PROBLEMS

ENHANCED WebAssign The problems in this chapter may be assigned online in Enhanced WebAssign. Selected problems also have Watch It video solutions.

1. denotes straightforward problem; 2. denotes intermediate problem;
3. denotes challenging problem
1. denotes full solution available in *Student Solutions Manual/ Study Guide*

1. denotes problems most often assigned in Enhanced WebAssign
BIO denotes biomedical problems
GP denotes guided problems
M denotes Master It tutorial available in Enhanced WebAssign
Q|C denotes asking for quantitative and conceptual reasoning
S denotes symbolic reasoning problem

16.1 Potential Difference and Electric Potential

1. A uniform electric field of magnitude 375 N/C pointing in the positive *x*-direction acts on an electron, which is initially at rest. After the electron has moved 3.20 cm, what is (a) the work done by the field on the electron, (b) the change in potential energy associated with the electron, and (c) the velocity of the electron?

2. A proton is released from rest in a uniform electric field of magnitude 385 N/C. Find (a) the electric force on the proton, (b) the acceleration of the proton, and (c) the distance it travels in 2.00 μs.

3. BIO A potential difference of 90 mV exists between the inner and outer surfaces of a cell membrane. The inner surface is negative relative to the outer surface. How much work is required to eject a positive sodium ion (Na^+) from the interior of the cell?

4. A metal sphere of radius 5.00 cm is initially uncharged. How many electrons would have to be placed on the sphere to produce an electric field of magnitude 1.50×10^5 N/C at a point 8.00 cm from the center of the sphere?

5. The potential difference between the accelerating plates of a TV set is about 25 kV. If the distance between the plates is 1.5 cm, find the magnitude of the uniform electric field in the region between the plates.

6. A point charge $q = +40.0\ \mu C$ moves from A to B separated by a distance $d = 0.180$ m in the presence of an external electric field $\vec{\mathbf{E}}$ of magnitude 275 N/C directed toward the right as in Figure P16.6. Find (a) the electric force exerted on the charge, (b) the work done by the electric force, (c) the change in the electric potential energy of the charge, and (d) the potential difference between A and B.

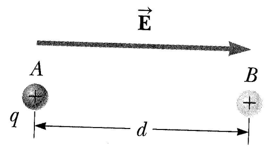

Figure P16.6

7. M Oppositely charged parallel plates are separated by 5.33 mm. A potential difference of 600 V exists between the plates. (a) What is the magnitude of the electric field between the plates? (b) What is the magnitude of the force on an electron between the plates? (c) How much work must be done on the electron to move it to the negative plate if it is initially positioned 2.90 mm from the positive plate?

8. Q|C S (a) Find the potential difference ΔV_e required to stop an electron (called a "stopping potential") moving with an initial speed of 2.85×10^7 m/s. (b) Would a proton traveling at the same speed require a greater or lesser magnitude potential difference? Explain. (c) Find a symbolic expression for the ratio of the proton stopping potential and the electron stopping potential, $\Delta V_p/\Delta V_e$. The answer should be in terms of the proton mass m_p and electron mass m_e.

9. Q|C A 74.0-g block carrying a charge $Q = 35.0\ \mu C$ is connected to a spring for which $k = 78.0$ N/m. The block lies on a frictionless, horizontal surface and is immersed in a uniform electric field of magnitude $E = 4.86 \times 10^4$ N/C directed as shown in Figure P16.9. If the block is released from rest when the spring is unstretched ($x = 0$), (a) by what maximum distance does the block move from its initial position? (b) Find the subsequent equilibrium position of the block and the amplitude of its motion. (c) Using conservation of energy, find a symbolic relationship giving the potential difference between its initial position and the point of maximum extension in terms of the spring constant k, the amplitude A, and the charge Q.

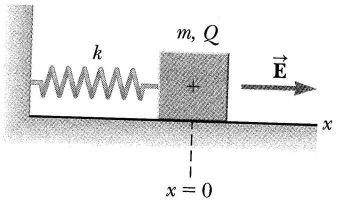

Figure P16.9

10. On planet Tehar, the free-fall acceleration is the same as that on the Earth, but there is also a strong downward electric field that is uniform close to the planet's surface. A 2.00-kg ball having a charge of 5.00 μC is thrown upward at a speed of 20.1 m/s. It hits the ground after an interval of 4.10 s. What is the potential difference between the starting point and the top point of the trajectory?

