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 15.1: POSITIVE & NEGATIVE CHARGE

SECTION 15.2: INSULATORS & CONDUCTORS

SECTION 15.3: COULOMB'S LAW

1. [I] By roughly how much does the mass of a copper object change when, upon being stroked with a piece of woolen cloth, it acquires an excess charge of $-1.0\ \mu C$?

2. [I] How many electrons are needed to produce a charge of -1.0 C?

3. [I] THIS PROBLEM EXPLORES THE BEHAVIOR OF CHARGE. Two identical very small conducting spheres carrying charges of $+6.0\ \mu C$ and $-2.0\ \mu C$ come into contact for a while and are then separated. (a) What happens, in general, when two charged conducting spheres touch? (b) What's the net charge on our specific two spheres once they are brought into contact? (c) If a net charge Q was on two identical spheres when they were touching, what charge would be on each sphere after separation? (d) How much charge is on each of our original spheres after they're parted?

4. [I] THIS PROBLEM EXPLORES THE BEHAVIOR OF CHARGE. Imagine that we have two tiny charged dust particles. (a) Under what circumstances, if any, would the force on either one due to the other become zero? (b) What happens to the force on each speck of dust as their center-to-center separation (r) decreases? (c) How does the force on either charged particle vary with r? (d) Considering Fig. P4, which sketch best represents the force on each particle versus their center-to-center separation?

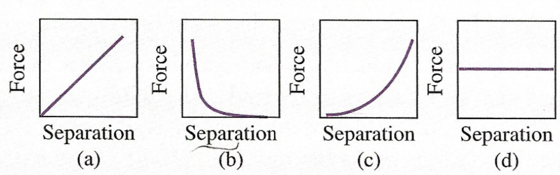

Figure P4

5. [I] THIS PROBLEM EXPLORES THE FORCE EXERTED BY CHARGE. A cloud of hairspray becomes charged as it leaves the nozzle of a spray can. Two droplets that happen to be 2.00 mm apart, each carry a charge of -16.02×10^{-19} C. (a) Is the force between them attractive or repulsive? Explain. (b) How many electrons has each sphere picked up? (c) What law describes the electrostatic force between the droplets. (d) Determine the value of the electrostatic force between the droplets.

6. [I] While flying around, two little bugs pick up charges of $+3.0 \times 10^{-14}$ C and $+4.0 \times 10^{-14}$ C, respectively. What will be the approximate electrostatic force between them when they are 2.00 cm apart?

SOLUTION: If you want the electrostatic force between two charges, you'll need Coulomb's Law: $F_E = k_0 q_{\cdot 1} q_{\cdot 2}/r^2$

$$F_E = (8.99 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{(3.0 \times 10^{-14}\ \text{C})(4.0 \times 10^{-14}\ \text{C})}{(2.00 \times 10^{-2}\ \text{m})^2}$$

$$F_E = 2.7 \times 10^{-14}\ \text{N}$$

The charges are both positive, and the force is repulsive.

7. [I] Two tiny gold-covered pith balls carrying the same charge are 1.0 m apart in vacuum and experience an electrical repulsion of 1.0 N. What is the charge on each of them?

8. [I] A very small conducting sphere in air carries a charge of 5.0 picocoulombs and is 0.20 m from another such sphere carrying a charge Q. If each sphere experiences a mutual electrical repulsion of 2.0 μN, find Q.

9. [I] Two protons are fired directly at each other in a vacuum chamber. What is the force each experiences at the instant they are 1.0×10^{-14} m apart? [*Hint: The particles are identically charged and will experience a Coulomb repulsion.*]

10. [I] Two point-charges of $+0.50\ \mu C$ are 0.10 m apart. Determine the electric force they each experience in air.

11. [I] Two equally charged small spheres repel each other with an electric force of 1.0 N when 0.50 m apart, center-to-center, in air. What is the charge on each sphere?

12. [I] Two tiny spores in vacuum carrying charges of $+1.00\ \mu C$ and $-1.00\ \mu C$ are 1.00 m apart, center-to-center. What is the electrostatic force each experiences?

13. [I] How far apart must an electron and a proton be in vacuum if they are to experience an attractive force of 1.00 N? Assume each is a point-charge.

14. [I] Compute the gravitational attraction between two electrons separated by 1.0 mm in vacuum, and compare that with the electrical repulsion they experience.

15. [I] An equilateral triangle with sides of 2.0 m is inscribed within a circle. A tiny charged sphere carrying ($+10\ \mu C$) is then fixed at each vertex, and one of $-25\ \mu C$ is placed at the center of the circle. What is the net force acting on that central charge (magnitude and direction)?

