End-of-Chapter Exercises

Exercises 1 – 12 are primarily conceptual questions designed to see whether you understand the main concepts of the chapter.

1. (a) If the electric field at a particular point is zero, does that imply that the electric potential is also zero at that point? If so, explain why. If not, give an example involving two or more point charges where the electric field is zero at a point but the electric potential is not. (b) If the electric potential at a particular point is zero, does that imply that the electric field is also zero at that point? If so, explain why. If not, give an example involving two or more point charges where the electric potential is zero at a point but the electric field is non-zero there.

2. For interactions between point charges, the electric potential energy is defined to be zero when the charges are separated by an infinite distance. Is it possible for a collection of two or more point charges to have an electric potential energy of zero when the charges are finite distances from one another? If not, explain why not. If so, give an example in which this happens.

3. An electric dipole consists of two charged particles, one with a charge of $+Q$ and the other with a charge of $-Q$, separated by some distance. In a particular dipole, the positive charge is located on the x-axis at $x = +10$ cm, and the negative charge is located on the x-axis at $x = -10$ cm. Assume non-conservative forces, and gravitational interactions, are negligible for this situation. (a) How much net work do you need to do to bring a third particle, with a charge of $+2Q$, from very far away to the origin if you bring the charge toward the origin along the positive y-axis? Justify your answer. (b) How much net work do you need to do if you bring the third particle to the origin by a more circuitous route, via a path that takes it quite close to the particle of charge $+Q$? Justify your answer.

4. (a) Sketch field lines that represent a uniform field directed down. Add some equipotential lines to your sketch. (b) Make a second diagram that shows a second electric field with twice the magnitude and the same direction as the first field. Add equipotential lines to this diagram so that the potential difference between the lines is the same as that in your first diagram.

5. Figure 17.16 shows electric field lines and equipotentials in three different regions. Comment on each diagram, stating either that it is physically possible or, if not, what is wrong with the situation shown.

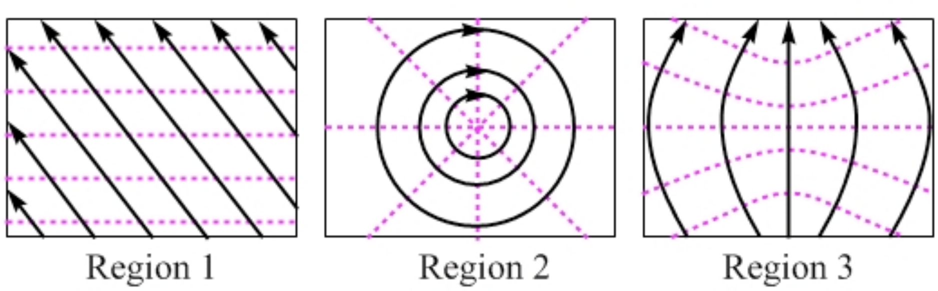

Figure 17.16: State whether the field lines (black arrows) and equipotential lines (dashed lines) are physically correct. For Exercise 5.

6. Two charged balls are placed on the *x*-axis, as shown in Figure 17.17. The first ball has a charge $+q$ and is located at the origin, while the second ball has a charge $+3q$ and is located at $x = +4a$. A third charged ball is now brought in and placed nearby. Your goal is to determine the sign of the charge on the third ball, and to narrow down its location. (a) The force on the third ball is in the $+x$ direction, with no component in any other direction. What, if anything, does this tell you about the third ball? (b) When the third ball is added to the system, the potential at $x = 2a$ decreases. What, if anything, do you know about the third ball now? (c) When the third ball is added to the system, the force on the ball of charge $+q$ increases, while the force on the ball of charge $+3q$ decreases. Both these forces maintain their original directions. What, if anything, do you know about the third ball now?

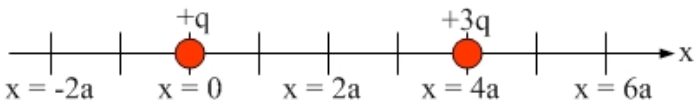

Figure 17.17: Two charged balls on the *x*-axis. For Exercise 6.

7. Four charged balls, with charges of $+4q$, $-5q$, $-6q$, and $-q$, are placed on either the *x* or *y* axes as shown in Figure 17.18. Each charge is the same distance from the origin. You will now remove one of the charged balls from the system. Which charged ball should you remove to cause (a) the largest decrease in the magnitude of the electric field at the origin? (b) the largest increase in the potential at the origin? (c) the largest increase in the potential energy of the system?

