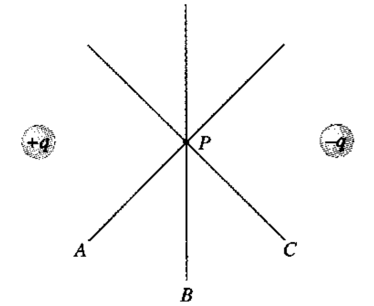
peated. Which is traveling faster when the collision occurs, the proton or the electron? Justify your answer.

9. The potential is constant throughout a given region of space. Is the electric field zero or nonzero in this region? Explain.

10. In a region of space where the electric field is constant everywhere, as it is inside a parallel plate capacitor, is the potential constant everywhere? Account for your answer.

11. A positive test charge is placed in an electric field. In what direction should the charge be moved relative to the field, such that the charge experiences a constant electric potential? Explain.

12. The location marked P in the drawing lies midway between the point charges $+q$ and $-q$. The blue lines labeled A, B, and C are edge-on views of three planes. Which one of these planes is an equipotential surface? Why?



Question 12

13. Imagine that you are moving a positive test charge along the line between two identical point charges. With regard to the electric potential, is the midpoint on the line analogous to the top of a mountain or the bottom of a valley when the two point charges are (a) positive and (b) negative? In each case, explain your answer.

14. Repeat question 13, assuming that you are moving a negative instead of a positive test charge.

15. The potential at a point in space has a certain value, which is not zero. Is the electric potential energy the same for every charge that is placed at that point? Give your reasoning.

16. A proton and an electron are released from rest at the midpoint between the plates of a charged parallel plate capacitor. Except for these particles, nothing else is between the plates. Ignore the attraction between the proton and the electron, and decide which particle strikes a capacitor plate first. Why?

17. A parallel plate capacitor is charged up by a battery. The battery is then disconnected, but the charge remains on the plates. The plates are then pulled apart. Explain whether each of the following quantities increases, decreases, or remains the same as the distance between the plates increases: (a) the capacitance of the capacitor, (b) the potential difference between the plates, (c) the electric field between the plates, and (d) the electric potential energy stored by the capacitor. Give reasons for your answers.

PROBLEMS

Note: All charges are assumed to be point charges unless specified otherwise.

ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 19.1 Potential Energy, Section 19.2 The Electric Potential Difference

1. **ssm** Suppose that the electric potential outside a living cell is higher than that inside the cell by 0.070 V. How much work is done by the electric force when a sodium ion (charge = $+e$) moves from the outside to the inside?

2. A particle has a charge of $+1.5\ \mu C$ and moves from point A to point B, a distance of 0.20 m. The particle experiences a constant electric force, and its motion is along the line of action of the force. The difference between the particle's electric potential energy at A and B is $EPE_A - EPE_B = +9.0 \times 10^{-4}$ J. (a) Find the magnitude and direction of the electric force that acts on the particle. (b) Find the magnitude and direction of the electric field that the particle experiences.

3. Just as you touch a metal door knob, a spark of electricity (electrons) jumps from your hand to the knob. The electric potential of the knob is 2.0×10^4 V greater than that of your hand. The work done by the electric force on the electrons is 1.5×10^{-7} J. How many electrons jump from your hand to the knob?

4. The anode (positive terminal) of an X-ray tube is at a potential of +125 000 V with respect to the cathode (negative terminal). (a) How much work (in joules) is done by the electric force when an electron is accelerated from the cathode to the anode? (b) If the electron is initially at rest, what kinetic energy does the electron have when it arrives at the anode?

5. **ssm** In a television picture tube, electrons strike the screen after being accelerated from rest through a potential difference of 25 000 V. The speeds of the electrons are quite large, and for accurate calculations of the speeds, the effects of special relativity must be taken into account. Ignoring such effects, find the electron speed just before the electron strikes the screen.

6. A particle with a charge of $-1.5\ \mu C$ and a mass of 2.5×10^{-6} kg is released from rest at point A and accelerates toward point B, arriving there with a speed of 42 m/s. (a) What is the potential difference $V_B - V_A$ between A and B? (b) Which point is at the higher potential? Give your reasoning.

