CHAPTER

21 Electric Fields

Practice Problems

21.1 Creating and Measuring Electric Fields pages 563–568

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1. A positive test charge of 5.0×10^{-6} C is in an electric field that exerts a force of 2.0×10^{-4} N on it. What is the magnitude of the electric field at the location of the test charge?

$$E = \frac{F}{q} = \frac{2.0\times10^{-4}\text{ N}}{5.0\times10^{-6}\text{ C}} = 4.0\times10^{1}\text{ N/C}$$

2. A negative charge of 2.0×10^{-8} C experiences a force of 0.060 N to the right in an electric field. What are the field's magnitude and direction at that location?

$$E = \frac{F}{q} = \frac{0.060\text{ N}}{2.0\times10^{-8}\text{ C}} = 3.0\times10^{6}\text{ N/C}$$

directed to the left

3. A positive charge of 3.0×10^{-7} C is located in a field of 27 N/C directed toward the south. What is the force acting on the charge?

$$E = \frac{F}{q}$$

$$F = Eq = (27\text{ N/C})(3.0\times10^{-7}\text{ C})$$

$$= 8.1\times10^{-6}\text{ N}$$

4. A pith ball weighing 2.1×10^{-3} N is placed in a downward electric field of 6.5×10^{4} N/C. What charge (magnitude and sign) must be placed on the pith ball so that the electric force acting on it will suspend it against the force of gravity?

The electric force and the gravitational force algebraically sum to zero because the ball is suspended, i.e. not in motion:

$$F_g + F_e = 0, \text{ so } F_e = -F_g$$

$$E = \frac{F_e}{q}$$

$$q = \frac{F_e}{E} = -\frac{F_g}{E} = -\frac{2.1\times10^{-3}\text{ N}}{6.5\times10^{4}\text{ N/C}}$$

$$= -3.2\times10^{-8}\text{ C}$$

The electric force is upward (opposite the field), so the charge is negative.

5. You are probing the electric field of a charge of unknown magnitude and sign. You first map the field with a 1.0×10^{-6}-C test charge, then repeat your work with a 2.0×10^{-6}-C test charge.

a. Would you measure the same forces at the same place with the two test charges? Explain.

No. The force on the 2.0-μC charge would be twice that on the 1.0-μC charge.

b. Would you find the same field strengths? Explain.

Yes. You would divide the force by the strength of the test charge, so the results would be the same.

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6. What is the magnitude of the electric field strength at a position that is 1.2 m from a point charge of 4.2×10^{-6} C?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$= (9\times10^{9}\text{ N·m}^2/\text{C}^2)\frac{(4.2\times10^{-6}\text{ C})}{(1.2\text{ m})^2}$$

$$= 2.6\times10^{4}\text{ N/C}$$

7. What is the magnitude of the electric field strength at a distance twice as far from the point charge in problem 6?

Because the field strength varies as the square of the distance from the point charge, the new field strength will be one-fourth of the old field strength, or 6.5×10^{3} N/C.

8. What is the electric field at a position that is 1.6 m east of a point charge of $+7.2\times10^{-6}$ C?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$= (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(7.2\times10^{-6}\ \text{C})}{(1.6\ \text{m})^2}$$

$$= 2.5\times10^4\ \text{N/C}$$

The direction of the field is east (away from the positive point charge).

9. The electric field that is 0.25 m from a small sphere is 450 N/C toward the sphere. What is the charge on the sphere?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$q = \frac{Ed^2}{K}$$

$$= \frac{(450\ \text{N/C})(0.25\ \text{m})^2}{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)} = -3.1\times10^{-9}\ \text{C}$$

The charge is negative, because the field is directed toward it.

10. How far from a point charge of $+2.4\times10^{-6}$ C must a test charge be placed to measure a field of 360 N/C?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$d = \sqrt{\frac{Kq}{E}}$$

$$= \sqrt{\frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(2.4\times10^{-6}\ \text{C})}{360\ \text{N/C}}}$$

$$= 7.7\ \text{m}$$

Section Review

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11. Measuring Electric Fields Suppose you are asked to measure the electric field in space. How do you detect the field at a point? How do you determine the magnitude of the field? How do you choose the magnitude of the test charge? What do you do next?

To detect a field at a point, place a test charge at that point and determine if there is a force on it.

To determine the magnitude of the field, divide the magnitude of the force on the test charge by the magnitude of the test charge.

The magnitude of the test charge must be chosen so that it is very small compared to the magnitudes of the charges producing the field.

The next thing you should do is measure the direction of the force on the test charge. The direction of the field is the same as the direction of the force if the test charge is positive; otherwise, it is in the opposite direction.

12. Field Strength and Direction A positive test charge of magnitude 2.40×10^{-8} C experiences a force of 1.50×10^{-3} N toward the east. What is the electric field at the position of the test charge?

$$E = \frac{F}{q} = \frac{1.50\times10^{-3}\ \text{N east}}{2.40\times10^{-8}\ \text{C}}$$

$$= 6.25\times10^4\ \text{N/C east}$$

13. Field Lines In Figure 21-4, can you tell which charges are positive and which are negative? What would you add to complete the field lines?

No. The field lines must have arrowheads indicating their directions, from positive to negative charges.

14. Field Versus Force How does the electric field, *E*, at the test charge differ from the force, *F*, on it?

The field is a property of that region of space, and does not depend on the test charge used to measure it. The force depends on the magnitude and sign of the test charge.

15. Critical Thinking Suppose the top charge in Figure 21-2c is a test charge measuring the field resulting from the two negative charges. Is it small enough to produce an accurate measure? Explain.

No. This charge is large enough to distort the field produced by the other charges with its own field. Compare with Figure 21-4b.

Practice Problems

21.2 Applications of Electric Fields pages 569–579

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16. The electric field intensity between two large, charged, parallel metal plates is 6000 N/C. The plates are 0.05 m apart. What is the electric potential difference between them?

$\Delta V = Ed = (6000\ \text{N/C})(0.05\ \text{m})$

$= 300\ \text{J/C} = 3\times10^{2}\ \text{V}$

17. A voltmeter reads 400 V across two charged, parallel plates that are 0.020 m apart. What is the electric field between them?

$\Delta V = Ed$

$E = \frac{\Delta V}{d} = \frac{400\ \text{V}}{0.020\ \text{m}} = 2\times10^{4}\ \text{N/C}$

18. What electric potential difference is applied to two metal plates that are 0.200 m apart if the electric field between them is 2.50×10^{3} N/C?

$\Delta V = Ed = (2.50\times10^{3}\ \text{N/C})(0.200\ \text{m})$

$= 5.00\times10^{2}\ \text{V}$

19. When a potential difference of 125 V is applied to two parallel plates, the field between them is 4.25×10^{3} N/C. How far apart are the plates?

$\Delta V = Ed$

$d = \frac{\Delta V}{E} = \frac{125\ \text{V}}{4.25\times10^{3}\ \text{N/C}} = 2.94\times10^{-2}\ \text{m}$

20. A potential difference of 275 V is applied to two parallel plates that are 0.35 cm apart. What is the electric field between the plates?

