PROBLEMS

1, **2**, **3** = straightforward, intermediate, challenging ☐ = full solution available in Student Solutions Manual/Study Guide = biomedical application

Section 15.3 Coulomb's Law

1. A 4.5×10^{-9} C charge is located 3.2 m from a -2.8×10^{-9} C charge. Find the electrostatic force exerted by one charge on the other.

2. Two neighboring cells are ionized (charged) by x-radiation. (a) If the charge on each cell is equal to 1.60×10^{-14} C and the cells are 2.5 μm apart, what is the force exerted by each cell? (b) If the distance between the cells is doubled, what happens to the force between them?

3. An alpha particle (charge = $+2.0e$) is sent at high speed toward a gold nucleus (charge = $+79e$). What is the electrical force acting on the alpha particle when it is 2.0×10^{-14} m from the gold nucleus?

4. Determine what the mass of a proton would be if the gravitational force between two of them were equal to the electrical force between them.

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 will be the magnitude of the acceleration of the alpha particles due to this force? Note that the mass of an alpha particle is 4.0026 u.

6. 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. Suppose that 1.00 g of hydrogen is separated into electrons and protons. Suppose also that the protons are placed at Earth's North Pole and the electrons are placed at the South Pole. What is the resulting compressional force on Earth?

8. An electron is released a short distance above Earth's surface. A second electron directly below it exerts an electrostatic force on the first electron just great enough to cancel the gravitational force on it. How far below the first electron is the second?

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

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

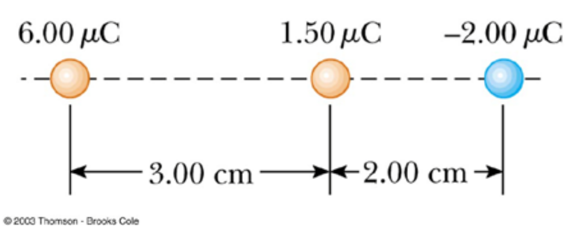

Figure P15.10

11. 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.

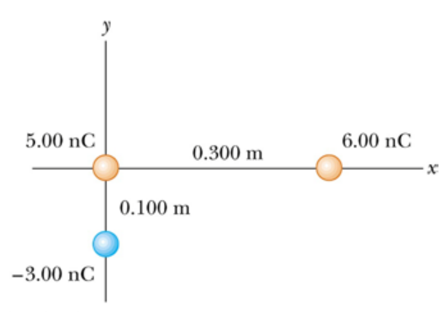

Figure P15.11

12. Three charges are arranged as shown in Figure P15.12. Find the magnitude and direction of the electrostatic force on the 6.00-nC charge.

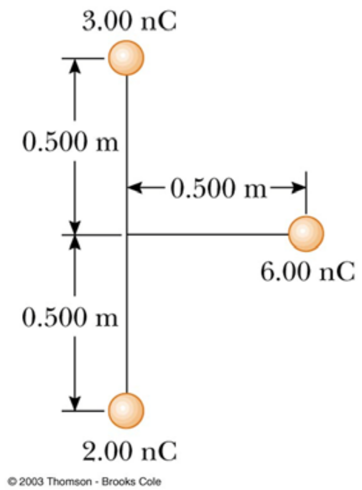

Figure P15.12

13. Three point charges are located at the corners of an equilateral triangle as in Figure P15.13. Calculate the net electric force on the 7.00-μC charge.

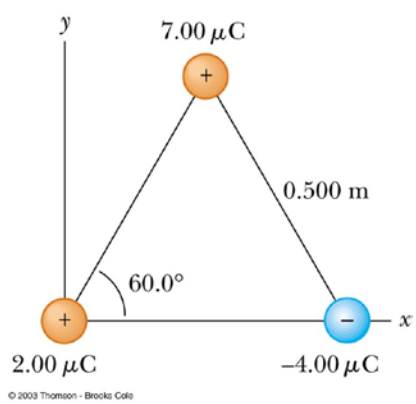

Figure P15.13

14. Two small beads having positive charges 3*q* and *q* are fixed at the opposite ends of a horizontal, insulating rod, extending from the origin to the point *x* × *d*. As in Figure P15.14, a third small charged bead is free to slide on the rod. At what position is the third bead in equilibrium? Can it be in stable equilibrium?

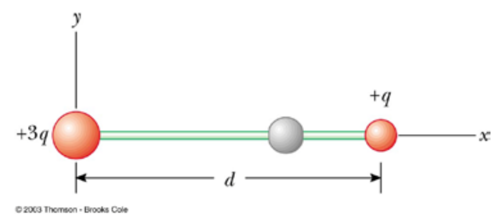

Figure P15.14

15. Two small metallic spheres, each of mass 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 the two come to equilibrium when each string is at an angle of 5.0° with the vertical. If each string is 30.0 cm long, what is the magnitude of the charge on each sphere?