7. An electric car accelerates for 8.0 s by drawing energy from its 320-V battery pack. During this time, 1300 C of charge pass through the battery pack. Find the minimum horsepower rating of the car.

***8.** A typical 12-V car battery can deliver about 7.5×10^5 C of charge before dying. This is not very much. To get a feel for this, calculate the maximum number of kilograms of water (100 °C) that could be boiled into steam (100 °C) using energy from this battery.

***9.** **ssm** **www** The potential at location A is 452 V. A positively charged particle is released there from rest and arrives at location B with a speed v_B. The potential at location C is 791 V, and when released from rest from this spot, the particle arrives at B with twice the speed it previously had, or $2v_B$. Find the potential at B.

****10.** A particle is uncharged and is thrown vertically upward from ground level with a speed of 25.0 m/s. As a result, it attains a maximum height h. The particle is then given a positive charge $+q$ and reaches the same maximum height h when thrown vertically upward with a speed of 30.0 m/s. The electric potential at the height h exceeds the electric potential at ground level. Finally, the particle is given a negative charge $-q$. Ignoring air resistance, determine the speed with which the negatively charged particle must be thrown vertically upward, so that it attains exactly the maximum height h. In all three situations, be sure to include the effect of gravity.

Section 19.3 The Electric Potential Difference Created by Point Charges

11. **ssm** There is an electric potential of +130 V at a spot that is 0.25 m away from a charge. Find the magnitude and sign of the charge.

12. Two charges A and B are fixed in place, at different distances from a certain spot. At this spot the potentials due to the two charges are equal. Charge A is 0.18 m from the spot, while charge B is 0.43 m from it. Find the ratio q_B/q_A of the charges.

13. An electron and a proton are initially very far apart (effectively an infinite distance apart). They are then brought together to form a hydrogen atom, in which the electron orbits the proton at an average distance of 5.29×10^{-11} m. What is $EPE_{final} - EPE_{initial}$, which is the change in the electric potential energy?

14. Location A is 2.00 m from a charge of -3.00×10^{-8} C, while location B is 3.00 m from the charge. Find the potential difference $V_B - V_A$ between the two points, and state which point is at the higher potential.

15. **ssm** **www** Two identical point charges are fixed to diagonally opposite corners of a square that is 0.500 m on a side. Each charge is $+3.0 \times 10^{-6}$ C. How much work is done by the electric force as one of the charges moves to an empty corner?

16. Two positive point charges are held in place, 0.74 m apart. They are then moved so that their electric potential energy doubles. What is the new separation between the charges?

17. A charge of $+9q$ is fixed to one corner of a square, while a charge of $-8q$ is fixed to the opposite corner. Expressed in terms of q, what charge should be fixed to the center of the square, so the potential is zero at each of the two empty corners?

18. Review Conceptual Example 7 as background for this problem. Two charges are fixed in place with a separation d. One charge is positive and has twice the magnitude of the other charge, which is negative. The positive charge lies to the left of the negative charge, as in Figure 19.11. Relative to the negative charge, locate the two spots on the line through the charges where the total potential is zero.

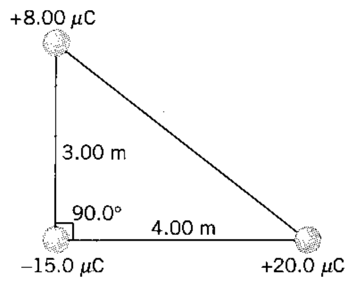
***19.** **ssm** A charge of $-3.00\ \mu$C is fixed in place. From a horizontal distance of 0.0450 m, a particle of mass 7.20×10^{-3} kg and charge $-8.00\ \mu$C is fired with an initial speed of 65.0 m/s directly toward the fixed charge. How far does the particle travel before its speed is zero?

***20.** Four identical charges (+2.0 μC each) are brought from infinity and fixed to a straight line. The charges are located 0.40 m apart. Determine the electric potential energy of this group.

***21.** Two protons are moving directly toward one another. When they are very far apart, their initial speeds are 1.5×10^6 m/s. What is the distance of closest approach?