$E = \frac{\Delta V}{d} = \frac{275\ \text{V}}{3.5\times10^{-3}\ \text{m}} = 7.9\times10^{4}\ \text{N/C}$

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21. What work is done when 3.0 C is moved through an electric potential difference of 1.5 V?

$W = q\Delta V = (3.0\ \text{C})(1.5\ \text{V}) = 4.5\ \text{J}$

22. A 12-V car battery can store 1.44×10^{6} C when it is fully charged. How much work can be done by this battery before it needs recharging?

$W = q\Delta V = (1.44\times10^{6}\ \text{C})(12\ \text{V})$

$= 1.7\times10^{7}\ \text{J}$

23. An electron in a television picture tube passes through a potential difference of 18,000 V. How much work is done on the electron as it passes through that potential difference?

$W = q\Delta V = (1.60\times10^{-19}\ \text{C})(1.8\times10^{4}\ \text{V})$

$= 2.9\times10^{-15}\ \text{J}$

24. If the potential difference in problem 18 is between two parallel plates that are 2.4 cm apart, what is the magnitude of the electric field between them?

$E = \frac{\Delta V}{d} = \frac{5.00\times10^{2}\ \text{V}}{0.024\ \text{m}} = 2.1\times10^{4}\ \text{N/C}$

25. The electric field in a particle-accelerator machine is 4.5×10^{5} N/C. How much work is done to move a proton 25 cm through that field?

$W = q\Delta V = qEd$

$= (1.60\times10^{-19}\ \text{C})(4.5\times10^{5}\ \text{N/C})(0.25\ \text{m})$

$= 1.8\times10^{-14}\ \text{J}$

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26. A drop is falling in a Millikan oil-drop apparatus with no electric field. What forces are acting on the oil drop, regardless of its acceleration? If the drop is falling at a constant velocity, describe the forces acting on it.

Gravitational force (weight) downward, friction force of air upward. The two forces are equal in magnitude if the drop falls at constant velocity.

27. An oil drop weighs 1.9×10^{-15} N. It is suspended in an electric field of 6.0×10^{3} N/C. What is the charge on the drop? How many excess electrons does it carry?

$$F_g = Eq$$

$$q = \frac{F_g}{E} = \frac{1.9\times10^{-15}\ \text{N}}{6.0\times10^{3}\ \text{N/C}}$$

$$= 3.2\times10^{-19}\ \text{C}$$

$$\#\ \text{electrons} = \frac{q}{q_e} = \frac{3.2\times10^{-19}\ \text{C}}{1.60\times10^{-19}\ \text{C}} = 2$$

28. An oil drop carries one excess electron and weighs 6.4×10^{-15} N. What electric field strength is required to suspend the drop so it is motionless?

$$E = \frac{F}{q} = \frac{6.4\times10^{-15}\ \text{N}}{1.60\times10^{-19}\ \text{C}} = 4.0\times10^{4}\ \text{N/C}$$

29. A positively charged oil drop weighing 1.2×10^{-14} N is suspended between parallel plates separated by 0.64 cm. The potential difference between the plates is 240 V. What is the charge on the drop? How many electrons is the drop missing?

$$E = \frac{\Delta V}{d} = \frac{240\ \text{V}}{6.4\times10^{-3}\ \text{m}} = 3.8\times10^{4}\ \text{N/C}$$

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{1.2\times10^{-14}\ \text{N}}{3.8\times10^{4}\ \text{N/C}} = 3.2\times10^{-19}\ \text{C}$$

$$\#\ \text{electrons} = \frac{q}{q_e} = \frac{3.4\times10^{-19}\ \text{C}}{1.60\times10^{-19}\ \text{C}} = 2$$

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30. A 27-μF capacitor has an electric potential difference of 45 V across it. What is the charge on the capacitor?

$$q = C\Delta V = (27\times10^{-6}\ \text{F})(45\ \text{V})$$

$$= 1.2\times10^{-3}\ \text{C}$$

31. Both a 3.3-μF and a 6.8-μF capacitor are connected across a 24-V electric potential difference. Which capacitor has a greater charge? What is it?

$q = C\Delta V$, so the larger capacitor has a greater charge.

$$q = (6.8\times10^{-6}\ \text{F})(24\ \text{V}) = 1.6\times10^{-4}\ \text{C}$$

32. The same two capacitors as in problem 31 are each charged to 3.5×10^{-4} C. Which has the larger electric potential difference across it? What is it?

$\Delta V = \frac{q}{C}$, so the smaller capacitor has the larger potential difference.

$$\Delta V = \frac{3.5\times10^{-4}\ \text{C}}{3.5\times10^{-6}\ \text{F}} = 1.1\times10^{2}\ \text{V}$$

33. A 2.2-μF capacitor first is charged so that the electric potential difference is 6.0 V. How much additional charge is needed to increase the electric potential difference to 15.0 V?

$$q = C\Delta V$$

$$\Delta q = C(\Delta V_2 - \Delta V_1)$$

$$= (2.2\times10^{-6}\ \text{F})(15.0\ \text{V} - 6.0\ \text{V})$$

$$= 2.0\times10^{-5}\ \text{C}$$

34. When a charge of 2.5×10^{-5} C is added to a capacitor, the potential difference increases from 12.0 V to 14.5 V. What is the capacitance of the capacitor?

$$C = \frac{q}{\Delta V_2 - \Delta V_1} = \frac{2.5\times10^{-5}\ \text{C}}{14.5\ \text{V} - 12.0\ \text{V}}$$

$$= 1.0\times10^{-5}\ \text{F}$$

Section Review

21.2 Applications of Electric Fields pages 569–579

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35. **Potential Difference** What is the difference between electric potential energy and electric potential difference?

Electric potential energy changes when work is done to move a charge in an electric field. It depends on the amount of charge involved. Electric potential difference is the work done per unit charge to move a charge in an electric field. It is independent of the amount of charge that is moved.

36. Electric Field and Potential Difference Show that a volt per meter is the same as a newton per coulomb.

V/m = J/C·m = N·m/C·m = N/C

37. Millikan Experiment When the charge on an oil drop suspended in a Millikan apparatus is changed, the drop begins to fall. How should the potential difference on the plates be changed to bring the drop back into balance?

The potential difference should be increased.

38. Charge and Potential Difference In problem 37, if changing the potential difference has no effect on the falling drop, what does this tell you about the new charge on the drop?

The drop is electrically neutral (no electron excess or deficiency).

39. Capacitance How much charge is stored on a 0.47-μF capacitor when a potential difference of 12 V is applied to it?

$$q = C\Delta V = (4.7\times10^{-7}\ \text{F})(12\ \text{V})$$
$$= 5.6\times10^{-6}\ \text{C}$$

40. Charge Sharing If a large, positively charged, conducting sphere is touched by a small, negatively charged, conducting sphere, what can be said about the following?

a. the potentials of the two spheres

The spheres will have equal potentials.

b. the charges on the two spheres

The large sphere will have more charge than the small sphere, but they will be the same sign. The sign of the charge will depend on which sphere began with more charge.