8. Return to the system of four charged balls described in Exercise 7 and shown in Figure 17.18. The system is now changed by reversing the sign of each of the charges. Describe what effect, if any, that change has on the answers to Exercise 7.

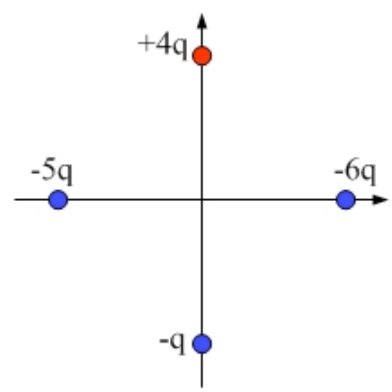

Figure 17.18: Four charged balls are placed on either the *x* or *y* axis so that each ball is the same distance from the origin. For Exercises 7 and 8.

9. A parallel-plate capacitor is connected to a battery that has a voltage of V_0. The capacitor has an initial capacitance of C_0, with a dielectric of dielectric constant three times larger than that of air filling the space between the plates. The capacitor stores a charge Q_0, has an electric field of magnitude of E_0, and stores an energy U_0. With the battery still connected to the capacitor, the dielectric is removed, leaving air between the plates. The distance between the plates is then decreased by a factor of 2. Make a table to show the potential difference, capacitance, charge, magnitude of the field inside the capacitor, and energy stored by the capacitor, in terms of their initial values, after each change is made.

10. Repeat Exercise 9 but, this time, the wires connecting the capacitor to the battery are removed before the changes are made.

11. Return to the situation described in Exploration 17.7B. When the dielectric is inserted, the energy stored by the capacitor is reduced by a factor of 5. If the dielectric is removed, the energy returns to its original value. (a) Where does the energy go when the dielectric is inserted? (b) Where does the energy come from when the dielectric is removed?

12. A parallel-plate capacitor with air between the plates is connected to a 12-volt battery. (a) What is the potential difference across the capacitor? (b) Without bringing in additional batteries, is it possible to increase the potential difference across the capacitor to 36 V, by making changes such as removing the battery and/or changing the separation between the plates? If so, describe how you could do it. If not, explain why not.

Exercises 13 – 19 deal with electric potential energy.

13. In the Bohr model of the hydrogen atom, the electron in the ground state is a distance of 5.3×10^{-11} m from the proton in the nucleus. Assuming the proton remains at rest, what is the escape speed of the electron? In other words, if the electron was given an initial velocity directed away from the proton, what is the minimum speed it has to have to completely escape from the proton? Assume nothing but the proton influences the electron.

14. Two charged objects are released from rest when they are a particular distance apart. As they accelerate away from one another, their velocities are always equal in magnitude and opposite in direction. Assuming that the only thing acting on one object is the other object, are the following statements true or false? Justify each answer. Statement 1 – The two objects have charges of the same sign. Statement 2 – The two objects have charges of the same magnitude. Statement 3 – The two objects have equal mass.

15. Return to the situation described in Exercise 14. Let's say that the objects are identical small balls with the same mass and charge. If each ball has a mass of 25 grams, a charge of 5.0×10^{-6} C, and is originally separated by 8.0 cm, how fast is each ball moving when the separation between the balls has doubled?

16. Three balls, with charges of $+4q$, $-2q$, and $-q$, are equally spaced along a line. The spacing between the balls is r. We can arrange the balls in three different ways, as shown in Figure 17.19. In each case the balls are in an isolated region of space very far from anything else. (a) Rank the arrangements according to their potential energy, from most positive to most negative. See if you can do this without explicitly calculating the potential energy in each case. (b) Verify your answer to part (a) by calculating the potential energy in each case.

