Problems + Coordinated Problems + Progressive Problems + Solutions

STUDY GUIDE **1. Coordinated Problems:** The three problems within each magenta-colored grouping are solvable in similar ways. Note that the first of these always has a hint; moreover, its solution is provided in the back of the book. *Work out each of these sets; they'll strengthen technique and build confidence.* **2. Progressive Problems:** The problems introduced in blue unfold step-by-step carrying along the analysis in a more suggestive way than is customary. *Work out all of these; they'll guide you through the analytic process and help develop problem-solving skills.* **3. Worked-Out Solutions:** Studying worked-out solutions is an important part of learning how to solve problems. Accordingly, additional ***solutions*** to a number of model problems are given below. *Make sure you understand each of them before you go on to the next problem.* **4.** Also provided in the back of the book are the ***Answers*** to all odd-numbered problems, as well as worked-out ***solutions*** to those with boldface numbers. Problem numbers in italic indicate that a solution appears in the Student Solutions Manual.

SECTION 16.1: *ELECTRICAL*-PE & POTENTIAL

1. [I] THIS PROBLEM EXPLORES THE CONCEPTS OF POTENTIAL, WORK, AND ENERGY. We want to determine the work that must be delivered to a point-charge of +30.0 microcoulombs in order to move it from a location at 2.0 V to a location at 8.0 V. (a) How much of a potential difference does the charge experience? (b) Does its *electrical*-PE increase or decrease? (c) What is the change in the magnitude of its *electrical*-PE? (d) How much work was done in bringing the charge to its new location? (e) Was that work done on the point-charge by the field or by some external applied force?

2. [I] A small 12.0-V electric heating element provides 60 kJ of thermal energy in a certain amount of time. That energy is delivered electrically via the charge. How much charge must flow through the device during that interval?

SOLUTION: The potential difference is 12.0 V and that's a voltage drop. The charge delivers, or "loses," electrical energy in the amount of 60 kJ. $\Delta V = \Delta PE_E/q_o$ so that $\Delta PE_E = (12.0\text{ V})q_o = 60$ kJ and $q_o = 5.0$ kC.

3. [I] A +20.0-nC charge in an *E*-field is moved by an applied force. If 60.0 nJ of work are done on the charge by the force, what is the change in potential experienced by the charge? [*Hint: Use the definition of potential difference.*]

4. [I] A tiny positive charge of 50.0 μC is in a nonuniform electric field. An external force carries the charge from its original location, where the potential is 200.0 V, to a new location expending 100.0 mJ of work in the process. What is the potential of this new location?

5. [I] There is an *E*-field in a region of space, and a +50.0-nC charge is placed at a point where the potential is 500 V. When released the charge moves, while the field does 200.0 μJ of work on it. What is the potential of the final location of the charge?

6. [I] While carrying a charge of +30.0 nC, a small pith ball is released in an electric field. It subsequently moves and drops 150 V in the process. How much work was done on the charge by the field?

7. [I] THIS PROBLEM EXPLORES THE CONCEPTS OF POTENTIAL, WORK, AND ENERGY. A minute metal sphere has 1000 electrons removed from its surface. It is then placed at a point in an electric field where the potential is +2.00 V. (a) What is the charge on the sphere? (b) What is its electrostatic-PE at that location? (c) The sphere is subsequently moved to a new location where the potential is +12.00 V. Does it experience a decrease or an increase in potential, and by what amount? (d) Does the sphere gain or lose energy as a result of being moved, and how much? (e) Does the sphere have work done on it by the field, or must some external agency be acting on it? Explain. (f) How much work must be done in moving the sphere against the *E*-field?

8. [I] THIS PROBLEM WILL HELP US BETTER UNDERSTAND THE CONCEPTS OF POTENTIAL, WORK, AND ENERGY. A small droplet carrying −30.0 nC of charge is moved in an electric field from a location (point-*A*) where the potential is +1.00 V to a place (point-*B*) where the potential is −14.00 V. We want to determine what happened to it from an energy perspective. (a) Draw a picture of what's going on. (b) Is point-*A* at a higher or lower potential than point-*B*? (c) Does the droplet experience a decrease or an increase in potential, and by what amount? (d) Does the droplet gain or lose energy, and how much? (e) Does the droplet have work done on it by the field, or must some external agency be acting on it? Explain.

9. [I] A tiny sphere carrying a charge of −25.0 nC is moved 100 cm in a uniform electric field with no acceleration. It goes from a location at a potential of zero to a point where the potential is 100 V. How much work is done on it by the applied force? What is the significance of the sign of ΔW?

10. [I] Imagine a uniform *E*-field. A charge of −1.00 μC is moved parallel to the field by a force acting in the same direction as the field. If 500 nJ of work are done by the force and if the charge was initially at 1.00 V, what will be its final potential?