***22.** Identical point charges of +1.7 μC are fixed to diagonally opposite corners of a square. A third charge is then fixed at the center of the square, such that it causes the potentials at the empty corners to change signs without changing magnitudes. Find the sign and magnitude of the third charge.

***23.** **ssm** Determine the electric potential energy for the array of three charges shown in the drawing, relative to its value when the charges are infinitely far away.



Problem 23

****24.** A positive charge $+q_1$ is located to the left of a negative charge $-q_2$. On a line passing through the two charges, there are two places where the total potential is zero. The first place is between the charges and is 4.00 cm to the left of the negative charge. The second place is 7.00 cm to the right of the negative charge. (a) What is the distance between the charges? (b) Find q_1/q_2, the ratio of the magnitudes of the charges.

****25.** Charges q_1 and q_2 are fixed in place, q_2 being located at a distance d to the right of q_1. A third charge q_3 is then fixed to the line joining q_1 and q_2 at a distance d to the right of q_2. The third charge is chosen so the potential energy of the group is zero; that is, the potential energy has the same value as that of the three charges when they are widely separated. Determine q_3, assuming that (a) $q_1 = q_2 = q$ and (b) $q_1 = q$ and $q_2 = -q$. Express your answers in terms of q.

****26.** Two particles each have a mass of 6.0×10^{-3} kg. One has a charge of $+5.0 \times 10^{-6}$ C, and the other has a charge of -5.0×10^{-6} C. They are initially held at rest at a distance of 0.80 m apart. Both are then released and accelerate toward each other. How fast is each particle moving when the separation between them is one-half its initial value?

Section 19.4 Equipotential Surfaces and Their Relation to the Electric Field

27. **ssm** An equipotential surface that surrounds a $+3.0 \times 10^{-7}$ C point charge has a radius of 0.15 m. What is the potential of this surface?

28. What point charge is at the center of a +36-V equipotential surface that has a radius of 0.18 m?

29. A spark plug in an automobile engine consists of two metal conductors that are separated by a distance of 0.75 mm. When an electric spark jumps between them, the magnitude of the electric field is 4.7×10^7 V/m. What is the magnitude of the potential difference ΔV between the conductors?

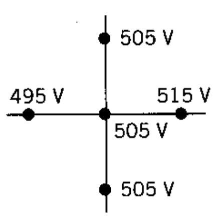
30. The inner and outer surfaces of a cell membrane carry a negative and positive charge, respectively. Because of these charges, a potential difference of about 0.070 V exists across the membrane. The thickness of the membrane is 8.0×10^{-9} m. What is the magnitude of the electric field in the membrane?

31. ssm Two points, A and B, are separated by 0.016 m. The potential at A is +95 V, and that at B is +28 V. Determine the magnitude and direction of the electric field between the two points.

***32.** At a distance of 1.60 m from a point charge of $+2.00 \times 10^{-6}$ C, there is an equipotential surface. At greater distances there are additional equipotential surfaces. The potential difference between any two successive surfaces is 1.00×10^3 V. Starting at a distance of 1.60 m and moving radially outward, how many of the additional equipotential surfaces are crossed by the time the electric field has shrunk to one-half its initial value? Do not include the starting surface.

***33.** The electric field has a constant value of 3.0×10^3 V/m and is directed downward. The field is the same everywhere. The potential at a point P within this region is 135 V. Find the potential at the following points: (a) 8.0×10^{-3} m directly above P, (b) 3.3×10^{-3} m directly below P, (c) 5.0×10^{-3} m directly to the right of P.

***34.** The drawing shows the potential at five points on a set of axes. Each of the four outer points is 6.0×10^{-3} m from the point at the origin. From the data shown, find the magnitude and direction of the electric field in the vicinity of the origin.



Problem 34

***35. ssm** Equipotential surface A has a potential of 5650 V, while equipotential surface B has a potential of 7850 V. A particle has a mass of 5.00×10^{-2} kg and a charge of $+4.00 \times 10^{-5}$ C. The particle has a speed of 2.00 m/s on surface A. An outside force is applied to the particle, and it moves to surface B, arriving there with a speed of 3.00 m/s. How much work is done by the outside force in moving the particle from A to B?