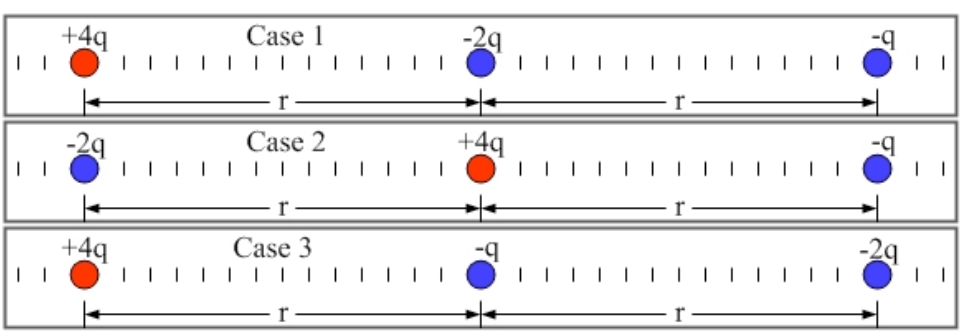

Figure 17.19: Three different arrangements of three balls of charge $+4q$, $-2q$, and $-q$ placed on a line with a distance r between neighboring balls. For Exercises 16 and 17.

17. Consider the three arrangements of charged balls shown in Figure 17.19. When assembling these arrangements, the middle ball is the last one added to the system in each case. How much work do you have to do, against the forces applied by the other two balls, to bring the middle ball from infinity to the point halfway between the other balls in (a) Case 1? (b) Case 2?, (c) Case 3?

18. An electron and a proton are each released from rest in a uniform electric field that has a magnitude of 500 N/C. The energy and speed of each particle is measured after it has moved through a distance of 25 cm. Assume the particles do not influence one another, but are influenced only by the electric field. Without doing any calculations, determine which particle (a) has more kinetic energy, (b) has a higher speed, (c) takes more time to cover 25 cm. Justify your answers. Now calculate the kinetic energy, speed, and elapsed time for (d) the electron, and (e) the proton.

19. In an electron beam in a cathode ray tube television, the electrons are accelerated from rest through a potential difference of 15 kV on their way to the screen. What is the speed of the electrons?

Exercises 20 – 26 deal with electric potential.

20. A ball of with a charge of $+6q$ is placed on the x-axis at $x = -2a$. There is a second ball of unknown charge at $x = +a$. If the net electric potential at the origin due to the two balls is $+\frac{2kq}{a}$, what is the charge of the second ball? Find all possible solutions.

21. A single point charge is located at an unknown point on the x-axis. There are no other charged objects nearby. You measure the electric potential at $x = +2.0$ m to be –200 volts, while the potential at $x = +5.0$ m is –400 volts. What is the sign and magnitude of the point charge, and where is it located? State all possible answers.

22. A single point charge is placed on the x-axis at $x = -2.0$ m. If the electric potential at $x = 0$ because of this charge is –500 volts, determine the sign and magnitude of the charge of the point charge.

23. Two charged balls are placed on the x-axis, as shown in Figure 17.20. The first ball has a charge $+q$ and is located at the origin, while the second ball has a charge $-3q$ and is located at $x = +4a$. Your goal is to find all the points on the axis, a finite distance from the charges, where the net electric potential due to these two balls is zero. Start qualitatively. Provide a justification for whether or not there are any such points (a) to the left of the ball of charge $+q$, (b) between the balls, and (c) to the right of the ball of charge $-3q$. (d) Find the locations of all such points.

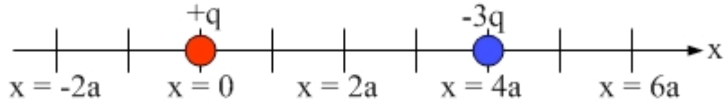

Figure 17.20: Two charged balls on the x-axis. For Exercises 23 and 24.

24. Return to the situation described in Exercise 23 and shown in Figure 17.20. (a) If we reverse the sign of the charge on both the balls, do the answers to Exercise 23 change? If so, describe how. (b) If we reverse the sign of the charge on just one of the balls, do the answers to the previous exercise change? If so, describe how.

25. The potential difference between two points, *A* and *B*, in a uniform electric field has a magnitude of 30 volts. Assume gravity is negligible in this situation. When an electron is released from rest at point *A*, it passes through *B* a short time later. (a) If the potential at point *A* is +50 volts, what is the potential at point *B*?