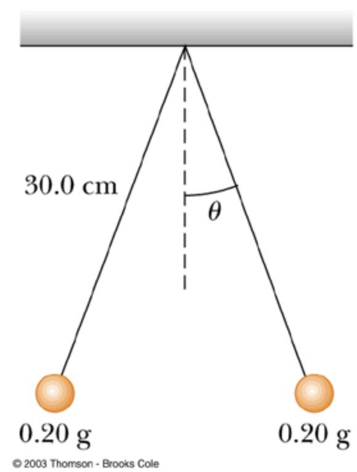

Figure P15.15

16. A charge of 6.00×10^{-9} C and a charge of -3.00×10^{-9} C are separated by a distance of 60.0 cm. Find the position at which a third charge of 12.0×10^{-9} C can be placed so that the net electrostatic force on it is zero.

Section 15.4 The Electric Field

17. In a hydrogen atom, what are the magnitude and direction of the electric field set up by the proton at the location of the electron (0.51×10^{-10} m away from the proton)?

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 airplane is flying through a thundercloud at a height of 2 000 m. (This is a very dangerous thing to do because of updrafts, turbulence, and the possibility of electric discharge.) If there are charge concentrations of +40.0 C at height 3 000 m within the cloud and –40.0 C at height 1 000 m, what is the electric field **E** at the aircraft?

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 piece of aluminum foil of mass 5.00×10^{-2} kg is suspended by a string in an electric field directed vertically upward. If the charge on the foil is 3.00 μC, find the strength of the field that will reduce the tension in the string to zero.

22. An electron with a speed of 3.00×10^{6} m/s moves into a uniform electric field of 1 000 N/C. The field is parallel to the electron's motion. How far does the electron travel before it is brought to rest?

23. 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 this interval? (d) What is its kinetic energy at the later time?

24. Positive charges are situated at three corners of a rectangle, as shown in Figure P15.24. Find the electric field at the fourth corner.

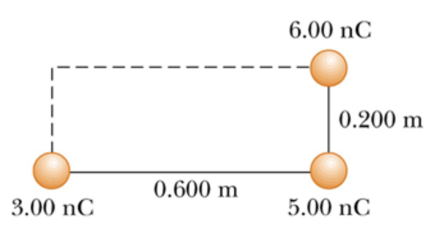

Figure P15.24

25. Three identical charges (q = –5.0 μC) are along a circle of 2.0-m radius at angles of 30°, 150°, and 270°, as shown in Figure P15.25. What is the resultant electric field at the center of the circle?

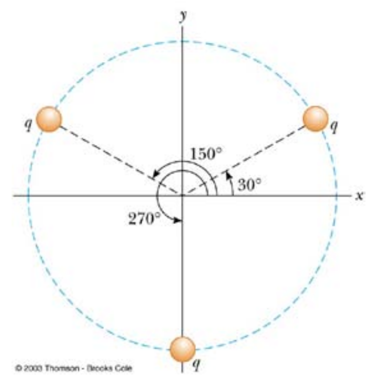

Figure P15.25

26. Two point charges lie along the y axis. A charge of q_1 = –9.0 μC is at y = 6.0 m, and a charge of q_2 = –8.0 μC is at y = –4.0 m. Locate the point (other than infinity) at which the total electric field is zero.

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

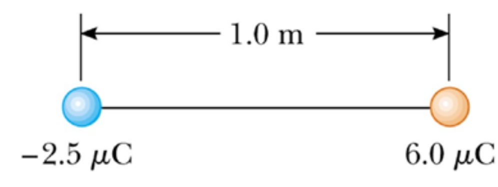

Figure P15.27

Section 15.5 Electric Field Lines

Section 15.6 Conductors in Electrostatic Equilibrium

28. Figure P15.28 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?

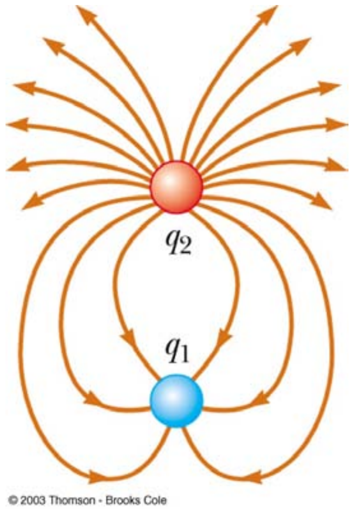

Figure P15.28

$\boxed{\textbf{29.}}$ (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 $-2q$.