41. Critical Thinking Referring back to Figure 21-3a, explain how charge continues to build up on the metal dome of a Van de Graaff generator. In particular, why isn't charge repelled back onto the belt at point B?

The charges on the metal dome produce no field inside the dome. The charges from the belt are transferred immediately to the outside of the dome, where they have no effect on new charges arriving at point B.

Chapter Assessment

Concept Mapping

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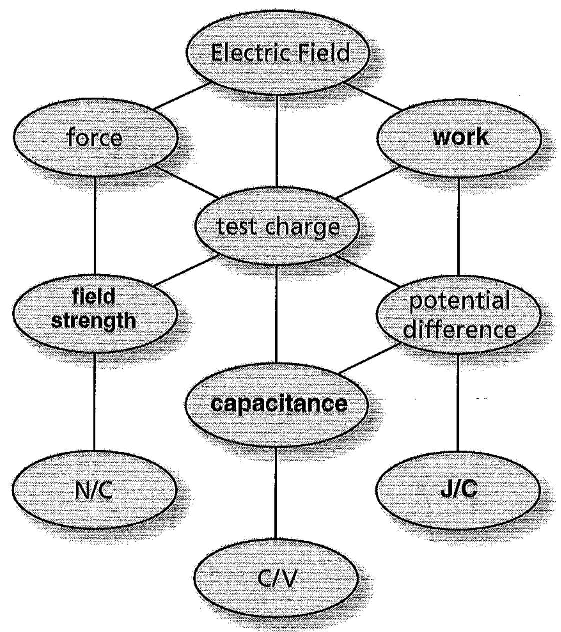
42. Complete the concept map below using the following terms: *capacitance, field strength, J/C, work.*



Mastering Concepts

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43. What are the two properties that a test charge must have? (21.1)

The test charge must be small in magnitude relative to the magnitudes of the charges producing the field and be positive.

44. How is the direction of an electric field defined? (21.1)

The direction of an electric field is the direction of the force on a positive charge placed in the field. This would be away from a positive object and toward a negative object.

45. What are electric field lines? (21.1)

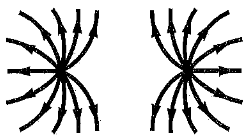
lines of force

46. How is the strength of an electric field indicated with electric field lines? (21.1)

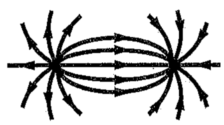
The closer together the electric field lines are, the stronger the electric field.

47. Draw some of the electric field lines between each of the following. (21.1)

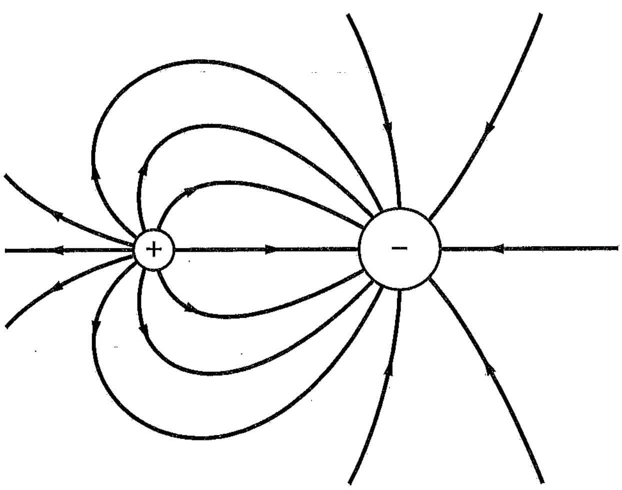
a. two like charges of equal magnitude



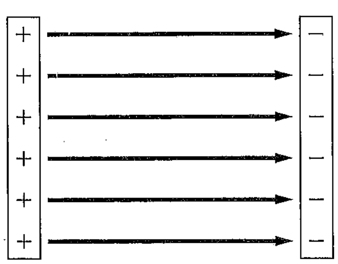
b. two unlike charges of equal magnitude



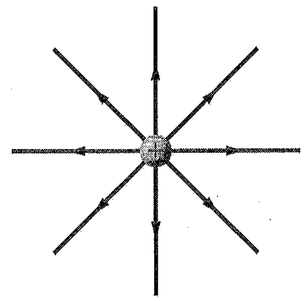
c. a positive charge and a negative charge having twice the magnitude of the positive charge



d. two oppositely charged parallel plates



48. In **Figure 21-15,** where do the electric field lines leave the positive charge end? (21.1)



■ **Figure 21-15**

They end on distant negative charges somewhere beyond the edges of the diagram.

49. What SI unit is used to measure electric potential energy? What SI unit is used to measure electric potential difference? (21.2)

electric potential energy: joule; electric potential: volt

50. Define *volt* in terms of the change in potential energy of a charge moving in an electric field. (21.2)

A *volt* is the change in electric potential energy, ΔPE, resulting from moving a unit test charge, q, a distance, d, of 1 m in an electric field, E, of 1 N/C.
$\Delta V = \Delta PE/q = Ed$

51. Why does a charged object lose its charge when it is touched to the ground? (21.2)

The charge is shared with the surface of Earth, which is an extremely large object.

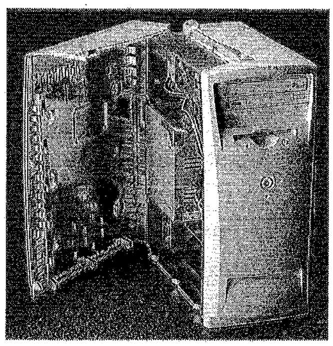
52. A charged rubber rod that is placed on a table maintains its charge for some time. Why is the charged rod not discharged immediately? (21.2)

The table is an insulator, or at least a very poor conductor.

53. A metal box is charged. Compare the concentration of charge at the corners of the box to the charge concentration on the sides of the box. (21.2)

The concentration of charge is greater at the corners.

54. Computers Delicate parts in electronic equipment, such as those pictured in **Figure 21-16,** are contained within a metal box inside a plastic case. Why? (21.2)



■ **Figure 21-16**

The metal box shields the parts from external electric fields, which do not exist inside a hollow conductor.

Applying Concepts

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55. What happens to the strength of an electric field when the charge on the test charge is halved?

Nothing. Because the force on the test charge also would be halved, the ratio F'/q' and the electric field would remain the same.

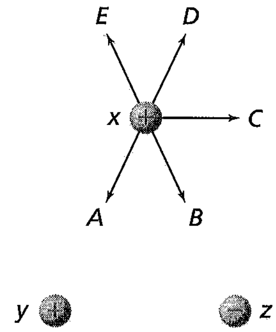
56. Does it require more energy or less energy to move a constant positive charge through an increasing electric field?

Energy is proportional to the force, and the force is proportional to the electric field. Therefore, it requires more energy.

57. What will happen to the electric potential energy of a charged particle in an electric field when the particle is released and free to move?

The electric potential energy of the particle will be converted into kinetic energy of the particle.

58. Figure 21-17 shows three spheres with charges of equal magnitude, with their signs as shown. Spheres y and z are held in place, but sphere x is free to move. Initially, sphere x is equidistant from spheres y and z. Choose the path that sphere x will begin to follow. Assume that no other forces are acting on the spheres.