26. (a) Make a sketch on a piece of paper showing three points, *A*, *B*, and *C*. Point *B* is located a distance of 20 cm from, and directly above, point *A*, while point *C* is located a distance of 20 cm, and horizontally to the right, from point *A*. The points are in a uniform electric field. All you know about its direction is that it is in the plane of the piece of paper. (b) You measure the electric potential at point *A* to be +40 volts, while the potential at point *B* is +50 volts. What, if anything, does this tell you about the magnitude and/or the direction of the electric field? (c) You then measure the electric potential at point C to be +50 volts. What, if anything, can you say about the magnitude and/or the direction of the electric field now? (d) If possible, sketch the field lines and show the +30 V, +40 V, +50 V, and +60 V equipotentials, and find the magnitude of the electric field.

Exercises 27 – 32 involve force, field, potential, and potential energy.

27. Two charged balls are placed on the *x*-axis, as shown in Figure 17.21. The first ball has a charge $+q$ and is located at the origin, while the second ball has a charge $+3q$ and is located at $x = +4a$. (a) Which of the balls experiences a larger magnitude force because of its interaction with the other ball? Why? (b) Determine the magnitude and direction of the force experienced by the ball of charge $+q$. (c) Calculate the magnitude and direction of the net electric field at $x = +2a$. (d) Determine the electric potential energy of this system. (e) Calculate the electric potential at $x = +2a$, relative to $V = 0$ at infinity.

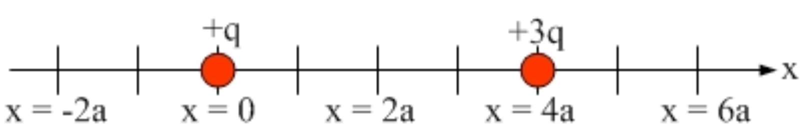

Figure 17.21: Two charged balls on the *x*-axis. For Exercises 27 and 28.

28. Two charged balls are placed on the *x*-axis, as shown in Figure 17.21. The first ball has a charge $+q$ and is located at the origin, while the second ball has a charge $+3q$ and is located at $x = +4a$. (a) Determine the location of all points on the *x*-axis, a finite distance from the balls, where the net electric field is zero. (b) Determine the location of all points on the *x*-axis, a finite distance from the balls, where the total electric potential is zero, relative to $V = 0$ at infinity.

29. Three charged balls, with charges of $+q$, $-3q$, and $+2q$, are placed at the corners of a square that measures L on each side, as shown in Figure 17.22. (a) What is the magnitude and direction of the force experienced by the ball at the top right corner? (b) What is the magnitude and direction of the net electric field at the lower left corner? (c) What is the electric potential energy of this set of charged objects? (d) What is the electric potential at the lower left corner?

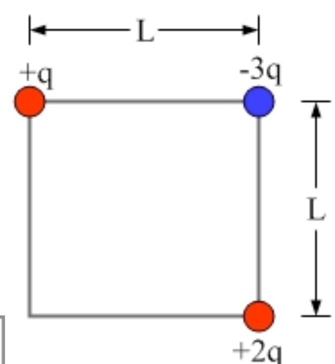

Figure 17.22: Three charged balls, with charges of $+q$, $-3q$, and $+2q$, are placed at the corners of a square that measures L on each side. For Exercise 29.

30. Four charged balls, with charges of $+4q$, $-5q$, $-6q$, and $-q$, are placed on either the x or y axes as shown in Figure 17.23. Each ball is a distance d from the origin. (a) Calculate the magnitude and direction of the force exerted on the ball of charge $+4q$ by the other three balls. (b) Calculate the magnitude and direction of the net electric field at the origin. (c) Calculate the electric potential energy of this set of charged balls. (d) Calculate the electric potential at the origin, relative to $V = 0$ at infinity.

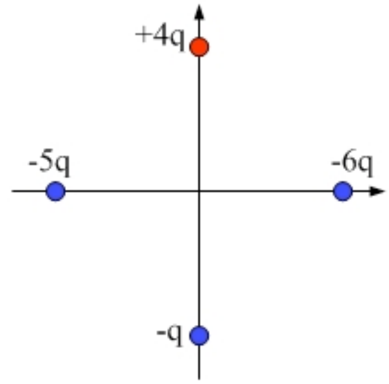

Figure 17.23: Four charged balls are placed on either the x or y axis so that each ball is the same distance from the origin. For Exercises 30 and 31.

31. Four charged balls, with charges of $+4q$, $-5q$, $-6q$, and $-q$, are placed on either the x or y axes as shown in Figure 17.23. Each ball is a distance d from the origin. (a) If you remove one ball from the system, which ball requires you to do the largest positive work to remove it? (b) Calculate the value of the work required to remove that ball.

