. **(a)** Find the surface charge density (sign and magnitude) on the surface of the Earth. **(b)** Given that the radius of the Earth is 6.38×10^6 m, find the total electric charge on the Earth. **(c)** If the Moon had the same amount of electric charge distributed uniformly over its surface, would its electric field at the surface be greater than, less than, or equal to 110 N/C? Explain.

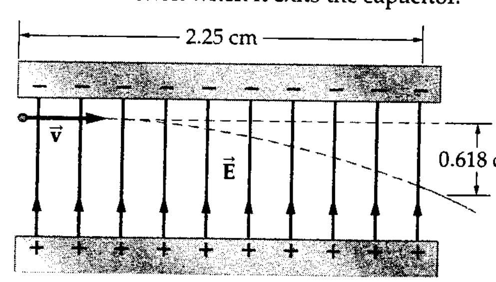
74. •• An object of mass $m = 3.7$ g and charge $Q = +44$ μC is attached to a string and placed in a uniform electric field that is inclined at an angle of 30.0° with the horizontal (**Figure 19–37**). The object is in static equilibrium when the string is horizontal. Find **(a)** the magnitude of the electric field and **(b)** the tension in the string.



▲ **FIGURE 19–37** Problem 74

75. ••• Four identical charges, $+Q$, occupy the corners of a square with sides of length a. A fifth charge, q, can be placed at any desired location. Find the location of the fifth charge, and the value of q, such that the net electric force acting on each of the original four charges, $+Q$, is zero.

76. •• **Figure 19–38** shows an electron entering a parallel-plate capacitor with a speed of 5.45×10^6 m/s. The electric field of the capacitor has deflected the electron downward by a distance of 0.618 cm at the point where the electron exits the capacitor. Find **(a)** the magnitude of the electric field in the capacitor and **(b)** the speed of the electron when it exits the capacitor.



▲ **FIGURE 19–38** Problem 76

77. ••• Two identical conducting spheres are separated by a fixed center to center distance of 45 cm and have different charges. Initially, the spheres attract each other with a force of 0.095 N. The spheres are now connected by a thin, conducting wire. After the wire is removed, the spheres are positively charged and repel one another with a force of 0.032 N. Find **(a)** the final and **(b)** the initial charges on the spheres.

distance of 1.5 mm. **(a)** What radius must the plates have if the capacitance of this capacitor is to be 1.0 μF? **(b)** If the separation between the plates is increased, should the radius of the plates be increased or decreased to maintain a capacitance of 1.0 μF? Explain. **(c)** Find the radius of the plates that gives a capacitance of 1.0 μF for a plate separation of 3.0 mm.

47. •• A parallel-plate capacitor has plates of area 3.45×10^{-4} m^2. What plate separation is required if the capacitance is to be 1330 pF? Assume that the space between the plates is filled with **(a)** air or **(b)** paper.

48. •• **IP** A parallel-plate capacitor filled with air has plates of area 0.0066 m^2 and a separation of 0.45 mm. **(a)** Find the magnitude of the charge on each plate when the capacitor is connected to a 12-V battery. **(b)** Will your answer to part (a) increase, decrease, or stay the same if the separation between the plates is increased? Explain. **(c)** Calculate the magnitude of the charge on the plates if the separation is 0.90 mm.

49. •• Suppose that after walking across a carpeted floor you reach for a doorknob, and just before you touch it a spark jumps 0.50 cm from your finger to the knob. Find the minimum voltage needed between your finger and the doorknob to generate this spark.

50. •• **(a)** What plate area is required if an air-filled, parallel-plate capacitor with a plate separation of 2.6 mm is to have a capacitance of 22 pF? **(b)** What is the maximum voltage that can be applied to this capacitor without causing dielectric breakdown?