16. [I] Two charged spheres each containing a quantity of excess electrons equal in number to Avogadro's number are separated by 1000 km in vacuum. Compute to two significant figures the electrical interaction between the spheres.

17. [I] Three small spheres immersed in air, each carrying a charge of +25 nC, are located at the vertices of a right isosceles triangle with a hypotenuse of 1.414 m, lying along the x-axis. Find the net electric force on the charge opposite the hypotenuse, located above it on the positive y-axis.

18. [I] A narrow conducting ring in vacuum, having a diameter of 10.0 cm, is given a charge of +20.0 nC; determine the electrostatic force that would act on a tiny sphere carrying a charge of +1.00 nC placed directly at the center.

19. [I] A square nonconducting framework is set up in space with a tiny metal sphere mounted at each corner. The spheres at either end of the 45° diagonal are charged equally with +45 nC each, while the other two spheres are both given charges of −45 nC. What is the net force on a charge of 10 nC at the very center of the square?

20. [II] How many electrons are there in a tablespoon (15 cm^3) of water? What is the net charge of all of these electrons?

21. [II] Three small negatively charged metal spheres in vacuum are fixed on a horizontal straight line, the x-axis. One (−12.5 μC) is at the origin, another (−5.0 μC) is at $x = 2.0$ m, and the third (−10.0 μC) is 1.0 m beyond that at $x = 3.0$ m. Compute the net electric force on the last sphere due to the other two. [*Hint: Draw a picture. Compute the effect of each charge on the target charge; draw in the corresponding force vectors and then add them.*]

22. [II] Imagine a vertical line marked off in 1.00-cm intervals and suppose you have three tiny identical silver spheres. While they are all in contact, you transfer 30.0 μC to the group and then fix them, one at a time, to points y = 1, 2, and 3. What is the electrostatic force on the last sphere? Take them to be surrounded by air.

23. [II] At a given instant three electrons, in vacuum, happen to lie on a straight line. The first and second are separated by 1.00×10^{-6} m, while the second and third are 2.00×10^{-6} m apart. What is the net electrostatic force on the middle electron, the second one?

24. [II] Two charges of +4.0 nC and −1.0 nC are fixed to a baseline at a separation of 1.0 m. Where on the baseline should a third charge of +2.0 nC be placed if it is to experience zero net electric force?

25. [II] Two very small identical conducting spheres carrying charges of +40.0 nC and −80.0 nC are 1.00 cm apart, center-to-center, in vacuum. Determine the force each experiences. They are then brought into contact and subsequently again separated to 1.00 cm. Determine the force each now experiences.

26. [II] Point-charges of +1.0 nC, +3.0 nC, and −3.0 nC are located, one each, at the three corners of an equilateral triangle of side-length 30 cm. Find the net electrostatic force exerted on the 1.0-nC charge. Assume the surrounding medium is vacuum.

27. [II] Figure P27 shows four point-charges fixed at the corners of a rectangle, in vacuum. Please compute the net electrostatic force acting on the 100-μC charge.

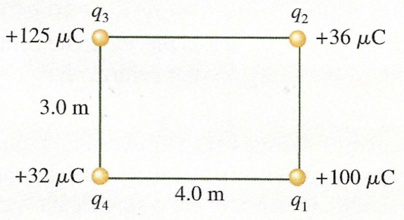

Figure P27

28. [II] Three very small charged spheres are located in a plane in air as follows: $q_1 = +15$ μC at point (0, 0), $q_2 = -20$ μC at point (2, 0), and $q_3 = +10$ μC at point (2, 2). Find the net force acting on the last charge.

29. [II] Redo Problem 27 where now q_4 is −32 μC.

30. [II] A cubic framework is inscribed within a sphere of 1.0-m radius. Tiny conducting spheres are then fixed at each corner and subsequently charged. There are four diagonals, and the pairs of spheres on the ends of each diagonal are equally charged with +10 nC, −10 nC, +20 nC, and −20 nC, respectively. What would be the resulting electric force on a +100-nC point-charge located at the center of the sphere? The surrounding medium is air.

31. [II] Two 2.0-g pith balls hang in air on essentially weightless cotton threads 50-cm long from a common point of support. The balls are then equally charged and they spring apart, each making an angle of 10° with the vertical. Find the magnitude of the charge on each ball.

