PROBLEMS

Problems that are not marked with a star are considered the easiest to solve. Problems that are marked with a single star (*) are more difficult, while those marked with a double star (**) are the most difficult. Note: All charges are 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 18.1 The Origin of Electricity, Section 18.2 Charged Objects and the Electric Force, Section 18.3 Conductors and Insulators, Section 18.4 Charging by Contact and by Induction

1. ssm How many electrons must be removed from an electrically neutral silver dollar to give it a charge of $+2.4\ \mu C$?

2. A rod has a charge of $-2.0\ \mu C$. How many electrons must be removed so that the charge becomes $+3.0\ \mu C$?

3. A metal sphere has a charge of $+8.0\ \mu C$. What is the net charge after 6.0×10^{13} electrons have been placed on it?

4. Object A is metallic and electrically neutral. It is charged by induction so that it acquires a charge of -3.0×10^{-6} C. Object B is identical to object A and is also electrically neutral. It is charged by induction so that it acquires a charge of $+3.0 \times 10^{-6}$ C. Find the *difference* in mass between the charged objects and state which has the greater mass.

5. ssm Consider three identical metal spheres, A, B, and C. Sphere A carries a charge of $+5q$. Sphere B carries a charge of $-q$. Sphere C carries no net charge. Spheres A and B are touched together and then separated. Sphere C is then touched to sphere A and separated from it. Lastly, sphere C is touched to sphere B and separated from it. (a) How much charge ends up on sphere C? What is the total charge on the three spheres (b) before they are allowed to touch each other and (c) after they have touched?

***6.** Water has a mass per mole of 18.0 g/mol, and each water molecule (H_2O) has 10 electrons. (a) How many electrons are there in one liter ($1.00 \times 10^{-3}\ m^3$) of water? (b) What is the net charge of all these electrons?

Section 18.5 Coulomb's Law

7. ssm www Two very small spheres are initially neutral and separated by a distance of 0.50 m. Suppose that 3.0×10^{13} electrons are removed from one sphere and placed on the other. (a) What is the magnitude of the electrostatic force that acts on each sphere? (b) Is the force attractive or repulsive? Why?

8. The nucleus of the helium atom contains two protons that are separated by about 3.0×10^{-15} m. Find the magnitude of the electrostatic force that each proton exerts on the other. (The protons remain together in the nucleus because the repulsive electrostatic force is balanced by an attractive force called the strong nuclear force.)

9. The force of repulsion that two like charges exert on each other is 3.5 N. What will the force be if the distance between the charges is increased to five times its original value?

10. In a vacuum, two particles have charges of q_1 and q_2, where $q_1 = +3.5\ \mu C$. They are separated by a distance of 0.26 m, and particle 1 experiences an attractive force of 3.4 N. What is q_2 (magnitude and sign)?

11. ssm Three charges are fixed to an xy coordinate system. A charge of $+18\ \mu C$ is on the y axis at $y = +3.0$ m. A charge of $-12\ \mu C$ is at the origin. Lastly, a charge of $+45\ \mu C$ is on the x axis at $x = +3.0$ m. Determine the magnitude and direction of the net electrostatic force on the charge at $x = +3.0$ m. Specify the direction relative to the $-x$ axis.

12. A charge of $-3.00\ \mu C$ is fixed at the center of a compass. Two additional charges are fixed on the circle of the compass (radius = 0.100 m). The charges on the circle are $-4.00\ \mu C$ at the position due north and $+5.00\ \mu C$ at the position due east. What is the magnitude and direction of the net electrostatic force acting on the charge at the center? Specify the direction relative to due east.

13. An equilateral triangle has sides of 0.15 m. Charges of -9.0, $+8.0$, and $+2.0\ \mu C$ are located at the corners of the triangle. Find the magnitude of the net electrostatic force exerted on the 2.0-μC charge.