51. •• As a crude model for lightning, consider the ground to be one plate of a parallel-plate capacitor and a cloud at an altitude of 550 m to be the other plate. Assume the surface area of the cloud to be the same as the area of a square that is 0.50 km on a side. **(a)** What is the capacitance of this capacitor? **(b)** How much charge can the cloud hold before the dielectric strength of the air is exceeded and a spark (lightning) results?

52. ••• A parallel-plate capacitor is made from two aluminum-foil sheets, each 3.00 cm wide and 10.0 m long. Between the sheets is a mica strip of the same width and length that is 0.0225 mm thick. What is the maximum charge that can be stored in this capacitor? (The dielectric constant of mica is 5.4, and its dielectric strength is 1.00×10^8 V/m.)

Section 20–6 Electrical Energy Storage

53. • Calculate the work done by a 3.0-V battery as it charges a 8.0-μF capacitor in the flash unit of a camera.

54. • **BIO** An automatic external defibrillator (AED) delivers 125 J of energy at a voltage of 1050 V. What is the capacitance of this device?

55. •• **IP BIO** The membrane of a living cell can be approximated by a parallel-plate capacitor with plates of area 4.75×10^{-9} m^2, a plate separation of 8.5×10^{-9} m, and a dielectric with a dielectric constant of 4.5. **(a)** What is the energy stored in such a cell membrane if the potential difference across it is 0.0725 V? **(b)** Would your answer to part (a) increase, decrease, or stay the same if the thickness of the cell membrane is increased? Explain.

56. •• A 0.22-μF capacitor is charged by a 1.5-V battery. After being charged, the capacitor is connected to a small electric motor. Assuming 100% efficiency, **(a)** to what height can the motor lift a 5.0-g mass? **(b)** What initial voltage must the capacitor have if it is to lift a 5.0-g mass through a height of 1.0 cm?

57. •• Find the electric energy density between the plates of a 225-μF parallel-plate capacitor. The potential difference between the plates is 315 V, and the plate separation is 0.200 mm.

58. •• What electric field strength would store 10.0 J of energy in every 1.00 mm^3 of space?

59. •• An electronic flash unit for a camera contains a capacitor with a capacitance of 850 μF. When the unit is fully charged and ready for operation the potential difference between the capacitor plates is 330 V. **(a)** What is the magnitude of the charge on each plate of the fully charged capacitor? **(b)** Find the energy stored in the "charged-up" flash unit.

60. ••• A parallel-plate capacitor has plates with an area of 405 cm^2 and an air-filled gap between the plates that is 2.25 mm thick. The capacitor is charged by a battery to 575 V and then is disconnected from the battery. **(a)** How much energy is stored in the capacitor? **(b)** The separation between the plates is now increased to 4.50 mm. How much energy is stored in the capacitor now? **(c)** How much work is required to increase the separation of the plates from 2.25 mm to 4.50 mm? Explain your reasoning.

General Problems

61. • Find the difference in electric potential, $\Delta V = V_B - V_A$, between the points A and B for the following cases: **(a)** The electric field does 0.052 J of work as you move a +5.7-μC charge from A to B. **(b)** The electric field does −0.052 J of work as you move a −5.7-μC charge from A to B. **(c)** You perform 0.052 J of work as you slowly move a +5.7-μC charge from A to B.

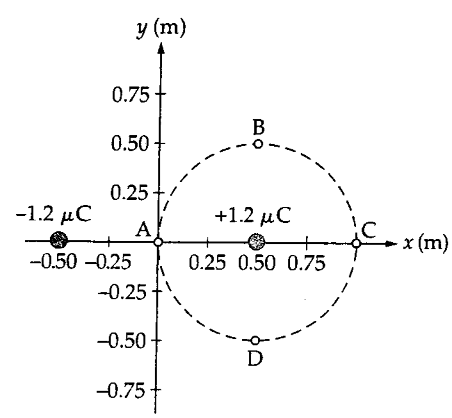
62. • The separation between the plates of a parallel-plate capacitor is doubled and the area of the plates is halved. How is the capacitance affected?