16.2 Electric Potential and Potential Energy Due to Point Charges

16.3 Potentials and Charged Conductors

16.4 Equipotential Surfaces

11. **Q|C** An electron is at the origin. (a) Calculate the electric potential V_A at point A, $x = 0.250$ cm. (b) Calculate the electric potential V_B at point B, $x = 0.750$ cm. What is the potential difference $V_B - V_A$? (c) Would a negatively charged particle placed at point A necessarily go through this same potential difference upon reaching point B? Explain.

12. The two charges in Figure P16.12 are separated by $d = 2.00$ cm. Find the electric potential at (a) point A and (b) point B, which is halfway between the charges.

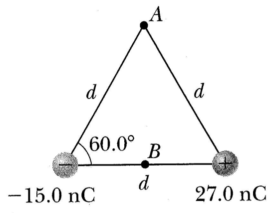

Figure P16.12

13. (a) Find the electric potential, taking zero at infinity, at the upper right corner (the corner without a charge) of the rectangle in Figure P16.13. (b) Repeat if the 2.00-μC charge is replaced with a charge of $-2.00\ \mu$C.

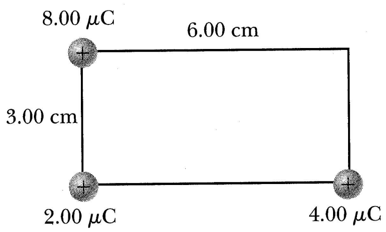

Figure P16.13 Problems 13 and 14.

14. Three charges are situated at corners of a rectangle as in Figure P16.13. How much energy would be expended in moving the 8.00-μC charge to infinity?

15. **M** **Q|C** Two point charges $Q_1 = +5.00$ nC and $Q_2 = -3.00$ nC are separated by 35.0 cm. (a) What is the electric potential at a point midway between the charges? (b) What is the potential energy of the pair of charges? What is the significance of the algebraic sign of your answer?

16. **Q|C** **S** Three identical point charges each of charge q are located at the vertices of an equilateral triangle as in Figure P16.16. The distance from the center of the triangle to each vertex is a. (a) Show that the electric field at the center of the triangle is zero. (b) Find a symbolic expression for the electric potential at the center of the triangle. (c) Give a physical explanation of the fact that the electric potential is not zero, yet the electric field is zero at the center.

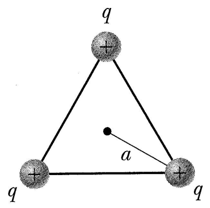

Figure P16.16

17. The three charges in Figure P16.17 are at the vertices of an isosceles triangle. Let $q = 7.00$ nC and calculate the electric potential at the midpoint of the base.

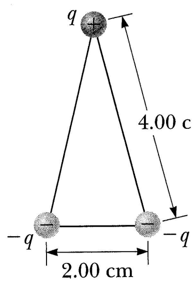

Figure P16.17

18. **S** A positive point charge $q = +2.50$ nC is located at $x = 1.20$ m and a negative charge of $-2q = -5.00$ nC is located at the origin as in Figure P16.18. (a) Sketch the electric potential versus x for points along the x-axis in the range $-1.50\text{ m} < x < 1.50$ m. (b) Find a symbolic expression for the potential on the x-axis at an arbitrary point P between the two charges. (c) Find the electric potential at $x = 0.600$ m. (d) Find the point along the x-axis between the two charges where the electric potential is zero.

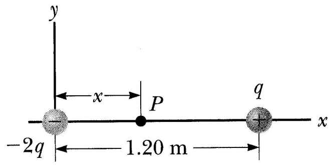

Figure P16.18

19. **GP** A proton is located at the origin, and a second proton is located on the x-axis at $x = 6.00$ fm (1 fm $= 10^{-15}$ m). (a) Calculate the electric potential energy associated with this configuration. (b) An alpha particle (charge $= 2e$, mass $= 6.64 \times 10^{-27}$ kg) is now placed at $(x, y) = (3.00, 3.00)$ fm. Calculate the electric potential energy associated with this configuration. (c) Starting with the three-particle system, find the change in electric potential energy if the alpha particle is allowed to escape to infinity while the two protons remain fixed in place. (Throughout, neglect any radiation effects.) (d) Use conservation of energy to calculate the speed of the alpha particle at infinity. (e) If the two protons are released from rest and the alpha particle remains fixed, calculate the speed of the protons at infinity.