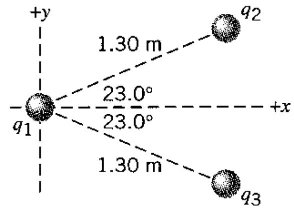
14. Two tiny conducting spheres are identical and carry charges of $-20.0\ \mu C$ and $+50.0\ \mu C$. They are separated by a distance of 2.50 cm. (a) What is the magnitude of the force that each sphere experiences, and is the force attractive or repulsive? (b) The spheres are brought into contact and then separated to a distance of 2.50 cm. Determine the magnitude of the force that each sphere now experiences, and state whether the force is attractive or repulsive.

15. ssm www Two particles, with identical positive charges and a separation of 2.60×10^{-2} m, are released from rest. Immediately after the release, particle 1 has an acceleration $\mathbf{a}_1$ whose magnitude is $4.60 \times 10^3\ m/s^2$, while particle 2 has an acceleration $\mathbf{a}_2$ whose magnitude is $8.50 \times 10^3\ m/s^2$. Particle 1 has a mass of 6.00×10^{-6} kg. Find (a) the charge on each particle and (b) the mass of particle 2.

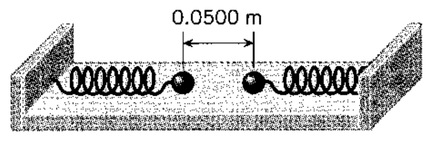
***16.** A point charge of $-0.70\ \mu C$ is fixed to one corner of a square. An identical charge is fixed to the diagonally opposite corner. A point charge q is fixed to each of the remaining corners. The net force acting on either of the charges q is zero. Find the magnitude and algebraic sign of q.

***17.** Two small objects, A and B, are fixed in place and separated by 2.00 cm in a vacuum. Object A has a charge of $+1.00\ \mu C$, and object B has a charge of $-1.00\ \mu C$. How many electrons must be removed from A and put onto B to make the electrostatic force that acts on each object an attractive force whose magnitude is 45.0 N?

*18. The drawing shows three point charges fixed in place. The charge at the coordinate origin has a value of $q_1 = +8.00\ \mu C$; the other two have identical magnitudes, but opposite signs: $q_2 = -5.00\ \mu C$ and $q_3 = +5.00\ \mu C$. (a) Determine the net force (magnitude and direction) exerted on q_1 by the other two charges. (b) If q_1 had a mass of 1.50 g and it were free to move, what would be its acceleration?



*19. **ssm** Two spheres are mounted on identical horizontal springs and rest on a frictionless table, as in the drawing. When the spheres are uncharged, the spacing between them is 0.0500 m, and the springs are unstrained. When each sphere has a charge of $+1.60\ \mu C$, the spacing doubles. Assuming that the spheres have a negligible diameter, determine the spring constant of the springs.

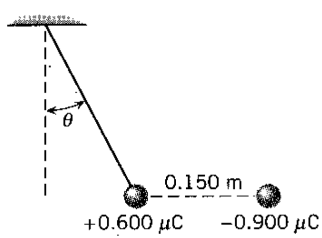


*20. Two positive charges, when combined, give a total charge of $+9.00\ \mu C$. When the charges are separated by 3.00 m, the force exerted by one charge on the other has a magnitude of 8.00×10^{-3} N. Find the amount of each charge.

*21. An electrically neutral model airplane is flying in a horizontal circle on a 3.0-m guideline, which is nearly parallel to the ground. The line breaks when the kinetic energy of the plane is 50.0 J. Reconsider the same situation, except that now there is a point charge of $+q$ on the plane and a point charge of $-q$ at the other end of the guideline. In this case, the line breaks when the kinetic energy of the plane is 51.8 J. Find the magnitude of the charges.

**22. Two objects are identical and small enough that their sizes can be ignored relative to the distance between them, which is 0.200 m. In a vacuum, each object carries a different charge, and they attract each other with a force of 1.20 N. The objects are brought into contact, so the net charge is shared equally, and then they are returned to their initial positions. Now it is found that the objects repel one another with a force whose magnitude is equal to that of the initial attractive force. What is the initial charge on each object? Note that there are two answers.

23. **ssm A small spherical insulator of mass 8.00×10^{-2} kg and charge $+0.600\ \mu C$ is hung by a thin wire of negligible mass. A charge of $-0.900\ \mu C$ is held 0.150 m away from the sphere and directly to the right of it, so the wire makes an angle θ with the vertical (see the drawing). Find (a) the angle θ and (b) the tension in the wire.