32. [III] Two charges $+q$ and $-q$ reside in vacuum on the y-axis at locations of $-\frac{1}{2}d$ and $+\frac{1}{2}d$, respectively. Determine the force on a third charge $+Q$ located at a distance of $+x$ from the origin on the x-axis.

33. [III] Three free charges (two of which are $+Q$ and $+2Q$, separated by a distance d) are in equilibrium. Find the size, polarity, and location of the third charge.

SECTION 15.4: DEFINITION OF THE $\vec{\mathbf{E}}$-FIELD

34. [I] A person becomes charged after walking across a woolen rug. A tiny piece of lint floating nearby carries a charge of -16.0×10^{-19} C and interacts with the person's E-field. If the lint experiences an electrostatic force of 3.0×10^{-14} N, what is the magnitude of the person's electric field at that location?

SOLUTION: We're asked to find the magnitude of the electric field, so we begin with the scalar version of its definition:

$$E = F_E / q_o = (3.0 \times 10^{-14}\ \text{N})/(-16.0 \times 10^{-19}\ \text{C})$$
$$|E| = 1.9 \times 10^4\ \text{N/C}$$

35. [I] A minute particle of toner carrying a charge of 5.0×10^{-15} C floats toward a sheet of paper in a copy machine. If the particle experiences an electrostatic force of 25.0×10^{-25} N, what is the value of the electric field at that location?

36. [I] Determine the electric force acting on an electron placed in a uniform north-to-south E-field of 8.0×10^4 N/C in vacuum.

37. [I] A test-charge of +5.0 nC placed at the origin of a coordinate system experiences a force of 4.0×10^{-6} N in the positive y-direction. What is the electric field at that location? Assume the medium is vacuum.

38. [I] A +10-μC test-charge at some point beyond a charged sphere experiences an attractive force of 40 μN. Please compute the value of the E-field of the sphere at that point in a vacuum.

39. [I] A very small conducting sphere carrying a charge of −20 nC is attached to a force gauge and lowered into a uniform electric field. A force of 2.0 nN due east keeps the sphere in equilibrium. Describe the E-field, assuming air is the medium. [*Hint: Use the defining expression for the electric field. Be especially careful about the sign of the charge and the direction of* $\vec{\mathbf{F}}$.]

40. [I] A region of space is permeated by an electric field. When a tiny gold sphere carrying a charge of +50.0 μC is placed at a particular point in the field, it experiences an electrostatic force of 100.0×10^{-6} N due south. Write an expression for the electric field vector at the location of the sphere.

41. [I] A −40.0-nC test charge is placed in a 2000.0-N/C electric field pointing due west in a region of space. Describe the electrostatic force the charge will experience.

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42. [I] A small positively charged object is placed, at rest, in a uniform electric field in vacuum. Write an equation giving its speed after a time t in terms of its mass m and charge q.

43. [I] Determine the magnitude and direction of an E-field if an electron placed in it, in vacuum, is to experience a force that will exactly cancel its weight at the Earth's surface.

44. [I] What is the magnitude and direction of the electric field of an electron at a point 1.0 m away in vacuum?

45. [I] THIS PROBLEM WILL HELP US UNDERSTAND THE ELECTRIC FIELD OF A POINT-CHARGE. Suppose the electric field at a given location beyond a point-charge in vacuum is $\vec{E}$. (a) What is the new electric field at the same location in terms of $\vec{E}$, if the charge is doubled? (b) What is the new electric field if now the original charge is maintained, but the distance is doubled? (c) What is the new electric field in terms of $\vec{E}$ if both the original charge and the distance are doubled?

46. [I] THIS PROBLEM EXPLORES THE ELECTRIC FIELD ARISING FROM SEVERAL POINT-CHARGES. Figure P46 depicts two uniformly charged minute spheres in vacuum. If each sphere carries a charge of $+2.00\ \mu$C, (a) what is the value of the electric field at point-A due to Q_1? (b) What's the direction of that field? (c) What is the value of the electric field at point-A due to Q_2? (d) What's the direction of that field? (e) What is the value of the electric field at point-A due to both Q_1 and Q_2? (f) What's the direction of that net field?

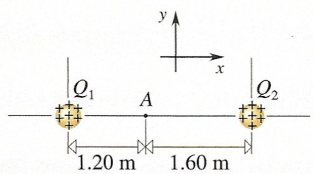

Figure P46

47. [I] Consider a hydrogen atom to be a central proton around which an electron circulates at a distance of 5.3×10^{-11} m. Find the electric field at the electron due to the proton.