20. **Q|C** A proton and an alpha particle (charge $= 2e$, mass $= 6.64 \times 10^{-27}$ kg) are initially at rest, separated by 4.00×10^{-15} m. (a) If they are both released simultaneously, explain why you can't find their velocities at infinity using only conservation of energy. (b) What other conservation law can be applied in this case? (c) Find the speeds of the proton and alpha particle, respectively, at infinity.

21. A tiny sphere of mass 8.00 m~~μ~~g and charge −2.80 nC is initially at a distance of 1.60 μm from a fixed charge of +8.50 nC. If the 8.00-mg sphere is released from rest, find (a) its kinetic energy when it is 0.500 μm from the fixed charge and (b) its speed when it is 0.500 μm from the fixed charge.

22. The metal sphere of a small Van de Graaff generator illustrated in Figure 15.23 has a radius of 18 cm. When the electric field at the surface of the sphere reaches 3.0×10^6 V/m, the air breaks down, and the generator discharges. What is the maximum potential the sphere can have before breakdown occurs?

23. In Rutherford's famous scattering experiments that led to the planetary model of the atom, alpha particles (having charges of $+2e$ and masses of 6.64×10^{-27} kg) were fired toward a gold nucleus with charge $+79e$. An alpha particle, initially very far from the gold nucleus, is fired at 2.00×10^7 m/s directly toward the nucleus, as in Figure P16.23. How close does the alpha particle get to the gold nucleus before turning around? Assume the gold nucleus remains stationary.

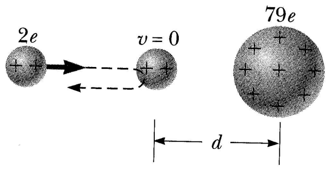

Figure P16.23

24. **S** Four point charges each having charge Q are located at the corners of a square having sides of length a. Find symbolic expressions for (a) the total electric potential at the center of the square due to the four charges and (b) the work required to bring a fifth charge q from infinity to the center of the square.

16.6 Capacitance

16.7 The Parallel-Plate Capacitor

25. Consider the Earth and a cloud layer 800 m above the planet to be the plates of a parallel-plate capacitor. (a) If the cloud layer has an area of $1.0 \text{ km}^2 = 1.0 \times 10^6 \text{ m}^2$, what is the capacitance? (b) If an electric field strength greater than 3.0×10^6 N/C causes the air to break down and conduct charge (lightning), what is the maximum charge the cloud can hold?

26. (a) When a 9.00-V battery is connected to the plates of a capacitor, it stores a charge of 27.0 μC. What is the value of the capacitance? (b) If the same capacitor is connected to a 12.0-V battery, what charge is stored?

27. An air-filled parallel-plate capacitor has plates of area 2.30 cm^2 separated by 1.50 mm. The capacitor is connected to a 12.0-V battery. (a) Find the value of its capacitance. (b) What is the charge on the capacitor? (c) What is the magnitude of the uniform electric field between the plates?

28. Two conductors having net charges of +10.0 μC and −10.0 μC have a potential difference of 10.0 V between them. (a) Determine the capacitance of the system. (b) What is the potential difference between the two conductors if the charges on each are increased to +100 μC and −100 μC?

29. **M** An air-filled capacitor consists of two parallel plates, each with an area of 7.60 cm^2 and separated by a distance of 1.80 mm. If a 20.0-V potential difference is applied to these plates, calculate (a) the electric field between the plates, (b) the capacitance, and (c) the charge on each plate.

30. A 1-megabit computer memory chip contains many 60.0×10^{-15}-F capacitors. Each capacitor has a plate area of 21.0×10^{-12} m^2. Determine the plate separation of such a capacitor. (Assume a parallel-plate configuration.) The diameter of an atom is on the order of 10^{-10} m = 1 Å. Express the plate separation in angstroms.

31. **QIC** A parallel-plate capacitor with area 0.200 m^2 and plate separation of 3.00 mm is connected to a 6.00-V battery. (a) What is the capacitance? (b) How much charge is stored on the plates? (c) What is the electric field between the plates? (d) Find the magnitude of the charge density on each plate. (e) Without disconnecting the battery, the plates are moved farther apart. Qualitatively, what happens to each of the previous answers?

32. A small object with a mass of 350 μg carries a charge of 30.0 nC and is suspended by a thread between the vertical plates of a parallel-plate capacitor. The plates are separated by 4.00 cm. If the thread makes an angle of 15.0° with the vertical, what is the potential difference between the plates?