**24. Two identical, small insulating balls are suspended by separate 0.25-m threads that are attached to a common point on the ceiling. Each ball has a mass of 8.0×10^{-4} kg. Initially the balls are uncharged and hang straight down. They are then given identical positive charges and, as a result, spread apart with an angle of 36° between the threads. Determine (a) the charge on each ball and (b) the tension in the threads.

Section 18.6 The Electric Field, Section 18.7 Electric Field Lines, Section 18.8 The Electric Field Inside a Conductor: Shielding

25. An electric field of 260 000 N/C points due west at a certain spot. What are the magnitude and direction of the force that acts on a charge of $-7.0\ \mu C$ at this spot?

26. Review Conceptual Example 12 as an aid in working this problem. Charges of $-4q$ are fixed to opposite corners of a square. A charge of $+5q$ is fixed to one of the remaining corners, and a charge of $+3q$ is fixed to the last corner. Assuming that ten electric field lines emerge from the $+5q$ charge, sketch the field lines in the vicinity of the four charges.

27. **ssm** A charge of $+3.0 \times 10^{-5}$ C is located at a place where there is an electric field that points due east and has a magnitude of 15 000 N/C. What are the magnitude and direction of the force acting on the charge?

28. Two charges are placed on the x axis. One charge ($q_1 = +8.5\ \mu C$) is at $x_1 = +3.0$ cm and the other ($q_2 = -21\ \mu C$) is at $x_1 = +9.0$ cm. Find the net electric field (magnitude and direction) at (a) $x = 0$ cm and (b) $x = +6.0$ cm.

29. Two charges, -16 and $+4.0\ \mu C$, are fixed in place and separated by 3.0 m. (a) At what spot along a line through the charges is the net electric field zero? Locate this spot relative to the positive charge. *(Hint: The spot does not necessarily lie between the two charges.)* (b) What would be the force on a charge of $+14\ \mu C$ placed at this spot?

30. An electric field with a magnitude of 160 N/C exists at a spot that is 0.15 m away from a charge. At a place that is 0.45 m away from this charge, what is the electric field strength?

31. **ssm** A 3.0-μC point charge is placed in an external uniform electric field of 1.6×10^4 N/C. At what distance from the charge is the net electric field zero?

32. A charge of $q = +7.50\ \mu C$ is located in an electric field. The x and y components of the electric field are $E_x = 6.00 \times 10^3$ N/C and $E_y = 8.00 \times 10^3$ N/C, respectively. (a) What is the magnitude of the force on the charge? (b) Determine the angle that the force makes with the $+x$ axis.

33. The magnitude of the electric field between the plates of a parallel plate capacitor is 2.4×10^5 N/C. Each plate carries a charge whose magnitude is 0.15 μC. What is the area of each plate?

34. Two charges are located on the x axis: $q_1 = +6.0\ \mu C$ at $x_1 = +4.0$ cm, and $q_2 = +6.0\ \mu C$ at $x_2 = -4.0$ cm. Two other charges are located on the y axis: $q_3 = +3.0\ \mu C$ at $y_3 = +5.0$ cm, and $q_4 = -8.0\ \mu C$ at $y_4 = +7.0$ cm. Find the net electric field (magnitude and direction) at the origin.

35. **ssm** A small drop of water is suspended motionless in air by a uniform electric field that is directed upward and has a

magnitude of 8480 N/C. The mass of the water drop is 3.50×10^{-9} kg. (a) Is the excess charge on the water drop positive or negative? Why? (b) How many excess electrons or protons reside on the drop?

36. Review Conceptual Example 11 before attempting this problem. The magnitude of each of the charges in Figure 18.21 is 8.60×10^{-12} C. The lengths of the sides of the rectangles are 3.00 cm and 5.00 cm. Find the magnitude of the electric field at the center of the rectangle in Figure 18.21*a* and *b*.