■ **Figure 21-17**

Sphere x will follow path C. It will experience forces shown by D and B. The vector sum is C.

59. What is the unit of electric potential difference in terms of m, kg, s, and C?

$$V = \text{J/C} = \text{N·m/C} = (\text{kg·m/s}^2)(\text{m/C})$$
$$= \text{kg·m}^2/\text{s}^2\text{·C}$$

60. What do the electric field lines look like when the electric field has the same strength at all points in a region?

They are parallel, equally spaced lines.

61. Millikan Oil-Drop Experiment When doing a Millikan oil-drop experiment, it is best to work with drops that have small charges. Therefore, when the electric field is turned on, should you try to find drops that are moving rapidly or slowly? Explain.

Slowly. The larger the charge, the stronger the force, and thus, the larger the (terminal) velocity.

62. Two oil drops are held motionless in a Millikan oil-drop experiment.

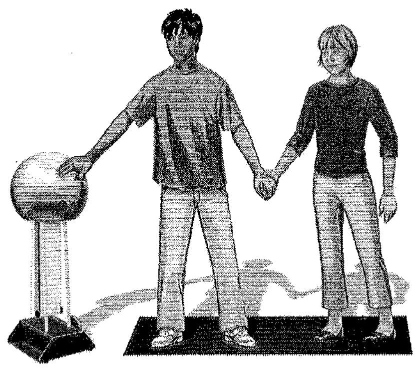
a. Can you be sure that the charges are the same?

No. Their masses could be different.

b. The ratios of which two properties of the oil drops have to be equal?

charge to mass ratio, q/m (or m/q)

63. José and Sue are standing on an insulating platform and holding hands when they are given a charge, as in **Figure 21-18.** José is larger than Sue. Who has the larger amount of charge, or do they both have the same amount?



■ Figure 21-18

José has a larger surface area, so he will have a larger amount of charge.

64. Which has a larger capacitance, an aluminum sphere with a 1-cm diameter or one with a 10-cm diameter?

The 10-cm diameter sphere has a larger capacitance because the charges can be farther apart, reducing potential rise as it is charged.

65. How can you store different amounts of charge in a capacitor?

Change the voltage across the capacitor.

Mastering Problems

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The charge of an electron is -1.60×10^{-19} C.

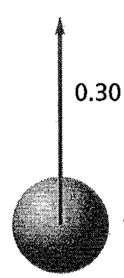
Level 1

66. What charge exists on a test charge that experiences a force of 1.4×10^{-8} N at a point where the electric field intensity is 5.0×10^{-4} N/C?

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{1.4\times10^{-8}\ \text{N}}{5.0\times10^{-4}\ \text{N/C}} = 2.8\times10^{-5}\ \text{C}$$

67. A positive charge of 1.0×10^{-5} C, shown in **Figure 21-19,** experiences a force of 0.30 N when it is located at a certain point. What is the electric field intensity at that point?



■ Figure 21-19

$$E = \frac{F}{q} = \frac{0.30\ \text{N}}{1.0\times10^{-5}\ \text{C}} = 3.0\times10^{4}\ \text{N/C}$$

in the same direction as the force

68. A test charge experiences a force of 0.30 N on it when it is placed in an electric field intensity of 4.5×10^{5} N/C. What is the magnitude of the charge?

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{0.30\ \text{N}}{4.5\times10^{5}\ \text{N/C}} = 6.7\times10^{-7}\ \text{C}$$

69. The electric field in the atmosphere is about 150 N/C downward.

a. What is the direction of the force on a negatively charged particle?

upward

b. Find the electric force on an electron with charge -1.6×10^{-19} C.

$$E = \frac{F}{q}$$

$$F = qE = (1.6\times10^{-19}\ \text{C})(150\ \text{N/C})$$
$$= 2.4\times10^{-17}\ \text{N}$$

$F = 2.4\times10^{-17}$ **N directed upward**

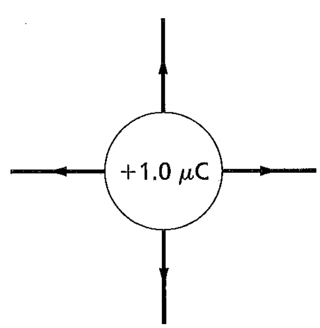
c. Compare the force in part **b** with the force of gravity on the same electron (mass $= 9.1\times10^{-31}$ kg).

$$F = mg = (9.1\times10^{-31}\ \text{kg})(9.80\ \text{m/s}^2)$$
$$= 8.9\times10^{-30}\ \text{N}$$

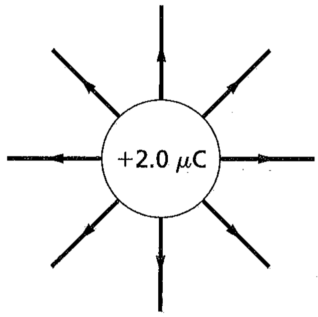
$F = 8.9\times10^{-30}$ **N (downward), more than one trillion times smaller**

70. Carefully sketch each of the following.

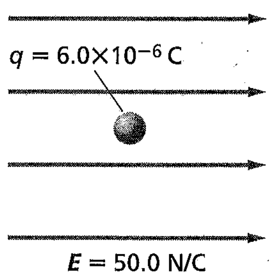
a. the electric field produced by a $+1.0$-μC charge



b. the electric field resulting from a $+2.0\text{-}\mu C$ charge (Make the number of field lines proportional to the change in charge.)



71. A positive test charge of 6.0×10^{-6} C is placed in an electric field of 50.0-N/C intensity, as in **Figure 21-20.** What is the strength of the force exerted on the test charge?



■ **Figure 21-20**

$$E = \frac{F}{q}$$

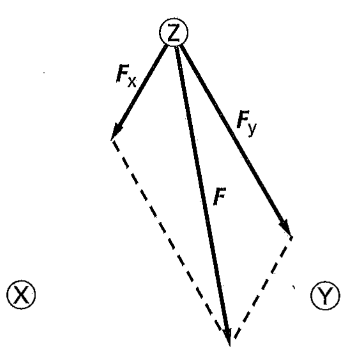
$$F = qE = (6.0\times10^{-6}\ \text{C})(50.0\ \text{N/C})$$

$$= 3.0\times10^{-4}\ \text{N}$$

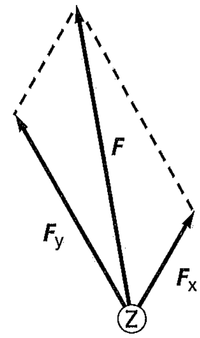
Level 2

72. Charges X, Y, and Z all are equidistant from each other. X has a $+1.0\text{-}\mu C$ charge, Y has a $+2.0\text{-}\mu C$ charge, and Z has a small negative charge.

a. Draw an arrow representing the force on charge Z.



b. Charge Z now has a small positive charge on it. Draw an arrow representing the force on it.