16.8 Combinations of Capacitors

33. Given a 2.50-μF capacitor, a 6.25-μF capacitor, and a 6.00-V battery, find the charge on each capacitor if you connect them (a) in series across the battery and (b) in parallel across the battery.

34. Two capacitors, $C_1 = 5.00$ μF and $C_2 = 12.0$ μF, are connected in parallel, and the resulting combination is connected to a 9.00-V battery. Find (a) the equivalent capacitance of the combination, (b) the potential difference across each capacitor, and (c) the charge stored on each capacitor.

35. Find (a) the equivalent capacitance of the capacitors in Figure P16.35, (b) the charge on each capacitor, and (c) the potential difference across each capacitor.

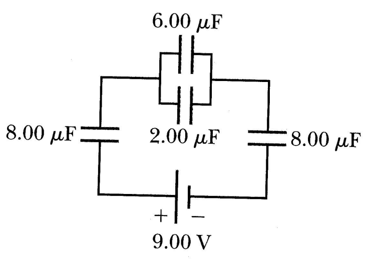

Figure P16.35

36. Two capacitors give an equivalent capacitance of 9.00 pF when connected in parallel and an equivalent capacitance of 2.00 pF when connected in series. What is the capacitance of each capacitor?

37. For the system of capacitors shown in Figure P16.37, find (a) the equivalent capacitance of the system, (b) the charge on each capacitor, and (c) the potential difference across each capacitor.

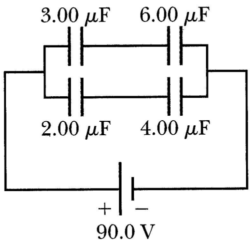

Figure P16.37 Problems 37 and 56.

38. **GP** Consider the combination of capacitors in Figure P16.38. (a) Find the equivalent single capacitance of the two capacitors in series and redraw the diagram (called diagram 1) with this equivalent capacitance. (b) In diagram 1 find the equivalent capacitance of the three capacitors in parallel and redraw the diagram as a single battery and single capacitor in a loop. (c) Compute the charge on the single equivalent capacitor. (d) Returning to diagram 1, compute the charge on each individual capacitor. Does the sum agree with the value found in part (c)? (e) What is the charge on the 24.0-μF capacitor and on the 8.00-μF capacitor? Compute the voltage drop across (f) the 24.0-μF capacitor and (g) the 8.00-μF capacitor.

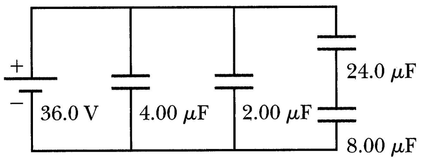

Figure P16.38

39. Find the charge on each of the capacitors in Figure P16.39.

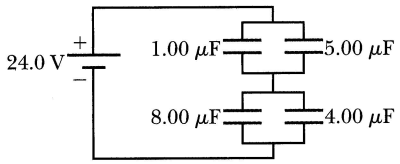

Figure P16.39

40. **Q|C** **S** Three capacitors are connected to a battery as shown in Figure P16.40. Their capacitances are $C_1 = 3C$, $C_2 = C$, and $C_3 = 5C$. (a) What is the equivalent capacitance of this set of capacitors? (b) State the ranking of the capacitors according to the charge they store from largest to smallest. (c) Rank the capacitors according to the potential differences across them from largest to smallest. (d) Assume C_3 is increased. Explain what happens to the charge stored by each capacitor.

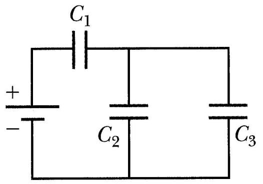

Figure P16.40

41. A 25.0-μF capacitor and a 40.0-μF capacitor are charged by being connected across separate 50.0-V batteries. (a) Determine the resulting charge on each capacitor. (b) The capacitors are then disconnected from their batteries and connected to each other, with each negative plate connected to the other positive plate. What is the final charge of each capacitor? (c) What is the final potential difference across the 40.0-μF capacitor?

42. (a) Find the equivalent capacitance between points *a* and *b* for the group of capacitors connected as shown in Figure P16.42 if $C_1 = 5.00\ \mu$F, $C_2 = 10.00\ \mu$F, and $C_3 = 2.00\ \mu$F. (b) If the potential between points *a* and *b* is 60.0 V, what charge is stored on C_3?