32. A point object with a charge of $+Q$ is placed on the x-axis at $x = -a$. A second point object of unknown charge is placed at an unknown location on either the x-axis or the y-axis. The potential energy associated with the point charges is $U = +2kQ^2 / a$; the electric potential at the origin due to the charges is $V = +4kQ / a$; and the net electric field at the origin due to the charges points in the negative x direction. (a) What is the sign of the charge on the second object? Justify your answer. (b) Qualitatively, what, if anything, can you say about the location of the second object? Explain. (c) Determine the sign and magnitude of the charge on the second object, and determine its location. (d) What is the magnitude of the net electric field at the origin due to the two charges?

Exercises 33 – 35 deal with capacitors.

33. A parallel-plate capacitor with air between the plates is connected to a battery that has a voltage of V_0. The capacitor has an initial capacitance of C_0. The capacitor stores a charge Q_0, has an electric field of magnitude of E_0, and stores an energy U_0. The following steps are then carried out. Step 1, the distance between the plates is doubled; step 2, the wires connecting the capacitor to the battery are removed; step 3, a dielectric with a dielectric constant 4 times that of air is inserted, completely filling the space between the plates; step 4, the capacitor is re-connected to the battery. Make a table to show the potential difference, capacitance, charge, magnitude of the field inside the capacitor, and energy stored by the capacitor, in terms of their initial values, after each step.

34. A parallel-plate capacitor with air between the plates is connected to a battery that has a voltage of V_0. The capacitor has an initial capacitance of C_0. The capacitor stores a charge Q_0, has an electric field of magnitude of E_0, and stores an energy U_0. The following steps are then carried out. Step 1, a second capacitor, identical to the first but initially uncharged, is placed so it is touching the first capacitor, effectively doubling the area of the capacitor plates; step 2, the wires connecting the capacitor to the battery are removed; step 3, the distance between the plates is doubled; step 4, the capacitor is re-connected to the battery. Make a table to show the potential difference, capacitance, charge, magnitude of the field inside the capacitor, and energy stored by the capacitor, in terms of their initial values, after each step.

35. The membrane of a living cell can be treated as a parallel-plate capacitor, with a plate separation of 10 nm and a dielectric constant of 5. The area of the plates is approximately $5\times10^{-9}\ \text{m}^2$. How much energy is stored in the cell membrane? Assume that the potential difference across the membrane has a magnitude of 100 millivolts.

General problems and conceptual questions

36. Two small charged balls are released from rest when they are 6.0 cm apart. One ball has a mass of 50 grams and a charge of 5.0×10^{-5} C, while the second ball has three times the mass and twice the charge as the first ball. Assuming the balls are influenced only by one another, how fast is each ball moving when they are very far apart?

37. Three identical balls, each with a mass of 75 grams and a charge of 8.0×10^{-4} C, are arranged so there is one ball at each corner of an equilateral triangle. Each side of the triangle measures 25 cm. (a) Assuming the balls are influenced only by one another, describe what will happen when the balls are released from rest. (b) When the balls are 50 cm from one another, how fast are they moving? (c) How fast are they moving when they are very far from one another?

38. A charged particle is given an initial speed of 80 cm/s in a uniform electric field. The initial velocity is the same direction as that of the field. Assume gravity can be neglected in this situation. After covering a distance of 30 cm, the particle has a velocity of 40 cm/s, directed in the same direction as its initial velocity. (a) What is the sign of the particle's charge? (b) How much time did the particle take to cover 30 cm? (c) What is the additional distance covered by the particle before it comes instantaneously to rest?

39. The electric potential in a particular region is due solely to a nearby point charge. You find that the potential at a location 50 cm from the charge is 60 volts higher than the potential at a location only 10 cm from the charge. (a) Is this possible? Explain. (b) If it is possible, determine the sign and magnitude of the charge on the point charge.

40. A ball of charge $+2q$ is placed on the x-axis at $x = -2a$. A second ball of charge $-q$ is placed nearby so that the net electric potential at the origin because of the two balls is $-\frac{2kq}{a}$. Where is the second ball?