11. [I] The *E*-field in a region of space is uniform and equal to 10.0 V/m. What voltage difference will a 20.0-μC charge experience when displaced 10.0 cm in the direction of the field?

12. [I] A stream of singly ionized gold atoms pouring from a small oven impinges on a metal target. The target is attached to the positive terminal of a 12-V battery, and the oven is attached to the negative terminal. How much kinetic energy do the ions pick up in the process of crossing over to the target?

13. [I] What voltage should be put across a pair of parallel metal plates 10.0 cm apart if the field between them is to be 1.00 V/m?

14. [I] Two charged parallel metal plates, inside the evacuated cathode-ray tube of a radar system, are separated by 1.00 cm and have a potential difference of 25.0 V. What is the value of the electric field in the gap?

15. [I] An electron is to be accelerated from rest at a grounded cathode to a metal plate at +500 V. Express in electron volts how much kinetic energy it will gain. How much electrical potential energy will it lose, if any?

16. [I] It is fairly easy to strip the two electrons off a helium atom, leaving a bare nucleus of two neutrons and two protons. That so-called *alpha particle* is to be accelerated, essentially from rest, up to a KE of 100 keV by having it "fall" through a potential difference. What is the necessary voltage difference?

17. [II] An electron initially at rest in an X-ray tube crosses a potential difference of 30 kV and crashes into a target that then emits radiation. Compute the KE of the electron (in joules) at impact. Determine its maximum speed.

18. [II] THIS PROBLEM TREATS THE FIELD BETWEEN CHARGED PARAL-

LEL PLATES. A small conducting ball carries a charge of −44.0 nC. It is placed between two large horizontal metal plates that are 40 mm apart. A 30-V battery is attached across the two plates (as in Fig. 16.24), and we want to find the electrostatic force on the ball. (a) Write an expression relating the voltage across the plates and the E-field between them. (b) Compute that E-field. (c) Determine the electrostatic force on the ball. (d) If the bottom plate is at a higher potential than the upper plate, in what direction is the force? Explain.

19. [II] THIS PROBLEM EXPLORES THE CONCEPTS OF POTENTIAL, WORK, AND ENERGY. A uniform electric field of 12.9 N/C exists in a region of space. A small gold-covered pith ball carrying a charge of +20.0 μC is pulled against the field (i.e., in the opposite direction to it) a distance of 15.0 cm. (a) What is the force on the charge? (b) How much work was done on the charge by the externally applied force? (c) What is the change in the electrostatic potential energy of the ball? (d) What is the change in the potential experienced by the ball? (e) If the ball is at a final position where the voltage is 100 V, at what voltage did it start?

20. [II] A proton is released from rest in a uniform electric field of 500 V/m. How fast will it be moving after traveling 40 cm in and parallel to the field?

21. [II] Two horizontal parallel metal plates 10.0 cm apart in a vacuum chamber are to be used to suspend an electron in "midair." What voltage must be put across the plates?

22. [II] Two parallel copper plates each of area A carry charges of $+Q$ and $-Q$. The gap between them is filled with a material having a dielectric constant K_e. Show that if a positive charge q is moved a distance d along but in the opposite direction to a field line, an amount of work will be done on it given by the expression

$$W = qQd/AK_e\varepsilon_0$$

23. [II] A region of space is traversed by a uniform electric field of strength 10.0 V/m directed due east. A small metal sphere on which has been deposited a charge of +50.0 nC is in the field. The sphere is moved (at a constant speed under the action of an external force) 10.0 cm north, 50.0 cm east, 20.0 cm south, and 50.0 cm east. How much work was done in total on the sphere by the applied force? What was its net change in potential?

24. [II] A uniform electric field in air has a strength of 100 V/m and points due north. An applied force causes an electron to travel without accelerating through the field a distance of 50.0 cm in a direction 36.9° north of west. What is the change in potential that it experiences? How much work was done on it by the applied force?

25. [II] The fluid within a living cell is rich in potassium chloride, while the fluid outside it predominantly contains sodium chloride. The membrane of a resting cell is far more permeable to ions of potassium than sodium, and so there is a transport out of positive ions, leaving the cell interior negative. The result is a voltage of about −85 mV across the membrane, called the *resting potential.* The membrane (about 50 atom-layers) is roughly 8.0-nm thick. Assuming the E-field across the cell membrane is constant, determine its magnitude.