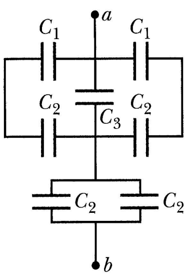

Figure P16.42

43. A 1.00-μF capacitor is charged by being connected across a 10.0-V battery. It is then disconnected from the battery and connected across an uncharged 2.00-μF capacitor. Determine the resulting charge on each capacitor.

44. **M** Four capacitors are connected as shown in Figure P16.44. (a) Find the equivalent capacitance between points *a* and *b*. (b) Calculate the charge on each capacitor, taking $\Delta V_{ab} = 15.0$ V.

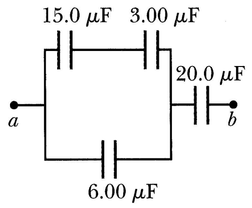

Figure P16.44

16.9 Energy Stored in a Charged Capacitor

45. A 12.0-V battery is connected to a 4.50-μF capacitor. How much energy is stored in the capacitor?

46. **Q|C** Two capacitors, $C_1 = 18.0\ \mu$F and $C_2 = 36.0\ \mu$F, are connected in series, and a 12.0-V battery is connected across them. (a) Find the equivalent capacitance, and the energy contained in this equivalent capacitor. (b) Find the energy stored in each individual capacitor. Show that the sum of these two energies is the same as the energy found in part (a). Will this equality always be true, or does it depend on the number of capacitors and their capacitances? (c) If the same capacitors were connected in parallel, what potential difference would be required across them so that the combination stores the same energy as in part (a)? Which capacitor stores more energy in this situation, C_1 or C_2?

47. A parallel-plate capacitor has capacitance 3.00 μF. (a) How much energy is stored in the capacitor if it is connected to a 6.00-V battery? (b) If the battery is disconnected and the distance between the charged plates doubled, what is the energy stored? (c) The battery is subsequently reattached to the capacitor, but the plate separation remains as in part (b). How much energy is stored? (Answer each part in microjoules.)

48. A certain storm cloud has a potential difference of 1.00×10^8 V relative to a tree. If, during a lightning storm, 50.0 C of charge is transferred through this potential difference and 1.00% of the energy is absorbed by the tree, how much water (sap in the tree) initially at 30.0°C can be boiled away? Water has a specific heat of 4 186 J/kg°C, a boiling point of 100°C, and a heat of vaporization of 2.26×10^6 J/kg.

16.10 Capacitors with Dielectrics

49. Q|C The voltage across an air-filled parallel-plate capacitor is measured to be 85.0 V. When a dielectric is inserted and completely fills the space between the plates as in Figure P16.49, the voltage drops to 25.0 V. (a) What is the dielectric constant of the inserted material? Can you identify the dielectric? (b) If the dielectric doesn't completely fill the space between the plates, what could you conclude about the voltage across the plates?

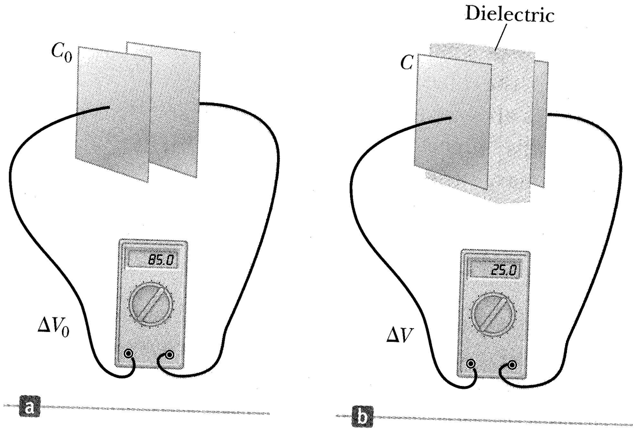

Figure P16.49

50. (a) How much charge can be placed on a capacitor with air between the plates before it breaks down if the area of each plate is 5.00 cm^2? (b) Find the maximum charge if polystyrene is used between the plates instead of air. Assume the dielectric strength of air is 3.00×10^6 V/m and that of polystyrene is 24.0×10^6 V/m.

51. Determine (a) the capacitance and (b) the maximum voltage that can be applied to a Teflon-filled parallel-plate capacitor having a plate area of 175 cm^2 and an insulation thickness of 0.040 0 mm.