30. (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 μC placed close together. (c) Sketch the pattern around two point charges of +1 μC and –2 μC placed close together.

31. 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.

32. (a) Sketch the electric field pattern set up by a positively charged hollow sphere. Include the regions both inside and outside the sphere. (b) A conducting cube is given a positive charge. Sketch the electric field pattern both inside and outside the cube.

33. 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.

Section 15.8 The Van de Graaff Generator

34. 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 the fact that the points on the surface are outside a spherically symmetric charge distribution; the total charge may be considered as located at the center of the sphere.)

$\boxed{\textbf{35.}}$ 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 34.)

36. Air breaks down (loses its insulating quality) and sparking results if the field strength is increased to about 3.0×10^{6} N/C. (a) What acceleration does an electron experience in such a field? (b) If the electron starts from rest, in what distance does it acquire a speed equal to 10% of the speed of light?

37. A Van de Graaff generator is charged so that the electric field at its surface is 3.0×10^{4} N/C. Find (a) the electric force exerted on a proton released at its surface and (b) the acceleration of the proton at this instant of time.

Section 15.9 Electric Flux and Gauss's Law

38. A flat surface having an area of 3.2 m^2 is rotated in a uniform electric field of magnitude $E = 6.2 \times 10^{5}$ N/C. Determine the electric flux through this area (a) when the electric field is perpendicular to the surface and (b) when the electric field is parallel to the surface.

39. 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.

40. The electric field everywhere on the surface of a thin spherical shell of radius 0.750 m is measured to be equal to 890 N/C and points radially toward the center of the sphere. (a) What is the net charge within the sphere's surface? (b) What can you conclude about the nature and distribution of the charge inside the spherical shell?

41. A 40-cm-diameter loop is rotated in a uniform electric field until the position of maximum electric flux is found. The flux in this position is measured to be 5.2×10^5 N · m^2/C. Calculate the electric field strength in this region.

42. A point charge of +5.00 μC is located at the center of a sphere with a radius of 12.0 cm. Determine the electric flux through the surface of the sphere.

43. A point charge q is located at the center of a spherical shell of radius a, which 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.

44. Use Gauss's law and the fact that the electric field inside any closed conductor in electrostatic equilibrium is zero to show that any excess charge placed on the conductor must reside on its surface.

45. An infinite plane conductor has charge spread out on its surface as shown in Figure P15.45. Use Gauss's law to show that the electric field at any point outside the conductor is given by $E = \sigma/\varepsilon_0$, where σ is the charge per unit area on the conductor. (*Hint:* Choose a gaussian surface in the shape of a cylinder with one end inside the conductor and one end outside the conductor.)

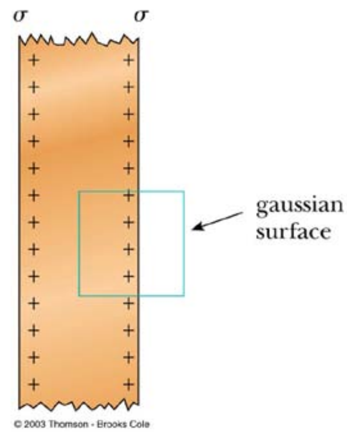

Figure P15.45

46. Show that the electric field just outside the surface of a good conductor of any shape is given by $E = \sigma/\varepsilon_0$, where σ is the charge per unit area on the conductor. (*Hint:* The electric field just outside the surface of a charged conductor is perpendicular to its surface.)

ADDITIONAL PROBLEMS

47. Two protons in an atomic nucleus are typically separated by a distance of 2×10^{-15} m. The electric repulsion force between the protons is huge, but the attractive nuclear force is even stronger, and keeps the nucleus from bursting apart. What is the magnitude of the electrical force between two protons separated by 2.00×10^{-15} m?

48. In the Bohr theory of the hydrogen atom, an electron moves in a circular orbit about a proton, where the radius of the orbit is 0.53×10^{-10} m. (a) Find the electrostatic force acting on each particle. (b) If this force causes the centripetal acceleration of the electron, what is the speed of the electron?

49. Three point charges are aligned along the x axis as shown in Figure P15.49. Find the electric field at the position $x = +2.0$ m, $y = 0$.

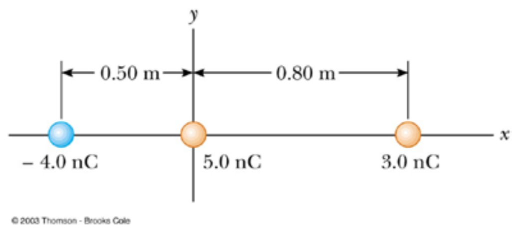

Figure P15.49

50. A small 2.00-g plastic ball is suspended by a 20.0-cm-long string in a uniform electric field, as shown in Figure P15.50. If the ball is in equilibrium when the string makes a 15.0° angle with the vertical as indicated, what is the net charge on the ball?