SECTION 16.2: POTENTIAL OF A POINT-CHARGE

26. [I] A 2.00-mm-diameter conducting sphere in vacuum is charged with +30.0 nC. Determine the potential at a distance of 2.00 m from its center. [*Hint: Since 2.00 m >> 2.00 mm, this is essentially a point-charge.*]

27. [I] Figure P27 shows two hollow concentric metal spheres of radii ρ and R. If the inner one is charged with $+Q$ and the outer surface is grounded, what is the potential at any point P outside the larger sphere? Explain your thinking.

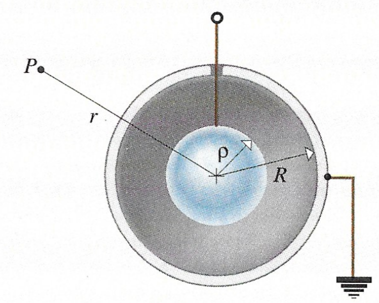

Figure P27

28. [I] At what distance from a 100-μC point-charge in air will the potential be 100 V?

29. [I] We wish to place a small charged sphere at a distance of 10.0 m from a point in space such that the voltage at that point is 1.00 V. How much charge should be on the sphere?

30. [I] A 10.0-cm-diameter solid gold sphere carries a charge of +0.100 μC. What is the potential 10.0 m away in the surrounding air?

31. [I] High atop a nonconducting rod is a small sphere carrying a uniform charge of +25.0 μC. Two detectors are located, respectively, 1.00 m due south and 20.0 m due east. What is the potential difference between the two locations? Which is at the higher voltage? [*Hint: We are being asked to find the potential at two locations in space due to a point-charge.*]

32. [I] Out in space there is a 1.0-cm copper sphere uniformly charged with −100.0 nC. Two small probes are located at point A (2.00 m due south) and point B (10.0 m north of west). What is the potential at B measured with respect to that at A?

33. [I] Imagine that a small metal sphere left by some alien civilization is floating in space. A probe is launched directly at the sphere in order to study it. When the probe is 1000 m from its target, it detects a voltage of 110.0 V; and when it's at 100.0 m, it records 10.0 V. What, if any, is the charge on the sphere?

34. [I] While surrounded by vacuum, a minute pith ball is charged with +50.0 μC. What is the potential 5.0 m away from it?

35. [II] A metal target sphere of 20-cm diameter suspended out in space is given a charge of +1.00 nC. How much work must be done on a proton in taking it from very far away (essentially infinity) to the surface of the sphere?

36. [II] A hydrogen atom consists of a proton around which circulates an electron at an average distance of 0.053 nm. Determine the potential at that distance due to the proton and find the potential energy of the electron (in joules).

37. [II] With Problem 35 in mind, through what voltage must the proton be accelerated from rest (by some sort of space weapon) if it is to arrive at the sphere at a speed of 8.5×10^4 m/s? Neglect any gravitational effects.

38. [II] Refer to Fig. P27. If the inner sphere is charged with $+Q$ and the outer surface is no longer grounded, how does the charge distribute itself and what is the potential in the region beyond the spheres in terms of ρ, R, and Q? Explain your answer. Write an expression for the field beyond the spheres.

39. [II] The radius of a steel ball is 1.00 mm, and it has a surface

charge density of 2.00 C/m^2. It is embedded in a medium that has a dielectric constant of 2.0. What is the potential 2.00 m from the center of the sphere?

40. [II] In the middle of a large tank of ethanol (at 25 °C) is suspended a small hollow copper sphere. If +40.0 μC of charge are deposited on the inside surface of the sphere what will be the electric potential 2.6 m from its center?

41. [II] A point-charge of −100 nC is surrounded by oil having a permittivity of 20×10^{-12} $C^2/N{\cdot}m^2$. How much work would be done on a proton in transporting it from a radial distance of 0.50 m to 1.50 m?

42. [III] If the inner sphere in Fig. P27 is charged with $+Q$ and the outer surface is grounded, show that

$$\Delta V = kQ\left(\frac{1}{\rho} - \frac{1}{R}\right)$$

is the expression for the potential difference across the gap.

SECTION 16.3: THE POTENTIAL OF SEVERAL CHARGES

43. [I] What is the electric potential at a point 1.00 m from each of two +30.0-nC point-charges? [*Hint: Potential is a scalar quantity.*]

44. [I] A point-charge of +50.0 nC is 0.50 m from a point-charge of −50.0 nC. What is the potential at a point equidistant from the two charges?

45. [I] Two small gold beads carry charges of +30.0 nC and −40.0 nC, respectively. What is the potential at a point 2.00 m from both spheres?

46. [I] Two steel ball bearings 1.00 m apart in air carry charges of +40.0 μC and −20.0 μC. What is the potential at a point 1.00 m from the negative charge and 2.00 m from the positive charge?

47. [I] Two small spheres carrying charges of +30.0 μC and −50 μC are 100 cm apart in air. What is the potential at a point on the center-to-center line midway between them?