52. Consider a plane parallel-plate capacitor made of two strips of aluminum foil separated by a layer of paraffin-coated paper. Each strip of foil and paper is 7.00 cm wide. The foil is 0.004 00 mm thick, and the paper is 0.025 0 mm thick and has a dielectric constant of 3.70. What length should the strips be if a capacitance of 9.50×10^{-8} F is desired? (If, after this plane capacitor is formed, a second paper strip can be added below the foil-paper-foil stack and the resulting assembly rolled into a cylindrical form—similar to that shown in Figure 16.26—the capacitance can be doubled because both surfaces of each foil strip would then store charge. Without the second strip of paper, however, rolling the layers would result in a short circuit.)

53. BIO A model of a red blood cell portrays the cell as a spherical capacitor, a positively charged liquid sphere of surface area A separated from the surrounding negatively charged fluid by a membrane of thickness t. Tiny electrodes introduced into the interior of the cell show a potential difference of 100 mV across the membrane. The membrane's thickness is estimated to be 100 nm and has a dielectric constant of 5.00. (a) If an average red blood cell has a mass of 1.00×10^{-12} kg, estimate the volume of the cell and thus find its surface area. The density of blood is 1 100 kg/m^3. (b) Estimate the capacitance of the cell by assuming the membrane surfaces act as parallel plates. (c) Calculate the charge on the surface of the membrane. How many electronic charges does the surface charge represent?

Additional Problems

54. When a potential difference of 150 V is applied to the plates of an air-filled parallel-plate capacitor, the plates carry a surface charge density of 3.00×10^{-10} C/cm^2. What is the spacing between the plates?

55. S Three parallel-plate capacitors are constructed, each having the same plate area A and with C_1 having plate spacing d_1, C_2 having plate spacing d_2, and C_3 having plate spacing d_3. Show that the total capacitance C of the three capacitors connected in series is the same as a capacitor of plate area A and with plate spacing $d = d_1 + d_2 + d_3$.

56. Q|C For the system of four capacitors shown in Figure P16.37, find (a) the total energy stored in the system and (b) the energy stored by each capacitor. (c) Compare the sum of the answers in part (b) with your result to part (a) and explain your observation.

57. S A parallel-plate capacitor with a plate separation d has a capacitance C_0 in the absence of a dielectric. A slab of dielectric material of dielectric constant κ and thickness $d/3$ is then inserted between the plates as in

Figure P16.57a. Show that the capacitance of this partially filled capacitor is given by

$$C = \left(\frac{3\kappa}{2\kappa + 1}\right)C_0$$

Hint: Treat the system as two capacitors connected in series as in Figure P16.57b, one with dielectric in it and the other one empty.

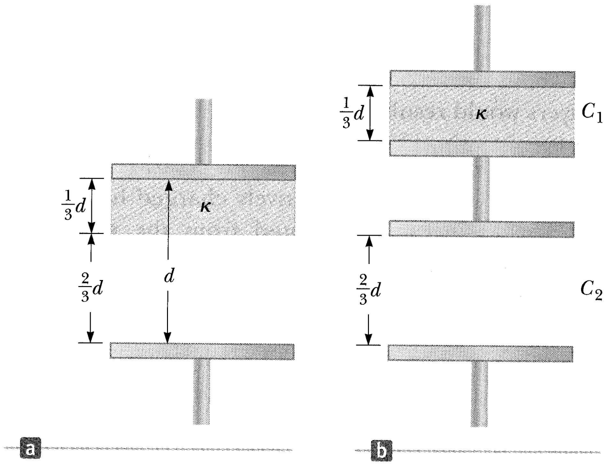

Figure P16.57

58. **S** Two capacitors give an equivalent capacitance of C_p when connected in parallel and an equivalent capacitance of C_s when connected in series. What is the capacitance of each capacitor?

59. **M** A parallel-plate capacitor is constructed using a dielectric material whose dielectric constant is 3.00 and whose dielectric strength is 2.00×10^8 V/m. The desired capacitance is 0.250 μF, and the capacitor must withstand a maximum potential difference of 4.00 kV. Find the minimum area of the capacitor plates.

60. Two charges of 1.0 μC and -2.0 μC are 0.50 m apart at two vertices of an equilateral triangle as in Figure P16.60. (a) What is the electric potential due to the 1.0-μC charge at the third vertex, point *P*? (b) What is the electric potential due to the -2.0-μC charge at *P*? (c) Find the total electric potential at *P*. (d) What is the work required to move a 3.0-μC charge from infinity to *P*?