Section 19.5 Capacitors and Dielectrics

36. What voltage is required to store 7.2×10^{-5} C of charge on the plates of a 6.0-μF capacitor?

37. ssm The electric potential energy stored in the capacitor of a defibrillator is 73 J, and the capacitance is 120 μF. What is the potential difference across the capacitor plates?

38. A capacitor stores 5.3×10^{-5} C of charge when connected to a 6.0-V battery. How much charge does the capacitor store when connected to a 9.0-V battery?

39. ssm The membrane that surrounds a certain type of living cell has a surface area of 5.0×10^{-9} m^2 and a thickness of 1.0×10^{-8} m. Assume that the membrane behaves like a parallel plate capacitor and has a dielectric constant of 5.0. (a) The potential on the outer surface of the membrane is +60.0 mV greater than that on the inside surface. How much charge resides on the outer surface? (b) If the charge in part (a) is due to K^+ ions (charge $+e$), how many such ions are present on the outer surface?

40. A capacitor has a capacitance of 2.5×10^{-8} F. In the charging process, electrons are removed from one plate and placed on the other plate. When the potential difference between the plates is 450 V, how many electrons have been transferred?

41. The electronic flash attachment for a camera contains a capacitor for storing the energy used to produce the flash. In one such unit, the potential difference between the plates of a 750-μF capacitor is 330 V. (a) Determine the energy that is used to produce the flash in this unit. (b) Assuming that the flash lasts for 5.0×10^{-3} s, find the effective power or "wattage" of the flash.

42. Two identical capacitors store different amounts of energy: capacitor A stores 310 J and capacitor B stores 34 J. The voltage across the plates of capacitor B is 12 V. Find the voltage across the plates of capacitor A.

***43. ssm** What is the potential difference between the plates of a 3.3-F capacitor that stores sufficient energy to operate a 75-W light bulb for one minute?

***44.** Two hollow metal spheres are concentric with each other. The inner sphere has a radius of 0.1500 m and a potential of 85.0 V. The radius of the outer sphere is 0.1520 m and its potential is 82.0 V. If the region between the spheres is filled with Teflon, find the electric energy contained in this space.

***45.** The dielectric strength of an insulating material is the maximum electric field strength to which the material can be subjected without electrical breakdown occurring. Suppose a parallel plate capacitor is filled with a material whose dielectric constant is 3.5 and whose dielectric strength is 1.4×10^7 N/C. If this capacitor is to store 1.7×10^{-7} C of charge on each plate without suffering breakdown, what must be the radius of its circular plates?

***46.** Review Conceptual Example 11 before attempting this problem. An empty capacitor is connected to a 12.0-V battery and charged up. The capacitor is then disconnected from the battery, and a slab of dielectric material ($\kappa = 2.8$) is inserted between the plates. Find the amount by which the potential difference across the plates changes. Specify whether the change is an increase or a decrease.

****47. ssm www** The potential difference between the plates of a capacitor is 175 V. Midway between the plates, a proton and an electron are released. The electron is released from rest. The proton is projected perpendicularly toward the negative plate with an initial speed. The proton strikes the negative plate at the same instant the electron strikes the positive plate. Ignore the attraction between the two particles, and find the initial speed of the proton.

****48.** The plate separation of a charged capacitor is 0.0800 m. A proton and an electron are released from rest at the midpoint between the plates. Ignore the attraction between the two particles, and determine how far the proton has traveled by the time the electron strikes the positive plate.

ADDITIONAL PROBLEMS

49. At a distance of 0.20 m from a charge, the electric potential is 164 V. What is the potential at a distance of 0.80 m?

50. An electric force moves a charge of $+1.80 \times 10^{-4}$ C from point A to point B and performs 5.80×10^{-3} J of work on the charge. (a) What is the difference ($EPE_A - EPE_B$) between the electric potential energies of the charge at the two points? (b) Determine the potential difference ($V_A - V_B$) between the two points. (c) State which point is at the higher potential.

51. ssm A parallel plate capacitor has a capacitance of 7.0 μF when filled with a dielectric. The area of each plate is 1.5 m^2 and the separation between the plates is 1.0×10^{-5} m. What is the dielectric constant of the dielectric?