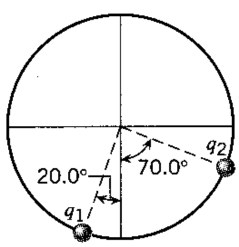
***37.** A proton is moving parallel to a uniform electric field. The electric field accelerates the proton and increases its linear momentum to 5.0×10^{-23} kg·m/s from 1.5×10^{-23} kg·m/s in a time of 6.3×10^{-6} s. What is the magnitude of the electric field?

***38.** An electron is released from rest at the negative plate of a parallel plate capacitor. The charge per unit area on each plate is $\sigma = 1.8 \times 10^{-7}$ C/m², and the plates are separated by a distance of 1.5×10^{-2} m. How fast is the electron moving just before it reaches the positive plate?

***39. ssm www** A rectangle has a length of $2d$ and a height of d. Each of the following three charges is located at a corner of the rectangle: $+q_1$ (upper left corner), $+q_2$ (lower right corner), and $-q$ (lower left corner). The net electric field at the (empty) upper right corner is zero. Find the magnitudes of q_1 and q_2. Express your answers in terms of q.

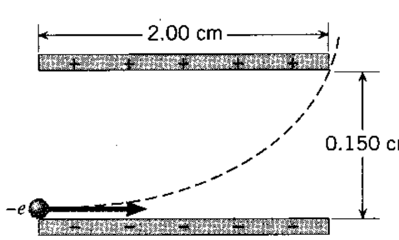
***40.** A small object, which has a charge $q = 7.5\ \mu$C and mass $m = 9.0 \times 10^{-5}$ kg, is placed in a constant electric field. Starting from rest, the object accelerates to a speed of 2.0×10^3 m/s in a time of 0.96 s. Determine the magnitude of the electric field.

***41.** The drawing shows two positive charges q_1 and q_2 fixed to a circle. At the center of the circle they produce a net electric field that is directed upward along the vertical axis. Determine the ratio q_2/q_1.

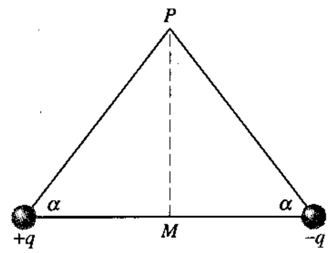


Problem 41

****42.** The drawing shows an electron entering the lower left side of a parallel plate capacitor and exiting at the upper right side. The initial speed of the electron is 7.00×10^6 m/s. The capacitor is 2.00 cm long, and its plates are separated by 0.150 cm. Assume that the electric field between the plates is uniform everywhere and find its magnitude.



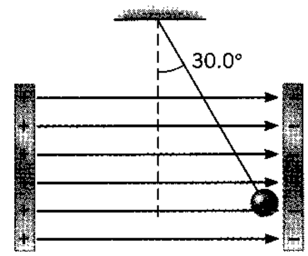
****43. ssm** Two point charges of the same magnitude but opposite signs are fixed to either end of the base of an isosceles triangle, as the drawing shows. The electric field at the midpoint M between the charges has a magnitude E_M. The field directly above the midpoint at point P has a magnitude E_P. The ratio of these two field magnitudes is $E_M/E_P = 9.0$. Find the angle α in the drawing.



Problem 43

****44.** The magnitude of the electric field between the plates of a parallel plate capacitor is 480 N/C. A silver dollar is placed between the plates and oriented parallel to the plates. (a) Ignoring the edges of the coin, find the induced charge density σ on each face of the coin. (b) Assuming the coin has a radius of 1.9 cm, find the magnitude of the total charge on each face of the coin.

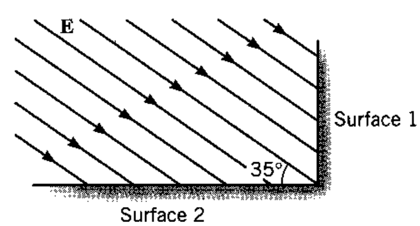
****45.** A small plastic ball of mass 6.50×10^{-3} kg and charge $+0.150\ \mu$C is suspended from an insulating thread and hangs between the plates of a capacitor (see the drawing). The ball is in equilibrium, with the thread making an angle of 30.0° with respect to the vertical. The area of each plate is 0.0150 m². What is the magnitude of the charge on each plate?