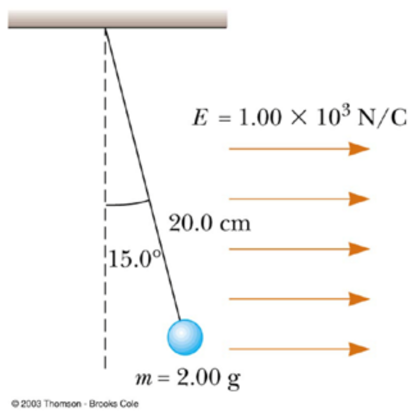

Figure P15.50

51. (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 very many pairs of identical point charges positioned at ends of diameters of the ring.)

52. A positively charged bead having a mass of 1.00 g falls from rest in a vacuum from a height of 5.00 m in a uniform vertical electric field with a magnitude of 1.00×10^4 N/C. The bead hits the ground at a speed of 21.0 m/s. Determine (a) the direction of the electric field (up or down), and (b) the charge on the bead.

53. 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.

54. Two small silver spheres, each with a mass of 100 g, are separated by 1.00 m. Calculate the fraction of the electrons in one sphere that must be transferred to the other in order to produce an attractive force of 1.00×10^4 N (about a ton) between the spheres. (The number of electrons per atom of silver is 47, and the number of atoms per gram is Avogadro's number divided by the molar mass of silver, 107.87.)

55. A vertical electric field of magnitude 2.00×10^4 N/C exists above Earth's surface on a day when a thunderstorm is brewing. A car with a rectangular size of 6.00 m by 3.00 m is traveling along a roadway sloping downward at 10.0°. Determine the electric flux through the bottom of the car.

56. A 2.00-μC charged 1.00-g cork ball 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. If the ball is displaced slightly from the vertical, it oscillates like a simple pendulum. (a) Determine the period of this oscillation. (b) Should gravity be included in the calculation for part (a)? Explain.

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 $\theta = 10°$.

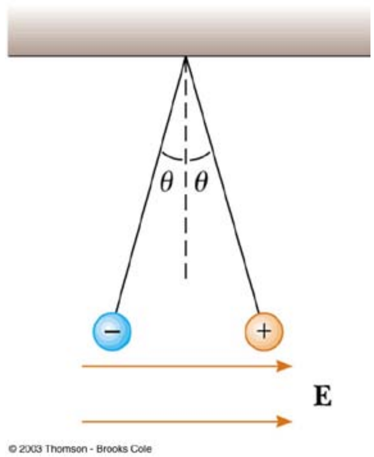

Figure P15.57

58. Two point charges like those in Figure P15.58 are called an electric dipole. Show that the electric field at a distant point along the x axis is given by the expression $E_x = 4k_e qa/x^3$.

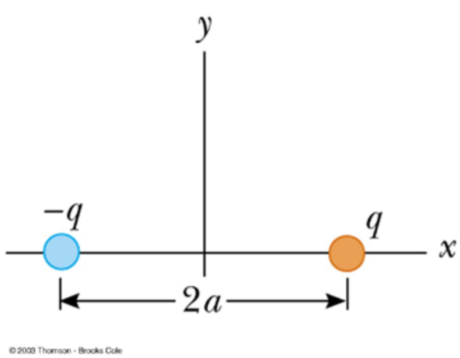

Figure P15.58

59. A charged cork ball of mass 1.00 g is suspended on a light string in the presence of a uniform electric field as in Figure P15.59. When the electric field has an x component of 3.00×10^5 N/C and a y component of 5.00×10^5 N/C, the ball is in equilibrium at $\theta = 37.0°$. Find (a) the charge on the ball and (b) the tension in the string.

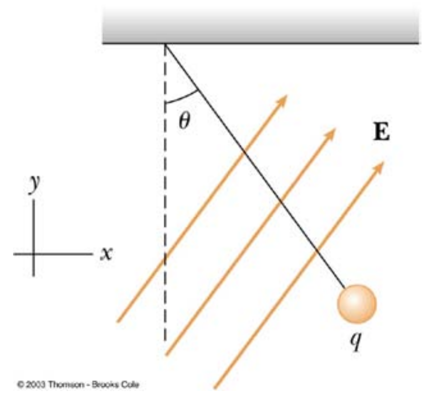

Figure P15.59