48. [I] Two point-charges of +10 nC and −20 nC lie on the x-axis at points $x = 0$ and $x = +10$ m, respectively. Find the electric field on the axis at point $x = +5.0$ m. Assume vacuum.

49. [I] Positive point-charges of $+20\ \mu$C are fixed at two of the vertices of an equilateral triangle with sides of 2.0 m, located in vacuum. Determine the magnitude of the E-field at the third vertex.

50. [I] Redo Problem 49, this time with charges of $+20\ \mu$C and $-20\ \mu$C at either end of the baseline (creating the field at the remaining vertex).

51. [I] Two point-charges of +50 nC each are separated in air by 1.414 m. What is the value of the net electric field they produce at a point that is 1.0 m away from both of them?

52. [II] Two tiny gold spheres lie on the x-axis at $x = 0$ and $x = 1.00$ cm. The one at the origin carries a charge of +40.0 nC, whereas the other has a charge of −80.0 nC. What is the value of the net electric field they produce at a point that is 2.00 m away from each of them?

53. [II] We can produce a uniform $\vec{E}$-field by charging two parallel plates. Suppose such a uniform field of 30.00 N/C due north is overlapped with a uniform field of 40.0 N/C due east; determine the net $\vec{E}$-field in the region of overlap.

54. [II] A uniform field of 1.200 N/C pointing due north exists in a region of space. A point-charge of 6.00×10^{-12} C is then placed in that original field. What is the magnitude of the net field now at a point 20.0 cm due east of the charge?

55. [II] Charged parallel plates are used to set up a uniform E-field of 1.20 N/C pointing due west in a region of vacuum. A tiny silver sphere exists in the space, and it is desired to charge the sphere such that the net field so produced at a point 20.0 cm due south of it will be 1.805 N/C—AT 48.33° SOUTH OF WEST; what charge should the sphere receive?

56. [II] Three point-charges are placed at the corners of an isosceles triangle. At the left and right, end points of the base are $+1.0\ \mu$C and $+1.0\ \mu$C, respectively, and at the vertex $+3.0\ \mu$C. The base of the triangle is 40-cm long, and the altitude is 30-cm high. Find the E-field at the midpoint of the baseline.

57. [II] An electron is placed in a uniform electric field of 1.5×10^4 N/C. Please determine its acceleration.

58. [II] Two point-charges of +10 nC and −20 nC lie on the x-axis at points $x = 0$ and $x = +10$ m, respectively. Find a point where the net electric field is zero, if such a point exists.

59. [II] A section of an advertising sign consists of a long tube filled with neon gas having electrodes inside at both ends. A uniform electric field of 20 kN/C is set up between the electrodes, and neon ions accelerate along the length of the tube. Given that the ions each have a mass of 3.35×10^{-26} kg and are singly ionized, determine their acceleration.

60. [II] THIS PROBLEM DEALS WITH THE ELECTRIC FIELD AND ITS ACTION ON CHARGE. A uniform downward electric field of 6.0×10^4 N/C exists in a region of space. A tiny charged chunk of Styrofoam of mass 0.010 g floats motionlessly in the field. (a) In what direction is the electrostatic force on the Styrofoam? (b) What is the polarity of the charge on the Styrofoam? (c) What two forces act on the chunk? (d) Draw a free-body diagram of the particle. (e) Compute the charge on the piece of Styrofoam. Ignore air friction.

61. [II] THIS PROBLEM EXPLORES THE ELECTRIC FIELD AND ITS ACTION ON CHARGE. Figure P61 shows a small charged 1.00-g sphere in equilibrium at the end of an essentially weightless fiber. Knowing that the E-field is uniform and has a value of 200 N/C, we want to determine the charge on the sphere. (a) What is the sign of the charge on the sphere? Explain. (b) What three forces act on the sphere? (c) Draw a free-body diagram of the sphere. (d) Prove that $mg = F_T \cos 12.0°$. (e) Determine the value of the tension in the fiber. (f) Prove that $F_E = F_T \sin 12.0°$. (g) Determine the charge on the sphere.

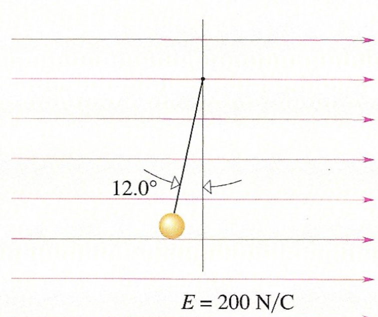

Figure P61