Section 18.9 Gauss' Law

46. A spherical surface completely surrounds a collection of charges. Find the electric flux through the surface if the collection consists of (a) a single $+3.5 \times 10^{-6}$ C charge, (b) a single -2.3×10^{-6} C charge, and (c) both of the charges in (a) and (b).

47. ssm The drawing shows an edge-on view of two planar surfaces that intersect and are mutually perpendicular. Surface 1 has an area of 1.7 m², while surface 2 has an area of 3.2 m². The electric field **E** in the drawing is uniform and has a magnitude of 250 N/C. Find the electric flux through (a) surface 1 and (b) surface 2.



48. A rectangular surface (0.16 m × 0.38 m) is oriented in a uniform electric field of 580 N/C. What is the maximum possible electric flux through the surface?

49. A surface completely surrounds a $+2.0 \times 10^{-6}$ C charge. Find the electric flux through this surface when the surface is (a) a sphere with a radius of 0.50 m, (b) a sphere with a radius of 0.25 m, and (c) a cube with edges that are 0.25 m long.

50. A vertical wall (5.9 m × 2.5 m) in a house faces due east. A uniform electric field has a magnitude of 150 N/C. This field is parallel to the ground and points 35° north of east. What is the electric flux through the wall?

***51. ssm** A cube is located with one corner at the origin of an x, y, z, coordinate system. One of the cube's faces lies in the x, y plane, another in the y, z plane, and another in the x, z plane. In other words, the cube is in the first octant of the coordinate system. The edges of the cube are 0.20 m long. A uniform electric field is parallel to the x, y plane and points in the direction of the $+y$ axis. The magnitude of the field is 1500 N/C. (a) Find the electric flux through each of the six faces of the cube. (b) Add the six values obtained in part (a) to show that the electric flux through the cubical surface is zero, as Gauss' law predicts, since there is no net charge within the cube.

*52. Two spherical shells have a common center. A -1.6×10^{-6}-C charge is spread uniformly over the inner shell, which has a radius of 0.050 m. A $+5.1 \times 10^{-6}$-C charge is spread uniformly over the outer shell, which has a radius of 0.15 m. Find the magnitude and direction of the electric field at a distance (measured from the common center) of (a) 0.20 m, (b) 0.10 m, and (c) 0.025 m.

**53. A long, thin, straight wire of length L has a positive charge Q distributed uniformly along it. Use Gauss' law to show that the electric field created by this wire at a radial distance r has a magnitude of $E = \lambda/(2\pi\epsilon_0 r)$, where $\lambda = Q/L$. *(Hint: For a Gaussian surface, use a cylinder aligned with its axis along the wire and note that the cylinder has a flat surface at either end, as well as a curved surface.)*

ADDITIONAL PROBLEMS

54. Review the important features of electric field lines discussed in Conceptual Example 12. Three point charges ($+q$, $+2q$, and $-3q$) are at the corners of an equilateral triangle. Sketch in six electric field lines between the three charges.

55. **ssm** Two charges attract each other with a force of 1.5 N. What will be the force if the distance between them is reduced to one-ninth of its original value?

56. Conceptual Example 13 in the text deals with the hollow spherical conductor in Figure 18.31. The conductor is initially electrically neutral, and then a charge $+q$ is placed at the center of the hollow space. Suppose the conductor initially has a net charge of $+2q$ instead of being neutral. What is the total charge on the interior and on the exterior surface when the $+q$ charge is placed at the center?

57. A charge $+q$ is located at the origin, while an identical charge is located on the x axis at $x = +0.50$ m. A third charge of $+2\,q$ is located on the x axis at such a place that the net electrostatic force on the charge at the origin doubles, its direction remaining unchanged. Where should the third charge be located?

58. Three charges are located on the $+x$ axis as follows: $q_1 = +25$ μC at $x = 0$ m, $q_2 = +11$ μC at $x = +2.0$ m, and $q_3 = +45$ μC at $x = +3.5$ m. (a) Find the electrostatic force (magnitude and direction) acting on q_2. (b) Suppose q_2 were -11 μC, rather than $+11$ μC. Without performing any further detailed calculations, specify the magnitude and direction of the force exerted on q_2. Give your reasoning.