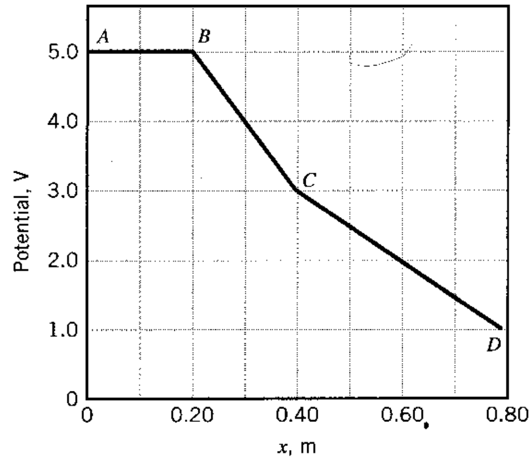
52. Point A is at a potential of +250 V, and point B is at a potential of −150 V. An α-particle is a helium nucleus that contains two protons and two neutrons; the neutrons are electrically neutral. An α-particle starts from rest at A and accelerates toward B. When the α-particle arrives at B, what kinetic energy (in electron volts) does it have?

53. An axon is the relatively long tail-like part of a neuron, or nerve cell. The outer surface of the axon membrane (dielectric constant = 5, thickness = 1×10^{-8} m) is charged positively, and the inner portion is charged negatively. Thus, the membrane is a kind of capacitor. Assuming that an axon can be treated like a parallel plate capacitor with a plate area of 5×10^{-6} m^2, what is its capacitance?

54. A charge of +125 μC is fixed at the center of a square that is 0.64 m on a side. How much work is done by the electric force as a charge of +7.0 μC moves from one corner of the square to any other empty corner? Explain.

55. ssm www When you walk across a rug on a dry day, your body can become electrified, and its electric potential can change. When the potential becomes large enough, a spark of negative charges can jump between your hand and a metal surface. A spark occurs when the electric field strength created by the charges on your body reaches the dielectric strength of the air. The dielectric strength of the air is 3.0×10^6 N/C and is the electric field strength at which the air suffers electrical breakdown. Suppose a spark 3.0 mm long jumps between your hand and a metal doorknob. Assuming that the electric field is uniform, find the potential difference ($V_{knob} - V_{hand}$) between your hand and the doorknob.

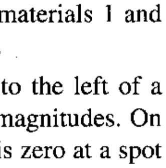
***56.** The drawing shows the electric potential as a function of distance along the x axis. Determine the magnitude of the electric field in the region (a) A to B, (b) B to C, and (c) C to D.



***57.** An empty capacitor has a capacitance of 2.7 μF and is connected to a 12-V battery. A dielectric material ($\kappa = 4.0$) is inserted between the plates of this capacitor. What is the magnitude of the surface charge on the dielectric that is adjacent to either plate of the capacitor? *(Hint: The surface charge is equal to the difference in the charge on the plates with and without the dielectric.)*

****58.** One particle has a mass of 3.00×10^{-3} kg and a charge of +8.00 μC. A second particle has a mass of 6.00×10^{-3} kg and the same charge. The two particles are initially held in place and then released. The particles fly apart, and when the separation between them is 0.100 m, the speed of the 3.00×10^{-3}-kg particle is 125 m/s. Find the initial separation between the particles.

****59. ssm** The drawing shows a parallel plate capacitor. One-half of the region between the plates is filled with a material that has a dielectric constant κ_1. The other half is filled with a material that has a dielectric constant κ_2. The area of each plate is A, and the plate separation is d. The potential difference across the plates is V. Note especially that the charge stored by the capacitor is $q_1 + q_2 = CV$, where q_1 and q_2 are the charges on the area of the plates in contact with materials 1 and 2, respectively. Show that $C = \epsilon_0 A(\kappa_1 + \kappa_2)/(2d)$.



****60.** A positive charge of $+q_1$ is located 3.00 m to the left of a negative charge $-q_2$. The charges have different magnitudes. On the line through the charges, the net *electric field* is zero at a spot 1.00 m to the right of the negative charge. On this line there are also two spots where the potential is zero. Locate these two spots relative to the negative charge.