41. Three small balls, with charges of $+q$, $-2q$, and $+3q$, can be placed on the x-axis in three different configurations, as shown in Figure 17.24. In each case one charge is at $x = -a$, one is at $x = +a$, and the third is at $x = +2a$. Rank the configurations based on (a) the magnitude of the force experienced by the ball of charge $-2q$, (b) the net electric field at $x = 0$, (c) the potential energy of the configuration, (d) the total electric potential at $x = 0$.

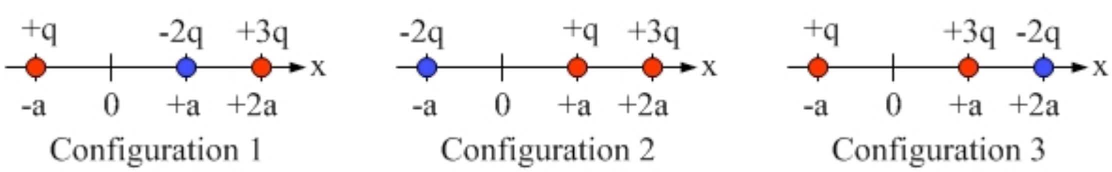

Figure 17.24: Three different configurations of three charged balls, for Exercises 41 and 42.

42. Return to the system described in Exercise 41 and shown in Figure 17.24. Calculate the potential energy in (a) configuration 1, (b) configuration 2, and (c) configuration 3. (d) Is it possible to reverse the locations of two of the charged balls in any configuration without affecting the potential energy of the configuration? Explain.

43. A particle with a mass of 24 grams and a charge of $+3.0\times10^{-5}$ C has a speed of 0.75 m/s when it passes through a point at which the potential is +1200 volts. What is the particle's speed when it passes through a second point at which the potential is –1200 volts? Assume that the only force acting on the particle comes from the electric field.

44. The electric potential a distance *r* from the center of a charged sphere with a spherically symmetric charge distribution is the same as that from a point charge that has the same total charge as the sphere, as long as the point is outside the sphere. Consider a conducting sphere with a net charge of +30 μC and a radius of 4.0 cm. Assume that the system is in electrostatic equilibrium, and that there are no other objects nearby. (a) What is the electric potential at a point 10 cm from the center of the sphere? (b) What is the electric potential at the surface of the sphere? (c) What is the electric field at the center of the sphere? (d) What is the electric potential at the center of the sphere?

45. Consider the three cases shown in Figure 17.25. Rank these cases, from most positive to most negative, based on the (a) electric potential at the origin; (b) electric potential energy of the set of charges.

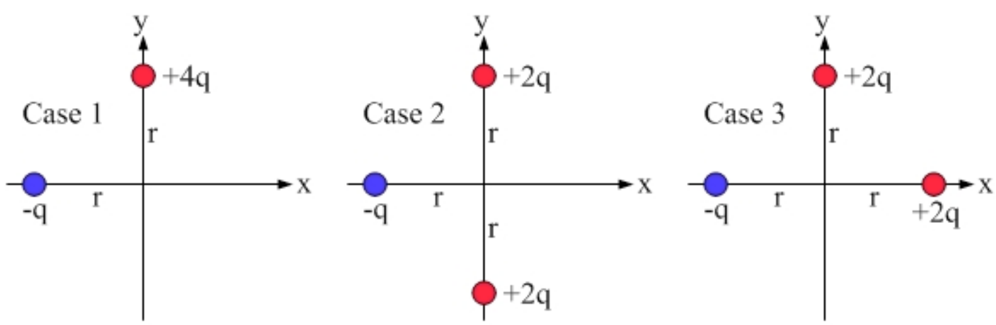

Figure 17.25: Three different configurations of charged objects, for Exercises 45 – 47.

46. Consider the three cases shown in Figure 17.25. Calculate the electric potential energy of the set of charges in (a) case1; (b) case 2; (c) case 3.

47. Consider the three cases shown in Figure 17.25. Determine the electric potential at the origin in (a) case1; (b) case 2; (c) case 3.

48. Four small charged balls are arranged at the corners of a square that measures L on each side, as shown in Figure 17.26 (a) Find the electric potential energy associated with this set of balls. (b) What is the electric potential at the center of the square, relative to $V = 0$ at infinity? (c) If you doubled the length of each side of the square, so neighboring charges were separated by a distance of $2L$ instead, what would happen to your answer to part (a)?