73. In a television picture tube, electrons are accelerated by an electric field having a value of 1.00×10^{5} N/C.

a. Find the force on an electron.

$$E = \frac{F}{q}$$

$$F = Eq$$

$$= (-1.60\times10^{-19}\ \text{C})(1.00\times10^{5}\ \text{N/C})$$

$$= -1.60\times10^{-14}\ \text{N}$$

b. If the field is constant, find the acceleration of the electron (mass $= 9.11\times10^{-31}$ kg).

$$F = ma$$

$$a = \frac{F}{m} = \frac{-1.60\times10^{-14}\ \text{N}}{9.11\times10^{-31}\ \text{kg}}$$

$$= -1.76\times10^{16}\ \text{m/s}^2$$

74. What is the electric field strength 20.0 cm from a point charge of 8.0×10^{-7} C?

$$E = \frac{F}{q'},\ \text{and}\ F = \frac{Kqq'}{d^2}$$

$$\text{so}\ E = \frac{Kq}{d^2}$$

$$= \frac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(8.0\times10^{-7}\ \text{C})}{(0.200\ \text{m})^2}$$

$$= 1.8\times10^{5}\ \text{N/C}$$

75. The nucleus of a lead atom has a charge of 82 protons.

a. What are the direction and magnitude of the electric field at 1.0×10^{-10} m from the nucleus?

$$Q = (82\text{ protons})(1.60\times10^{-19}\text{ C/proton})$$
$$= 1.31\times10^{-17}\text{ C}$$
$$E = \frac{F}{q} = \frac{1}{q}\left(\frac{KqQ}{d^2}\right) = \frac{KQ}{d^2}$$
$$= \frac{(9.0\times10^{9}\text{ N·m}^2/\text{C}^2)(1.31\times10^{-17}\text{ C})}{(1.0\times10^{-10}\text{ m})^2}$$
$$= 1.2\times10^{13}\text{ N/C, outward}$$

b. What are the direction and magnitude of the force exerted on an electron located at this distance?

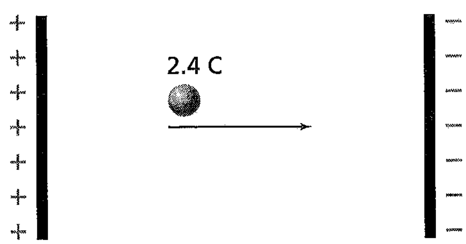
$$F = Eq$$
$$= (1.2\times10^{13}\text{ N/C})(-1.60\times10^{-19}\text{ C})$$
$$= -1.9\times10^{-6}\text{ N, toward the nucleus}$$

21.2 Applications of Electric Fields

pages 586–587

Level 1

76. If 120 J of work is performed to move 2.4 C of charge from the positive plate to the negative plate shown in **Figure 21-21,** what potential difference exists between the plates?



■ **Figure 21-21**

$$\Delta V = \frac{W}{q} = \frac{120\text{ J}}{2.4\text{ C}} = 5.0\times10^{1}\text{ V}$$

77. How much work is done to transfer 0.15 C of charge through an electric potential difference of 9.0 V?

$$\Delta V = \frac{W}{q}$$
$$W = q\Delta V = (0.15\text{ C})(9.0\text{ V}) = 1.4\text{ J}$$

78. An electron is moved through an electric potential difference of 450 V. How much work is done on the electron?

$$\Delta V = \frac{W}{q}$$
$$W = q\Delta V$$
$$= (-1.60\times10^{-19}\text{ C})(450\text{ V})$$
$$= -7.2\times10^{-17}\text{ J}$$

79. A 12-V battery does 1200 J of work transferring charge. How much charge is transferred?

$$\Delta V = \frac{W}{q}$$
$$q = \frac{W}{\Delta V} = \frac{1200\text{ J}}{12\text{ V}} = 1.0\times10^{2}\text{ C}$$

80. The electric field intensity between two charged plates is 1.5×10^{3} N/C. The plates are 0.060 m apart. What is the electric potential difference, in volts, between the plates?

$$\Delta V = Ed$$
$$= (1.5\times10^{3}\text{ N/C})(0.060\text{ m})$$
$$= 9.0\times10^{1}\text{ V}$$

81. A voltmeter indicates that the electric potential difference between two plates is 70.0 V. The plates are 0.020 m apart. What electric field intensity exists between them?

$$\Delta V = Ed$$
$$E = \frac{\Delta V}{d} = \frac{70.0\text{ V}}{0.020\text{ m}} = 3500\text{ V/m}$$
$$= 3500\text{ N/C}$$

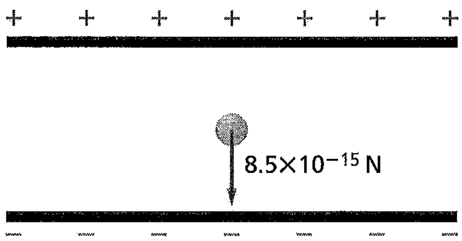
82. A capacitor that is connected to a 45.0-V source contains 90.0 μC of charge. What is the capacitor's capacitance?

$$C = \frac{q}{\Delta V} = \frac{90.0\times10^{-6}\text{ C}}{45.0\text{ V}} = 2.00\ \mu\text{F}$$

83. What electric potential difference exists across a 5.4-μF capacitor that has a charge of 8.1×10^{-4} C?

$$C = \frac{q}{\Delta V}$$
$$\Delta V = \frac{q}{C} = \frac{8.1\times10^{-4}\text{ C}}{5.4\times10^{-6}\text{ F}}$$
$$= 1.5\times10^{2}\text{ V}$$

84. The oil drop shown in **Figure 21-22** is negatively charged and weighs 4.5×10^{-15} N. The drop is suspended in an electric field intensity of 5.6×10^{3} N/C.



■ **Figure 21-22**

a. What is the charge on the drop?

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{4.5\times10^{-15}\ \text{N}}{5.6\times10^{3}\ \text{N/C}}$$

$$= 8.0\times10^{-19}\ \text{C}$$

b. How many excess electrons does it carry?

$$(8.0\times10^{-19}\ \text{C})\left(\frac{1\ \text{electron}}{1.60\times10^{-19}\ \text{C}}\right)$$

$$= 5\ \text{electrons}$$

85. What is the charge on a 15.0-pF capacitor when it is connected across a 45.0-V source?

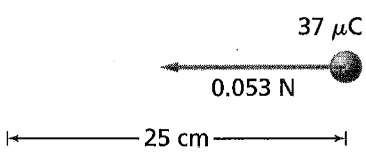
$$C = \frac{q}{\Delta V}$$

$$q = C\Delta V = (15.0\times10^{-12}\ \text{F})(45.0\ \text{V})$$

$$= 6.75\times10^{-10}\ \text{C}$$

Level 2

86. A force of 0.065 N is required to move a charge of 37 μC a distance of 25 cm in a uniform electric field, as in **Figure 21-23.** What is the size of the electric potential difference between the two points?