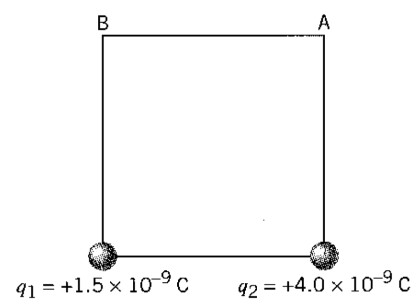
CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

61. Concept Questions The drawing shows a square, on two corners of which are fixed different positive charges. A third charge that is negative is brought to one of the empty corners. (a) At which of the empty corners, A or B, is the potential greater? (b) Is the electric potential energy of the third charge positive or negative? (c) For which location of the third charge, corner A or B, is the magnitude of the electric potential energy greater? Explain your answers.

Problem The length of a side of the square is $L = 0.25$ m. Find the electric potential energy of a charge $q_3 = -6.0 \times 10^{-9}$ C placed at corner A and then at corner B. Compare your answers for consistency with your answers to the Concept Questions.



62. Concept Questions Charges of $-q$ and $+2q$ are fixed in place, with a distance d between them. A dashed line is drawn through the negative charge, perpendicular to the line between the charges. On the dashed line, at a distance L from the negative charge, there is at least one spot where the total potential is zero. (a) At this spot, is the magnitude of the potential from the positive charge greater than, less than, or equal to the magnitude of the potential from the negative charge? (b) Is the distance from the positive charge to the zero-potential spot greater than, less than, or equal to L? (c) How many spots on the dashed line are there where the total potential is zero? Account for your answers.

Problem The distance between the charges is $d = 2.00$ m. Find L.

63. Concept Questions An electron and a proton, starting from rest, are accelerated through an electric potential difference of the same magnitude. In the process, the electron acquires a speed v_e, while the proton acquires a speed v_p. (a) As each particle accelerates from rest, it gains kinetic energy. Does it gain or lose electric potential energy? (b) Does the electron gain more, less, or the same amount of kinetic energy as the proton does? (c) Is v_e greater than, less than, or equal to v_p? Justify your answers.

Problem Find the ratio v_e/v_p. Verify that your answer is consistent with your answers to the Concept Questions.

64. Concept Questions A positive point charge is surrounded by an equipotential surface A, which has a radius of r_A. A positive test charge moves from surface A to another equipotential surface B, which has a radius of r_B. In the process, the electric force does negative work. (a) Does the electric force acting on the test charge have the same or opposite direction as the displacement of the test charge? (b) Is r_B greater than or less than r_A? Explain your answers.

Problem The positive point charge is $q = +7.2 \times 10^{-8}$ C, and the test charge is $q_0 = +4.5 \times 10^{-11}$ C. The work done as the test charge moves from surface A to surface B is $W_{AB} = -8.1 \times 10^{-9}$ J. The radius of surface A is $r_A = 1.8$ m. Find r_B. Check to see that your answer is consistent with your answers to the Concept Questions.

65. Concept Questions Two capacitors have the same plate separation. However, one has square plates, while the other has circular plates. The square plates are a length L on each side, and the diameter of the circular plates is L. (a) If the same dielectric material were between the plates in each capacitor, which one would have the greater capacitance? (b) By putting different dielectric materials between the capacitor plates, the two capacitors can be made to have the same capacitance. Which capacitor should contain the dielectric material with the greater dielectric constant? Give your reasoning in each case.

Problem The capacitors have the same capacitance because they contain different dielectric materials. The dielectric constant of the material between the square plates has a value of $\kappa_{\text{square}} = 3.00$. What is the dielectric constant κ_{circle} of the material between the circular plates? Be sure that your answer is consistent with your answers to the Concept Questions.

66. Concept Questions Capacitor A and capacitor B each have the same voltage across their plates. However, the energy of capacitor A can melt m kilograms of ice at 0 °C, while the energy of capacitor B can boil away the same amount of water at 100 °C. (a) Which requires more energy, melting the ice or boiling the water? (b) Which capacitor has the greater capacitance? Explain your answers.

Problem The capacitance of capacitor A is 9.3 μF. What is the capacitance of capacitor B? Be sure that your answer is consistent with your answers to the Concept Questions.