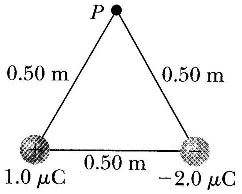

Figure P16.60

61. Find the equivalent capacitance of the group of capacitors shown in Figure P16.61.

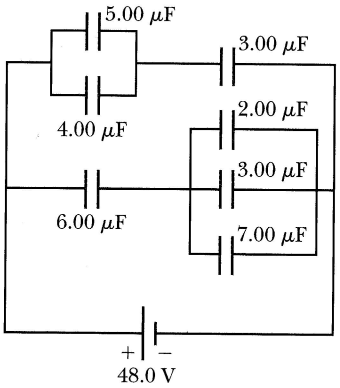

Figure P16.61

62. A spherical capacitor consists of a spherical conducting shell of radius *b* and charge $-Q$ concentric with a smaller conducting sphere of radius *a* and charge *Q*. (a) Find the capacitance of this device. (b) Show that as the radius *b* of the outer sphere approaches infinity, the capacitance approaches the value $a/k_e = 4\pi\epsilon_0 a$.

63. **BIO** The immediate cause of many deaths is ventricular fibrillation, an uncoordinated quivering of the heart, as opposed to proper beating. An electric shock to the chest can cause momentary paralysis of the heart muscle, after which the heart will sometimes start organized beating again. A *defibrillator* is a device that applies a strong electric shock to the chest over a time of a few milliseconds. The device contains a capacitor of a few microfarads, charged to several thousand volts. Electrodes called paddles, about 8 cm across and coated with conducting paste, are held against the chest on both sides of the heart. Their handles are insulated to prevent injury to the operator, who calls "Clear!" and pushes a button on one paddle to discharge the capacitor through the patient's chest. Assume an energy of 300 W · s is to be delivered from a 30.0-μF capacitor. To what potential difference must it be charged?

64. When a certain air-filled parallel-plate capacitor is connected across a battery, it acquires a charge of 150 μC on each plate. While the battery connection is maintained, a dielectric slab is inserted into, and fills, the region between the plates. This results in the accumulation of an additional charge of 200 μC on each plate. What is the dielectric constant of the slab?

65. Capacitors C_1 = 6.0 μF and C_2 = 2.0 μF are charged as a parallel combination across a 250-V battery. The capacitors are disconnected from the battery and from each other. They are then connected positive plate to negative plate and negative plate to positive plate. Calculate the resulting charge on each capacitor.

66. **S** Two positive charges each of charge q are fixed on the y-axis, one at $y = d$ and the other at $y = -d$ as in Figure P16.66. A third positive charge $2q$ located on the x-axis at $x = 2d$ is released from rest. Find symbolic expressions for (a) the total electric potential due to the first two charges at the location of the charge $2q$, (b) the electric potential energy of the charge $2q$, (c) the kinetic energy of the charge $2q$ after it has moved infinitely far from the other charges, and (d) the speed of the charge $2q$ after it has moved infinitely far from the other charges if its mass is m.

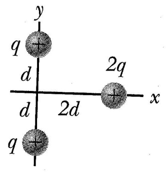

Figure P16.66

67. Metal sphere A of radius 12.0 cm carries 6.00 μC of charge, and metal sphere B of radius 18.0 cm carries -4.00 μC of charge. If the two spheres are attached by a very long conducting thread, what is the final distribution of charge on the two spheres?

68. An electron is fired at a speed $v_0 = 5.6 \times 10^6$ m/s and at an angle $\theta_0 = -45°$ between two parallel conducting plates that are $D = 2.0$ mm apart, as in Figure P16.68. If the voltage difference between the plates is $\Delta V = 100$ V, determine (a) how close, d, the electron will get to the bottom plate and (b) where the electron will strike the top plate.

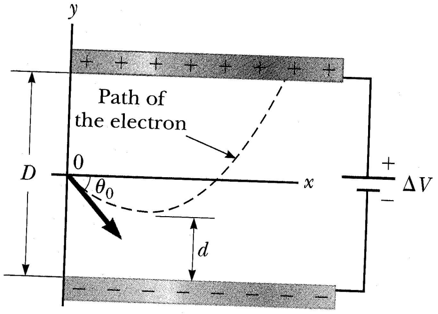

Figure P16.68