■ **Figure 21-23**

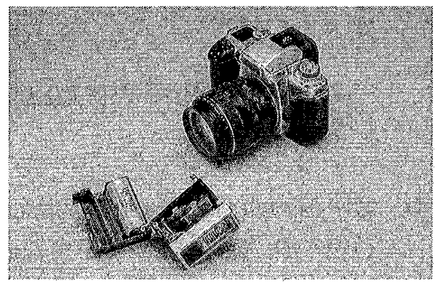
$$W = Fd$$

$$\text{and } \Delta V = \frac{W}{q} = \frac{Fd}{q}$$

$$= \frac{(0.065\ \text{N})(0.25\ \text{m})}{37\times10^{-6}\ \text{C}}$$

$$= 4.4\times10^{2}\ \text{V}$$

87. Photoflash The energy stored in a capacitor with capacitance C, and an electric potential difference, ΔV, is represented by $W = \frac{1}{2}C\Delta V^2$. One application of this is in the electronic photoflash of a strobe light, like the one in **Figure 21-24.** In such a unit, a capacitor of 10.0 μF is charged to 3.0×10^{2} V. Find the energy stored.



■ **Figure 21-24**

$$W = \frac{1}{2}C\Delta V^2$$

$$= \left(\frac{1}{2}\right)(10.0\times10^{-6}\ \text{F})(3.0\times10^{2}\ \text{V})^2$$

$$= 0.45\ \text{J}$$

88. Suppose it took 25 s to charge the capacitor in problem 87.

a. Find the average power required to charge the capacitor in this time.

$$P = \frac{W}{t} = \frac{0.45\ \text{J}}{25\ \text{s}} = 1.8\times10^{-2}\ \text{W}$$

b. When this capacitor is discharged through the strobe lamp, it transfers all its energy in 1.0×10^{-4} s. Find the power delivered to the lamp.

$$P = \frac{W}{t} = \frac{0.45\ \text{J}}{1.0\times10^{-4}\ \text{s}} = 4.5\times10^{3}\ \text{W}$$

c. How is such a large amount of power possible?

Power is inversely proportional to the time. The shorter the time for a given amount of energy to be expended, the greater the power.

89. Lasers Lasers are used to try to produce controlled fusion reactions. These lasers require brief pulses of energy that are stored in large rooms filled with capacitors. One such room has a capacitance of 61×10^{-3} F charged to a potential difference of 10.0 kV.

a. Given that $W = \frac{1}{2}C\Delta V^2$, find the energy stored in the capacitors.

$$W = \frac{1}{2}C\Delta V^2$$
$$= \left(\frac{1}{2}\right)(61\times10^{-3}\ \text{F})(1.00\times10^{4}\ \text{V})^2$$
$$= 3.1\times10^{6}\ \text{J}$$

b. The capacitors are discharged in 10 ns (1.0×10^{-8} s). What power is produced?

$$P = \frac{W}{t} = \frac{3.1\times10^{6}\ \text{J}}{1.0\times10^{-8}\ \text{s}} = 3.1\times10^{14}\ \text{W}$$

c. If the capacitors are charged by a generator with a power capacity of 1.0 kW, how many seconds will be required to charge the capacitors?

$$t = \frac{W}{P} = \frac{3.1\times10^{6}\ \text{J}}{1.0\times10^{3}\ \text{W}} = 3.1\times10^{3}\ \text{s}$$

Mixed Review

page 587

Level 1

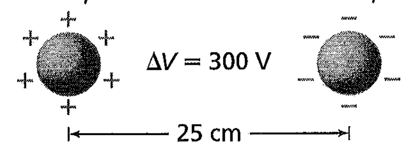
90. How much work does it take to move 0.25 μC between two parallel plates that are 0.40 cm apart if the field between the plates is 6400 N/C?

$$W = q\Delta V = qEd$$
$$= (2.5\times10^{-7}\ \text{C})(6400\ \text{N/C})(4.0\times10^{-3}\ \text{m})$$
$$= 6.4\times10^{-6}\ \text{J}$$

91. How much charge is stored on a 0.22-μF parallel plate capacitor if the plates are 1.2 cm apart and the electric field between them is 2400 N/C?

$$q = C\Delta V = CEd$$
$$= (2.2\times10^{-7}\ \text{F})(2400\ \text{N/C})(1.2\times10^{-2}\ \text{m})$$
$$= 6.3\ \mu\text{C}$$

92. Two identical small spheres, 25 cm apart, carry equal but opposite charges of 0.060 μC, as in **Figure 21-25.** If the potential difference between them is 300 V, what is the capacitance of the system?



■ Figure 21-25

$$C = \frac{q}{\Delta V} = \frac{6.0\times10^{-8}\ \text{C}}{300\ \text{V}} = 2\times10^{-10}\ \text{F}$$

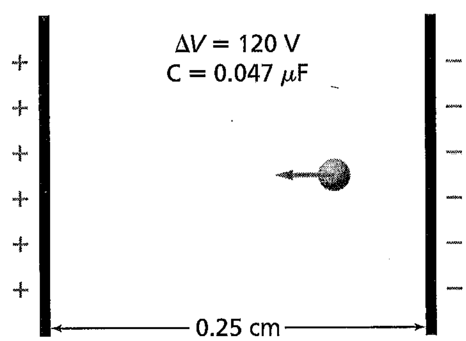
93. The plates of a 0.047 μF capacitor are 0.25 cm apart and are charged to a potential difference of 120 V. How much charge is stored on the capacitor?

$$C = \frac{q}{\Delta V}$$
$$q = C\Delta V$$
$$= (4.7\times10^{-8}\ \text{F})(120\ \text{V})$$
$$= 5.6\times10^{-6}\ \text{C} = 5.6\ \mu\text{C}$$

94. What is the strength of the electric field between the plates of the capacitor in Problem 93 above?

$$\Delta V = Ed$$
$$E = \frac{\Delta V}{d}$$
$$= \frac{120\ \text{V}}{2.5\times10^{-3}\ \text{m}} = 4.8\times10^{4}\ \text{V/m}$$

95. An electron is placed between the plates of the capacitor in Problem 93 above, as in **Figure 21-26.** What force is exerted on that electron?



■ Figure 21-26

$E = \frac{F}{q}$

$F = Eq$

$= (4.8\times10^{4}\ \text{V/m})(1.6\times10^{-19}\ \text{C})$

$= 7.7\times10^{-15}\ \text{N}$

96. How much work would it take to move an additional 0.010 μC between the plates at 120 V in Problem 93?

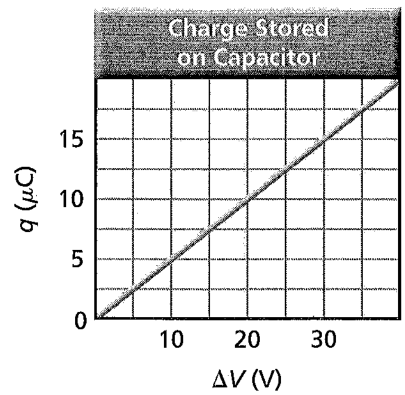
$\Delta V = \frac{W}{q}$

$W = q\Delta V$

$= (1.0\times10^{-8}\ \text{C})(120\ \text{V}) = 1.2\times10^{-6}\ \text{J}$

Level 2

97. The graph in **Figure 21-27** represents the charge stored in a capacitor as the charging potential increases. What does the slope of the line represent?