48. [I] THIS PROBLEM EXPLORES THE POTENTIAL OF A COLLECTION OF CHARGES. A tiny conducting sphere carrying a charge of either +60 μC or −60 μC is fixed at each of the four corners of a square 20 cm on a side. Going around the square from corner to corner, the charges have alternating polarities of +−+−. (a) Show that the diagonal of the square has a length of $20\sqrt{2}$ cm. (b) What is the magnitude of the potential due to each charge at the center of the square? (c) What is the net potential at the center? Explain. (d) What is the electric field at the center? Explain. Assume the medium is vacuum.

49. [I] A large hollow metal sphere with a radius of 1.00 m carries a charge of +2.00 μC. What is the potential at its surface? What is the voltage at its center?

SOLUTION: The entire inside of the sphere is an equipotential volume which has the same voltage as the surface. The potential at the surface is given by $V = k_0Q/R = (8.99 \times 10^9\ \mathrm{N{\cdot}m^2/C^2})(+2.00 \times 10^{-6}\ \mathrm{C})/(1.00\ \mathrm{m}) = 18.0$ kV.

50. [I] THIS PROBLEM DEALS WITH THE POTENTIAL OF A SPHERE. Consider a 30.0-cm diameter hollow metal sphere in air. It's momentarily touched to a running Van de Graaff generator (Fig. Q14, p. 563) operating at −30.0 kV. The sphere becomes charged, and we want to determine the magnitude of that charge. (a) What is the radius of the sphere in meters? (b) What is the voltage of the sphere? (c) What is the charge on the sphere?

51. [I] THIS PROBLEM DEALS WITH THE POTENTIAL OF A SPHERE. A solid aluminum sphere has a radius of 8.99 cm. It is brought into contact with a charged hollow copper sphere, and both come to equilibrium at 8.00 kV. We want to determine the resulting surface charge density on the solid sphere. (a) What is the radius of the solid sphere in meters? (b) What is the voltage of the aluminum sphere once the two spheres are separated? (c) What is the net charge on the aluminum sphere? (d) What is the surface charge density on that sphere?

52. [II] A +60.0-nC point-charge is at each of the vertices of an equilateral triangle. What is the potential at a point 25.0 cm from each of the charges?

53. [II] Two very small metal spheres carrying charges of +10 μC and −25 μC are located at coordinates (0, 0) and (3.0 m, 0), respectively, in air. How much work would have to be done to bring a third sphere with a charge of −10 μC from very far away to the point (0, 4.0 m)?

54. [II] Tiny conducting spheres carrying charges of +60 μC are fixed at each of the four corners of a square 20 cm on a side. What is the potential at the very center? What is the electric field at the center? Assume the medium is vacuum.

55. [II] Three 80.0-nC point-charges form a triangle. What is the potential 1.00 m from two of them and 2.00 m from the third?

56. [II] Point-charges of +300 nC, −700 nC, +500 nC, and −100 nC are located in sequence at the corners of a square 40 cm on a side. Determine the potential at the center of the square.

57. [II] THIS PROBLEM EXAMINES THE POTENTIAL OF SEVERAL CHARGES. Two identical very small silver balls in air are touching each other when a charge of +2.00 μC is deposited on one of them. They are then separated, one being fixed at +1.00 m, the other at −1.00 m on the x-axis. A third small gold ball carrying +4.00 μC is brought from across the street to a point-A +2.00 m up on the y-axis. And we want to find out how much work it took to bring over the third ball. (a) How much charge ultimately resides on each of the silver balls? (b) What is the distance from either silver ball to point-A? (c) What is the potential at point-A due to either silver ball? (d) What is the potential at point-A due to both silver balls? (e) What is the electrostatic potential energy of the gold ball at point-A?

58. [II] THIS PROBLEM EXAMINES POTENTIAL AND THE WAY CHARGE DISTRIBUTES ITSELF AMONG CONDUCTORS. Two identical hollow gold spheres 2.00 cm in diameter having a center-to-center separation of 1.00 m are connected to each other by a very fine gold wire. A charge of +200 nC is sprayed onto one of the spheres, and we want to determine the potential at its center once the system settles down. (a) Assuming that a negligible amount of charge resides on the wire, how much charge is on each sphere once equilibrium is established? (b) Would your answer be different if the spheres were not the same size? Explain. (c) Compare the potential of each sphere. (d) Imagining that one of the spheres is removed, what is the voltage at the surface of the remaining sphere? (e) What is the voltage at the center of the remaining sphere? (f) Now suppose both spheres are present, what is the net voltage at the center of each sphere?

59. [II] THIS PROBLEM DEALS WITH THE POTENTIAL OF A SPHERE.