59. **ssm www** A tiny ball (mass = 0.012 kg) carries a charge of -18 μC. What electric field (magnitude and direction) is needed to cause the ball to float above the ground?

60. A long, thin rod (length = 4.0 m) lies along the x axis, with its midpoint at the origin. In a vacuum, a $+8.0$ μC point charge is fixed to one end of the rod, while a -8.0 μC point charge is fixed to the other end. Everywhere in the x, y plane there is a constant external electric field (magnitude = 5.0×10^3 N/C) that is perpendicular to the rod. With respect to the z axis, find the magnitude of the net torque applied to the rod.

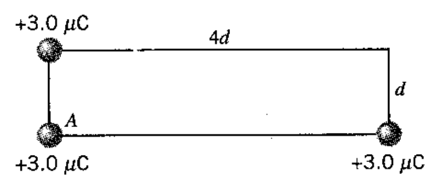
61. **ssm** Two tiny spheres have the same mass and carry charges of the same magnitude. The mass of each sphere is 2.0×10^{-6} kg. The gravitational force that each sphere exerts on the other is balanced by the electric force. (a) What algebraic signs can the charges have? (b) Determine the charge magnitude.

*62. Two charges are placed between the plates of a parallel plate capacitor. One charge is $+q_1$ and the other is $q_2 = +5.00$ μC. The charge per unit area on each plate has a magnitude of $\sigma = 1.30 \times 10^{-4}$ C/m^2. The force on q_1 due to q_2 equals the force on q_1 due to the electric field of the parallel plate capacitor. What is the distance r between the two charges?

*63. A small object has a mass of 2.0×10^{-3} kg and a charge of -25 μC. It is placed at a certain spot where there is an electric field. When released, the object experiences an acceleration of 3.5×10^3 m/s^2 in the direction of the $+x$ axis. Determine the magnitude and direction of the electric field.

*64. Two small charged objects are attached to a horizontal spring, one at each end. The magnitudes of the charges are equal, and the spring constant is 220 N/m. The spring is observed to be stretched by 0.020 m relative to its unstrained length of 0.32 m. Determine (a) the possible algebraic signs and (b) the magnitude of the charges.

*65. **ssm** In the rectangle in the drawing, a charge is to be placed at the empty corner to make the net force on the charge at corner A point along the vertical direction. What charge (magnitude and algebraic sign) must be placed at the empty corner?



*66. A uniform electric field has a magnitude of 2.3×10^3 N/C. In a vacuum, a proton begins with a speed of 2.5×10^4 m/s and moves in the direction of this field. Find the speed of the proton after it has moved a distance of 2.0 mm.

**67. There are four charges, each with a magnitude of 2.0 μC. Two are positive and two are negative. The charges are fixed to the corners of a 0.30-m square, one to a corner, in such a way that the net force on any charge is directed toward the center of the square. Find the magnitude of the net electrostatic force experienced by any charge.

CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

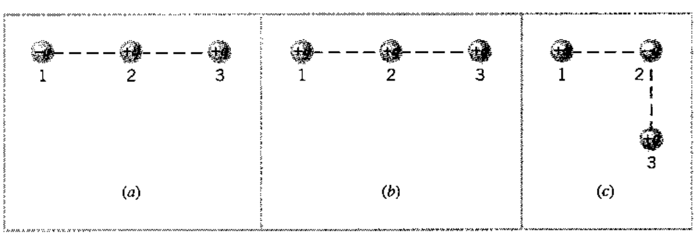
Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on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

68. Concept Questions Two identical metal spheres have charges of q_1 and q_2. They are brought together so they touch, and then they are separated. (a) How is the net charge on the two spheres before they touch related to the net charge after they touch? (b) After they touch and are separated, is the charge on each sphere the same? Why?