63. • A parallel-plate capacitor is connected to a battery that maintains a constant potential difference between the plates. If the spacing between the plates is doubled, how is the magnitude of charge on the plates affected?

64. •• A charge of 24.5 μC is located at (4.40 m, 6.02 m), and a charge of −11.2 μC is located at (−4.50 m, 6.75 m). What charge must be located at (2.23 m, −3.01 m) if the electric potential is to be zero at the origin?

65. •• In the Bohr model of the hydrogen atom (see Problem 23) what is the smallest amount of work that must be done on the electron to move it from its circular orbit, with a radius of 0.529×10^{-10} m, to an infinite distance from the proton? This value is referred to as the ionization energy of hydrogen.

66. •• **IP** A +1.2-μC charge and a −1.2-μC charge are placed at (0.50 m, 0) and (−0.50 m, 0), respectively. **(a)** In **Figure 20–27**, at which of the points A, B, C, or D is the electric potential smallest in value? At which of these points does it have its greatest value? Explain. **(b)** Calculate the electric potential at points A, B, C, and D.



▲ **FIGURE 20–27** Problems 66, 67, and 81

67. •• Repeat Problem 66 for the case where both charges are +1.2 μC.

68. •• How much work is required to bring three protons, initially infinitely far apart, to a configuration where each proton is 1.5×10^{-15} m from the other two? (This is a typical separation for protons in a nucleus.)

69. •• A point charge $Q = +87.1\ \mu C$ is held fixed at the origin. A second point charge, with mass $m = 0.0526$ kg and charge $q = -2.37\ \mu C$, is placed at the location (0.323 m, 0). **(a)** Find the electric potential energy of this system of charges. **(b)** If the second charge is released from rest, what is its speed when it reaches the point (0.121 m, 0)?

70. •• A parallel-plate capacitor is charged to an electric potential of 325 V by moving 3.75×10^{16} electrons from one plate to the other. How much work is done in charging the capacitor?

71. •• **IP** The three charges shown in Figure 20–24 are held in place as a fourth charge, q, is brought from infinity to the point P. The charge q starts at rest at infinity, and is also at rest when it is placed at the point P. **(a)** If q is a positive charge, is the work required to bring it to the point P positive, negative, or zero? Explain. **(b)** Find the value of q if the work needed to bring it to point P is -1.3×10^{-11} J.

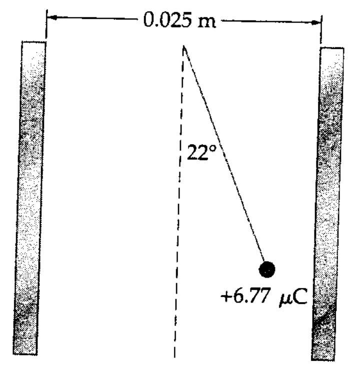
72. •• **(a)** In Figure 20–26 we see that the electric potential increases by 10.0 V as one moves 4.00 cm in the positive x direction. Use this information to calculate the x component of the electric field. (Ignore the y direction for the moment.) **(b)** Apply the same reasoning as in part (a) to calculate the y component of the electric field. **(c)** Combine the results from parts (a) and (b) to find the magnitude and direction of the electric field for this system.

73. •• **BIO IP** The electric catfish (*Malapterurus electricus*) is an aggressive fish, 1.0-m in length, found today in tropical Africa (and depicted in Egyptian hieroglyphics). The catfish is capable of generating jolts of electricity up to 350 V by producing a positively-charged region of muscle near the head and a negatively-charged region near the tail. **(a)** For the same amount of charge, does the catfish generate a higher voltage by separating the charge side-to-side or end-to-end? Explain. **(b)** Estimate the charge generated at each end of a catfish as follows: Treat the catfish as a parallel-plate capacitor with plates of area $1.8 \times 10^{-2}\ m^2$, separation 1.0 m, and filled with a dielectric with a dielectric constant $\kappa = 95$.