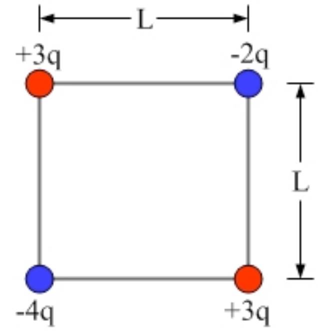

Figure 17.26: Four charged balls at the corners of a square, for Exercises 48 – 50.

49. Four small charged balls are arranged at the corners of a square that measures L on each side, as shown in Figure 17.26. How much work would you have to do to remove one of the balls with a charge of $+3q$ from the system?

50. Four small charged balls are arranged at the corners of a square that measures L on each side, as shown in Figure 17.26. If you could place a fifth ball, having any charge you wish, at the center of the square, could you give the system a total electric potential energy of zero? If not, explain why not. If so, determine the sign and magnitude of the fifth ball.

51. Three charged balls are placed in a line, as shown in Figure 17.27. Ball 1 has an unknown charge and sign, and is a distance $2r$ to the left of ball 2. Ball 2 has a charge of $+Q$. Ball 3 has an unknown non-zero charge and sign, and is a distance r to the right of ball 2. Ball 3 was the last ball brought into the system, and it required zero net work to bring ball 3 from very far away to the location shown. (a) Is there enough information here to find the sign of the charge on ball 1? If so, what is the sign? (b) Can we find the magnitude of the charge on ball 1? If so, what is it? (c) Can we find the sign of the charge on ball 3? If so, what is the sign? (d) Can we find the magnitude of the charge on ball 3? If so, what is it?

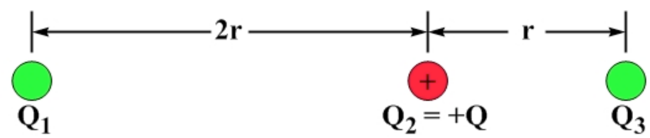

Figure 17.27: Three charges in a line. Only the sign and magnitude of charge 2 are known, although we also know that it took no net work to bring charge 3 into the system from far away. For Exercise 51.

52. A single point charge is located at an unknown point on the x-axis. There are no other objects nearby. You measure the electric potential at $x = +2.0$ m to be +600 volts, while the potential at $x = +5.0$ m is +150 volts. What is the sign and magnitude of the point charge? State all possible answers.

53. A point charge with a charge of +5.0 μC is located at the origin. A second point charge is located at $x = +2.0$ m, with a charge of –9.0 μC. (a) Analyze the situation qualitatively to determine approximate locations of any points along the straight line that passes through both charges where the net electric potential due to these two point charges is zero. (b) Determine the location of all such points that are a finite distance from the charges.

54. Repeat Exercise 53, except now the second point charge has a charge of +18.0 μC.

55. Return to the situation described in Exercise 53. Are there any points a finite distance from the charges at which the net electric potential due to the two charges is zero, that are off the line passing through the charges? If so, explain how you would locate them.

56. Two point charges are placed at different locations on the x-axis. The graph of the electric potential as a function of position on the axis is shown in Figure 17.28. The position is given in units of a. Note that the electric potential is zero at $x = +a$. (a) Where are the two charges located? (b) If one of the charges has a charge of $+3q$, what is the charge of the other point charge? (c) Is the electric field equal to zero at any point on the x-axis in the region shown on the graph, $-4a \le x \le +4a$? Justify your answer by referring to the graph.