Problem Four identical metal spheres have charges of $q_A = -8.0\ \mu C$, $q_B = -2.0\ \mu C$, $q_C = +5.0\ \mu C$, and $q_D = +12.0\ \mu C$. (a) Two of the spheres are brought together so they touch and then they are separated. Which spheres are they, if the final charge on each one is $+5.0\ \mu C$? (b) In a similar manner, which three spheres are brought together and then separated, if the final charge on each one is $+3.0\ \mu C$? (c) How many electrons would have to be added to one of the spheres in part (b) to make it electrically neutral?

69. Concept Questions The drawings show three charges that have the same magnitude, but different signs. In all cases the distance between charges 1 and 2 and between 2 and 3 is the same. (a) Draw the electrical force that each charge exerts on charge 2. Each force should be drawn in the correct direction, and its magnitude should be correct relative to that of the other force. (b) Rank the magnitudes of the net electrical force on charge 2, largest first. Explain.

Problem The magnitude of the charges is $q = 8.6\ \mu C$, and the distance between them is 3.8 mm. Determine the magnitude of the net force on charge 2 for each of the three drawings. Verify that your answers are consistent with your answers to the Concept Questions.



70. Concept Questions Suppose you want to neutralize the gravitational attraction between the earth and the moon by placing equal amounts of charge on each. (a) Should the charges be both positive, both negative, or one positive and the other negative? Why? (b) Do you need to know the distance between the earth and the moon to find the magnitude of the charge? Why or why not?

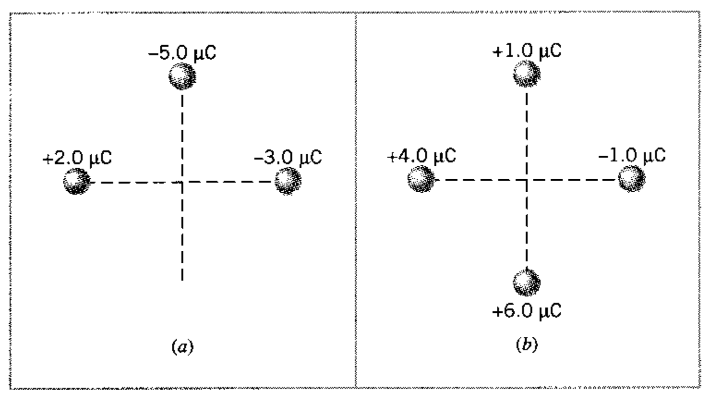
Problem The masses of the earth and moon are 5.98×10^{24} and 7.35×10^{22} kg, respectively. Identical amounts of charge are placed on each body, such that the net force (gravitational plus electrical) on each is zero. What is the magnitude of the charge?

71. Concept Questions Suppose you want to determine the electric field in a certain region of space. You have a small object of known charge and an instrument that measures the magnitude and direction of the force exerted on the object by the electric field. How would you determine the magnitude and direction of the electric field if the object were (a) positively charged and (b) negatively charged?

Problem The object has a charge of $+20.0\ \mu C$ and the instrument indicates that the electric force exerted on it is $40.0\ \mu N$, due east. What is the magnitude and direction of the electric field? (b) What is the magnitude and direction of the electric field if the object has a charge of $-10.0\ \mu C$ and the instrument indicates that the force is $20.0\ \mu N$ due west?

72. Concept Question The drawing shows two situations in which charges are placed on the x and y axes. They are all located at the same distance from the origin. Without doing any calculations, does the electric field at the origin in part (a) have a magnitude that is greater than, less than, or equal to the magnitude of the field at the origin in part (b)? Justify your answer.

Problem The distance between each of the charges and the origin is 6.1 cm. For each of the situations shown in the drawing, determine the magnitude of the electric field at the origin. Check to see that your results are consistent with your answer to the Concept Question.



73. Concept Questions A proton and an electron are moving due east in a constant electric field that also points due east. (a) Does each experience an electric force of the same magnitude and direction? (b) What is the direction of the proton's acceleration and the direction of the electron's acceleration? (c) Is the magnitude of the proton's acceleration greater than, less than, or the same as that of the electron's acceleration? Explain your answers.

Problem The electric field points due east and has a magnitude of 8.0×10^4 N/C. Determine the magnitude of the acceleration of the proton and the electron. Check that your answers are consistent with part *c* of the Concept Questions.