74. •• As a $+6.2$-μC charge moves along the x axis from $x = 0$ to $x = 0.70$ m, the electric potential it experiences is shown in Figure 20–22. Find the approximate location(s) of the charge when its electric potential energy is **(a)** 2.6×10^{-5} J and **(b)** 4.3×10^{-5} J.

75. •• **IP** Many computer keyboards operate on the principle of capacitance. As shown in Figure 20–16, each key forms a small parallel-plate capacitor whose separation is reduced when the key is depressed. **(a)** Does depressing a key increase or decrease its capacitance? Explain. **(b)** Suppose the plates for each key have an area of 47.5 mm² and an initial separation of 0.550 mm. In addition, let the dielectric have a dielectric constant of 3.75. If the circuitry of the computer can detect a change in capacitance of 0.425 pF, what is the minimum distance a key must be depressed to be detected?

76. •• **IP** A point charge of mass 0.071 kg and charge $+6.77\ \mu C$ is suspended by a thread between the vertical parallel plates of a parallel-plate capacitor, as shown in **Figure 20–28**. **(a)** If the charge deflects to the right of vertical, as indicated in the figure, which of the two plates is at the higher electric potential? **(b)** If the angle of deflection is 22°, and the separation between the plates is 0.025 m, what is the potential difference between the plates?



▲ **FIGURE 20–28** Problems 76 and 79

77. •• **BIO** Many cells in the body have a cell membrane whose inner and outer surfaces carry opposite charges, just like the plates of a parallel-plate capacitor. Suppose a typical cell membrane has a thickness of 7.5×10^{-9} m, and its inner and outer surfaces carry charge densities of $-0.62 \times 10^{-3}\ C/m^2$ and $+0.62 \times 10^{-3}\ C/m^2$, respectively. In addition, assume that the material in the cell membrane has a dielectric constant of 5.5. **(a)** Find the direction and magnitude of the electric field within the cell membrane. **(b)** Calculate the potential difference between the inner and outer walls of the membrane, and indicate which wall of the membrane has the higher potential.

78. ••• **IP (a)** One of the $-Q$ charges in Figure 20–25 is given an outward "kick" that sends it off with an initial speed v_0 while the other three charges are held at rest. If the moving charge has a mass m, what is its speed when it is infinitely far from the other charges? **(b)** Suppose the remaining $-Q$ charge, which also has a mass m, is now given the same initial speed, v_0. When it is infinitely far away from the two $+Q$ charges, is its speed greater than, less than, or the same as the speed found in part (a)? Explain.

79. ••• Figure 20–28 shows a charge $q = +6.77\ \mu C$ with a mass $m = 0.071$ kg suspended by a thread of length $L = 0.022$ m between the plates of a capacitor. **(a)** Plot the electric potential energy of the system as a function of the angle θ the thread makes with the vertical. (The electric field between the plates has a magnitude $E = 4.16 \times 10^4$ V/m.) **(b)** Repeat part (a) for the case of the gravitational potential energy of the system. **(c)** Show that the total potential energy of the system (electric plus gravitational) is a minimum when the angle θ satisfies the equilibrium condition for the charge, $\tan\theta = qE/mg = 22°$.

80. ••• The electric potential a distance r from a point charge q is 2.70×10^4 V. One meter farther away from the charge the potential is 6220 V. Find the charge q and the initial distance r.

81. ••• Referring to Problem 66, calculate and plot the electric potential on the circle centered at (0.50 m, 0). Give your results in terms of the angle θ, defined as follows: θ is the angle measured counterclockwise from a vertex at the center of the circle, with $\theta = 0$ at point C.

82. ••• When the potential difference between the plates of a capacitor is increased by 3.25 V the magnitude of the charge on each plate increases by 13.5 μC. What is the capacitance of this capacitor?

83. ••• The electric potential a distance r from a point charge q is 155 V, and the magnitude of the electric field is 2240 N/C. Find the values of q and r.