■ **Figure 21-27**

capacitance of the capacitor

98. What is the capacitance of the capacitor represented by Figure 21-27?

C = slope = 0.50 μF

99. What does the area under the graph line in Figure 21-27 represent?

work done to charge the capacitor

100. How much work is required to charge the capacitor in problem 98 to a potential difference of 25 V?

$W = \text{area} = \frac{1}{2}bh$

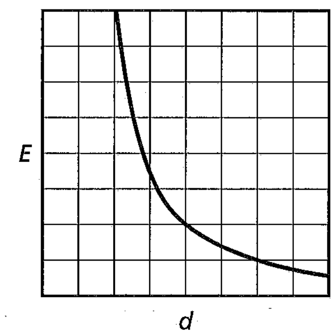
$= \left(\frac{1}{2}\right)(25\ \text{V})(12.5\ \mu\text{C})$

$= 160\ \mu\text{J}$

101. The work found in Problem 100 above is not equal to $q\Delta V$. Why not?

The potential difference is not constant as the capacitor is charged. Therefore, the area under the graph must be used to find work, not just simple multiplication.

102. Graph the electric field strength near a positive point charge as a function of distance from it.



103. Where is the field of a point charge equal to zero?

Nowhere, or at an infinite distance from the point charge.

104. What is the electric field strength at a distance of zero meters from a point charge? Is there such a thing as a true point charge?

Infinite. No.

Thinking Critically

pages 587–588

105. Apply Concepts Although a lightning rod is designed to carry charge safely to the ground, its primary purpose is to prevent lightning from striking in the first place. How does it do that?

The sharp point on the end of the rod leaks charge into the atmosphere before it has the chance to build up enough potential difference to cause a lightning strike.

106. Analyze and Conclude In an early set of experiments in 1911, Millikan observed that the following measured charges could appear on a single oil drop. What value of elementary charge can be deduced from these data?

a. 6.563×10^{-19} C **f.** 18.08×10^{-19} C

b. 8.204×10^{-19} C **g.** 19.71×10^{-19} C

c. 11.50×10^{-19} C **h.** 22.89×10^{-19} C

d. 13.13×10^{-19} C **i.** 26.13×10^{-19} C

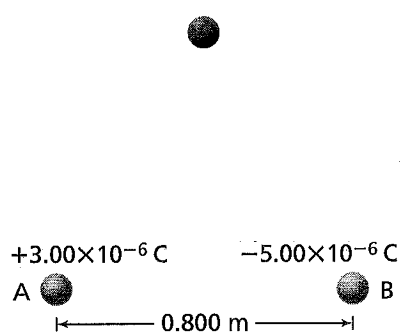
e. 16.48×10^{-19} C

1.63×10^{19} C. Subtracting adjacent values, $b - a$, $c - b$, $d - c$, etc. yields 1.641×10^{-19} C, 3.30×10^{-19} C, 1.63×10^{-19} C, 3.35×10^{-19} C, 1.60×10^{-19} C, 1.63×10^{-19} C, 3.18×10^{-19} C, 3.24×10^{-19} C.

There are two numbers, approximately 1.631×10^{-19} C and 3.2×10^{-19} C, that are common. Averaging each similar group produces one charge of 1.63×10^{-19} C and one charge of 3.27×10^{-19} C (which is two times 1.641×10^{-19} C).

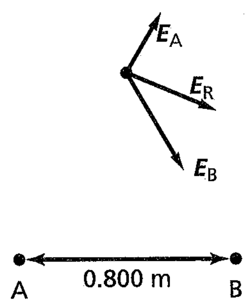
Dividing 1.63×10^{-19} C into each piece of data yields nearly whole-number quotients, indicating it is the value of an elementary charge.

107. Analyze and Conclude Two small spheres, A and B, lie on the x-axis, as in **Figure 21-28.** Sphere A has a charge of $+3.00\times10^{-6}$ C. Sphere B is 0.800 m to the right of sphere A and has a charge of -5.00×10^{-6} C. Find the magnitude and direction of the electric field strength at a point above the x-axis that would form the apex of an equilateral triangle with spheres A and B.



■ **Figure 21-28**

Draw the spheres and vectors representing the fields due to each charge at the given point.



Now do the math:

$$E_A = \frac{F_A}{q'} = \frac{Kq_A}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(3.00\times10^{-6}\ \text{C})}{(0.800\ \text{m})^2} = 4.22\times10^4\ \text{N/C}$$

$$E_B = \frac{F_B}{q'} = \frac{Kq_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(5.00\times10^{-6}\ \text{C})}{(0.800\ \text{m})^2} = 7.03\times10^4\ \text{N/C}$$

$$E_{Ax} = E_A \cos 60.0° = (4.22\times10^4\ \text{N/C})(\cos 60.0°) = 2.11\times10^4\ \text{N/C}$$

$$E_{Ay} = E_A \sin 60.0° = (4.22\times10^4\ \text{N/C})(\sin 60.0°) = 3.65\times10^4\ \text{N/C}$$

$E_{Bx} = E_B \cos(-60.0°) = (7.03\times10^4\ N/C)(\cos -60.0°) = 3.52\times10^4\ N/C$

$E_{By} = E_B \sin(-60.0°) = (7.03\times10^4\ N/C)(\sin -60.0°) = -6.09\times10^4\ N/C$

$E_x = E_{Ax} + E_{Bx} = (2.11\times10^4\ N/C) + (3.52\times10^4\ N/C) = 5.63\times10^4\ N/C$

$E_y = E_{Ay} + E_{By} = (3.65\times10^4\ N/C) + (-6.09\times10^4\ N/C) = -2.44\times10^4\ N/C$

$E_R = \sqrt{E_x^2 + E_y^2} = 6.14\times10^4\ N/C$

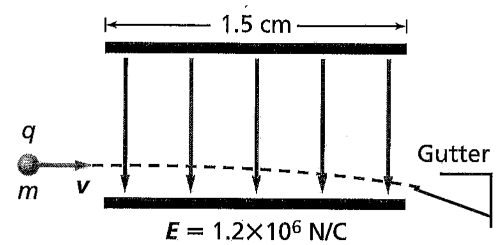
$\tan\theta = \frac{E_y}{E_x}$

$$\theta = \tan^{-1}\left(\frac{E_y}{E_x}\right)$$

$$= \tan^{-1}\left(\frac{-2.44\times10^4\ N/C}{5.63\times10^4\ N/C}\right)$$

$$= -23.4°$$

108. Analyze and Conclude In an ink-jet printer, drops of ink are given a certain amount of charge before they move between two large, parallel plates. The purpose of the plates is to deflect the charges so that they are stopped by a gutter and do not reach the paper. This is shown in **Figure 21-29.** The plates are 1.5-cm long and have an electric field of $E = 1.2\times10^6$ N/C between them. Drops with a mass $m = 0.10$ ng, and a charge $q = 1.0\times10^{-16}$ C, are moving horizontally at a speed, $v = 15$ m/s, parallel to the plates. What is the vertical displacement of the drops when they leave the plates? To answer this question, complete the following steps.