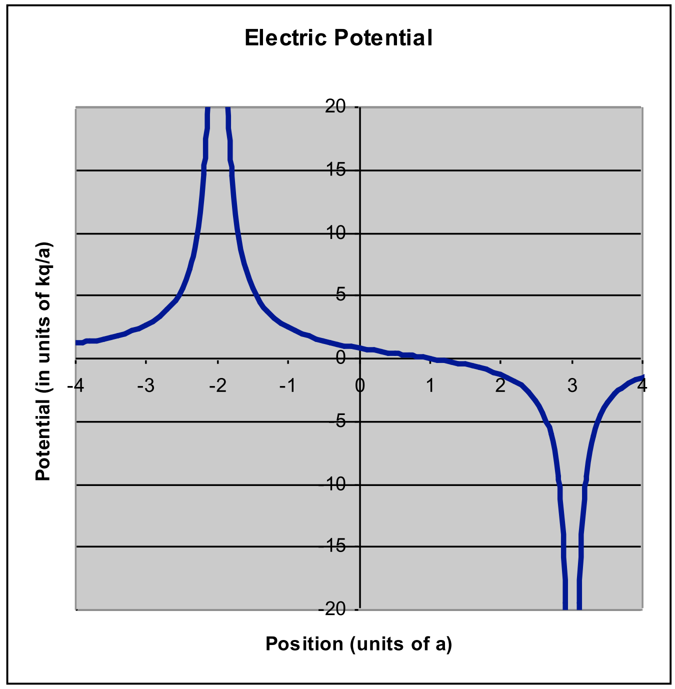

Figure 17.28: The graph of the electric potential along the x-axis in the region $-4a \le x \le +4a$. The potential is due to two point charges that are located on the x-axis. The electric potential is zero at $x = +a$. For Exercise 56.

57. Two point charges are placed at different locations on the x-axis. The graph of the electric potential as a function of position on the axis is shown in Figure 17.29. The position is given in units of a. (a) Where are the two charges located? (b) If one of the charges has a charge of $-2q$, what is the charge of the other point charge? (c) Is the electric field equal to zero at any point on the x-axis in the region shown on the graph, $-4a \le x \le +4a$? Justify your answer by referring to the graph.

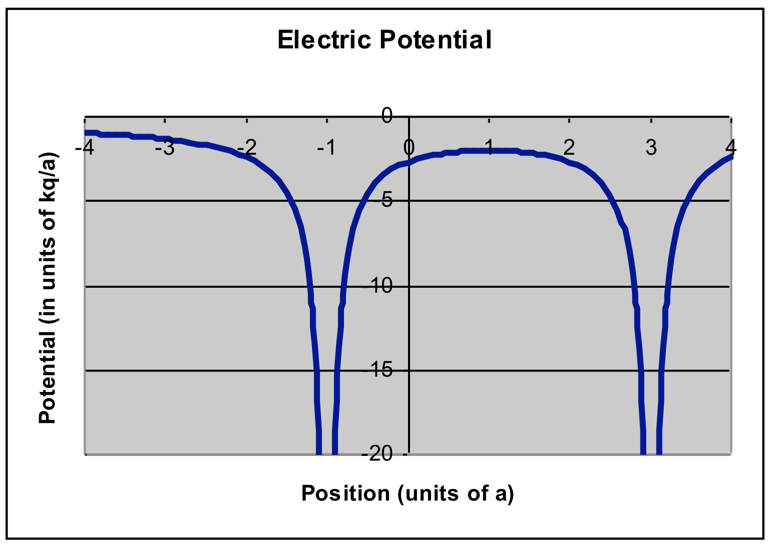

Figure 17.29: The graph of the electric potential along the x-axis in the region $-4a \le x \le +4a$. The potential is due to two point charges that are located on the x-axis. For Exercise 57.

58. A parallel-plate capacitor that has air between the plates is initially charged by being connected to a battery. With the battery still connected, one of the following changes is made. Change 1: the distance between the plates is tripled. Change 2: a dielectric with a dielectric constant 2 times that of air is inserted, completely filling the space between the plates. Change 3: another identical, but initially uncharged, capacitor is placed next to the first so they are touching, effectively doubling the area of each plate. Rank each of these changes, from largest to smallest, based on (a) the final potential difference across the capacitor, (b) the final charge stored on the capacitor, (c) the magnitude of the final electric field with the capacitor, (d) the final energy stored by the capacitor.

59. Repeat Exercise 58, but now the wires connecting the capacitor to the battery are removed before the changes take place.

60. (a) For a parallel-plate capacitor made up of two plates of area A separated by a distance d, what is the volume of the space between the plates? (b) Combine Equation 17.10, for the energy density, with Equations 17.7 and 17.8 to derive one form of Equation 17.11, for the energy stored in a capacitor. (c) Bring in one additional relationship to show how the other forms of Equation 17.11 follow from the expression you obtained in (b).

61. Comment on this part of a conversation between two of your classmates.

Paul: So, let's say we have a charged parallel-plate capacitor that has nothing between the plates. If I then insert a dielectric between the plates, the electric field in the capacitor is reduced, right?

Mary: I don't think so. Sometimes that's true but not always.