■ **Figure 21-29**

a. What is the vertical force on the drops?

$$F = Eq$$
$$= (1.0\times10^{-16}\ C)(1.2\times10^6\ N/C)$$
$$= 1.2\times10^{-10}\ N$$

b. What is their vertical acceleration?

$$a = \frac{F}{m} = \frac{1.2\times10^{-10}\ N}{1.0\times10^{-13}\ kg} = 1.2\times10^3\ m/s^2$$

c. How long are they between the plates?

$$t = \frac{L}{v} = \frac{1.5\times10^{-2}\ m}{15\ m/s} = 1.0\times10^{-3}\ s$$

d. How far are they displaced?

$$y = \frac{1}{2}at^2$$
$$= \left(\frac{1}{2}\right)(1.2\times10^3\ m/s^2)(1.0\times10^{-3}\ s)^2$$
$$= 6.0\times10^{-4}\ m = 0.60\ mm$$

109. **Apply Concepts** Suppose the Moon had a net negative charge equal to $-q$, and Earth had a net positive charge equal to $+10q$. What value of q would yield the same magnitude of force that you now attribute to gravity?

Equate the expressions for gravitational force and Coulombic force between Earth and the Moon:

$$F = \frac{Gm_Em_M}{d^2} = \frac{Kq_Eq_M}{d^2} = \frac{10Kq^2}{d^2}$$

where $-q$ is the net negative charge of the Moon and q_E, the net positive charge of Earth, is $+10q$.
Solve symbolically before substituting numbers.

$$q = \sqrt{\frac{Gm_Em_M}{10K}}$$

$$= \sqrt{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(6.00\times10^{24}\ \text{kg})(7.31\times10^{22}\ \text{kg})}{(10)(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)}}$$

$$= 1.8\times10^{13}\text{C}$$

Writing in Physics

page 588

110. Choose the name of an electric unit, such as coulomb, volt, or farad, and research the life and work of the scientist for whom it was named. Write a brief essay on this person and include a discussion of the work that justified the honor of having a unit named for him.

Student answers will vary. Some examples of scientists they could choose are Volta, Coulomb, Ohm, and Ampère.

Cumulative Review

page 588

111. Michelson measured the speed of light by sending a beam of light to a mirror on a mountain 35 km away. (Chapter 16)

a. How long does it take light to travel the distance to the mountain and back?

(35 km/trip)(2 trips)(1000 m/1 km)/ 3.00×10^8 m/s = 2.3×10^{-4} s

b. Assume that Michelson used a rotating octagon with a mirror on each face of the octagon. Also assume that the light reflects from one mirror, travels to the other mountain, reflects off of a fixed mirror on that mountain, and returns to the rotating mirrors. If the rotating mirror has advanced so that when the light returns, it reflects off of the next mirror in the rotation, how fast is the mirror rotating?

$$\left(\frac{2.3\times10^{-4}\ \text{s}}{1\ \text{mirror}}\right)(8\ \text{mirrors/rev}) = 1.8\times10^{-3}\ \text{s/rev} = T$$

$$f = \frac{1}{T} = \frac{1}{1.8\times10^{-3}\ \text{s/rev}} = 5.6\times10^{2}\ \text{rev/s}$$

Note that if students carry extra digits from part a to prevent rounding errors, they will get an answer of 5.4×10^2 rev/s.

c. If each mirror has a mass of 1.0×10^1 g and rotates in a circle with an average radius of 1.0×10^1 cm, what is the approximate centripetal force needed to hold the mirror while is it rotating?

$$F_c = 4\pi^2 mf^2 r$$
$$= 4\pi^2(0.010\text{ kg})(5.6\times10^2\text{ rev/s})^2(0.10\text{ m})$$
$$= 1.2\times10^4\text{ N}$$

Note that the answer should be 1.2×10^4 N regardless of whether the students use 5.4×10^2 rev/s or 5.6×10^4 rev/s for f.

112. Mountain Scene You can see an image of a distant mountain in a smooth lake just as you can see a mountain biker next to the lake because light from each strikes the surface of the lake at about the same angle of incidence and is reflected to your eyes. If the lake is about 100 m in diameter, the reflection of the top of the mountain is about in the middle of the lake, the mountain is about 50 km away from the lake, and you are about 2 m tall, then approximately how high above the lake does the top of the mountain reach? (Chapter 17)

Since the angle of incidence of the light from the top of the mountain is equal to its angle of reflection from the lake, you and the reflection of the top of the mountain form a triangle that is similar to a triangle formed by the mountain and the top of its reflection in the lake. Your height makes up one side, h_{you} = 2 m and the top of the mountain is halfway across the lake, d_{you} = 50 m. The mountain is a distance $d_{mountain}$ = 50,000 m from its reflection. Find $h_{mountain}$ by equating the ratios of the sides of the two similar triangles.

$$\frac{h_{you}}{d_{you}} = \frac{h_{mountain}}{d_{mountain}}$$
$$h_{mountain} = \frac{h_{you}d_{mountain}}{d_{you}}$$
$$= \frac{(2\text{ m})(50{,}000\text{ m})}{50\text{ m}}$$
$$= 2000\text{ m}$$

113. A converging lens has a focal length of 38.0 cm. If it is placed 60.0 cm from an object, at what distance from the lens will the image be? (Chapter 18)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$
$$d_i = \frac{d_o f}{d_o - f}$$
$$= \frac{(60.0\text{ cm})(38.0\text{ cm})}{60.0\text{ cm} - 38.0\text{ cm}}$$
$$= 104\text{ cm}$$

The image is 104 cm from the lens.

114. A force, F, is measured between two charges, Q and q, separated by a distance, r. What would the new force be for each of the following? (Chapter 20)

a. r is tripled

F/9

b. Q is tripled

3F

c. both r and Q are tripled

F/3

d. both r and Q are doubled

F/2

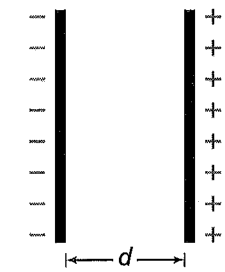
e. all three, r, Q, and q, are tripled

F

Challenge Problem

page 579

The plates of a capacitor attract each other because they carry opposite charges. A capacitor consisting of two parallel plates that are separated by a distance, *d*, has capacitance, *C*.



1. Derive an expression for the force between the two plates when the capacitor has charge, *q*.

   Combine the following equations:

   $$F = Eq,\ E = \frac{\Delta V}{d},\ \text{and}\ \Delta V = \frac{q}{C}$$

   $$F = Eq = \left(\frac{\Delta V}{d}\right)q = \left(\frac{\left(\frac{q}{C}\right)}{d}\right)q = \frac{q^2}{Cd}$$

2. What charge must be stored on a 22-μF capacitor to have a force of 2.0 N between the plates if they are separated by 1.5 mm?

   $$F = \frac{q^2}{Cd}$$

   $$\text{so } q = \sqrt{FCd}$$

   $$= \sqrt{(2.0\ \text{N})(2.2\times10^{-5}\ \text{F})(1.5\times10^{-3}\ \text{m})}$$

   $$= 2.6\times10^{-4}\ \text{C}$$