(a) $\vec{E} = \left\langle \frac{K}{x^2}, 0, 0 \right\rangle$, **(b)** $\vec{E} = \left\langle \frac{K}{x^3}, 0, 0 \right\rangle$, **(c)** $\vec{E} = \left\langle \frac{K}{x}, 0, 0 \right\rangle$,
(d) $\vec{E} = \langle Kx, 0, 0 \rangle$

1. $V_A - V_B = 0$
2. $V_A - V_B = K(a-b)$
3. $V_A - V_B = K\left(\frac{1}{a} - \frac{1}{b}\right)$
4. $V_A - V_B = K\left(\frac{1}{a^3}a - \frac{1}{b^3}b\right)$
5. $V_A - V_B = \frac{1}{2}K\left(b^2 - a^2\right)$
6. $V_A - V_B = K\ln\left(\frac{b}{a}\right)$
7. $V_A - V_B = K\left(a^2 - b^2\right)$
8. $V_A - V_B = \frac{1}{2}K\left(\frac{1}{a^2} - \frac{1}{b^2}\right)$

Q14 Figure 16.62 shows a pattern of electric field in which the electric field is horizontal throughout this region but is larger toward the top of the region and smaller toward the bottom. If this pattern of electric field can be produced by some arrangement of stationary charges, sketch such a distribution of charges. If this pattern of electric field cannot be produced by any arrangement of stationary charges, prove that it is impossible.

Figure 16.62

Q15 The graph in Figure 16.63 is a plot of electric potential versus distance from an object. Which of the following could be the object?
(1) A neutron, (2) A sodium ion (Na^+), (3) A chloride ion (Cl^-), (4) A proton, (5) An electron

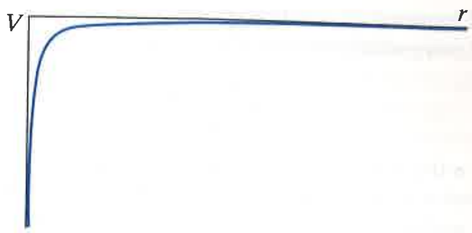

Figure 16.63

Q16 The graph in Figure 16.64 is a plot of electric potential versus distance from an object. Which of the following could be the object?

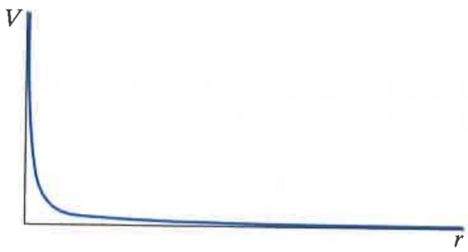

Figure 16.64

(1) A neutron, (2) A sodium ion (Na^+), (3) A chloride ion (Cl^-), (4) A proton, (5) An electron

Q17 A student said, "The electric field at the center of a charged spherical shell is zero, so the potential at that location is also zero." Explain to the student why this statement is incorrect.

Q18 For each of the following statements, say whether it is true or false and explain why it is true or false. Be complete in your explanation, but be brief. Pay particular attention to the distinction between potential V and potential difference ΔV. **(a)** The electric potential inside a metal in equilibrium is always zero. **(b)** If there is a constant large positive potential throughout a region, the electric field in that region is large. **(c)** If you get close enough to a negative point charge, the potential is negative, no matter what other charges are around. **(d)** Near a point charge, the potential difference between two points a distance L apart is $-EL$. **(e)** In a region where the electric field is varying, the potential difference between two points a distance L apart is $-(E_f - E_i)L$.

Q19 We discussed a method for measuring the dielectric constant by placing a slab of the material between the plates of a capacitor. Using this method, what would we get for the dielectric constant if we inserted a slab of metal (not quite touching the plates, of course)?

PROBLEMS

Section 16.1

•P20 What is the kinetic energy of a proton that is traveling at a speed of 3725 m/s?

•P21 If the kinetic energy of an electron is 4.4×10^{-18} J, what is the speed of the electron? You can use the approximate (nonrelativistic) equation here.

•P22 An electron passes through a region in which there is an electric field, and while it is in the region its kinetic energy decreases by 4×10^{-17} J. Initially the kinetic energy of the electron was 4.5×10^{-17} J. What is the final speed of the electron? (You can use the approximate (nonrelativistic) equation here.)

•P23 At a particular instant an electron is traveling with speed 6000 m/s. **(a)** What is the kinetic energy of the electron? **(b)** If a proton were traveling at the same speed (6000 m/s), what would be the kinetic energy of the proton?

•P24 In Chapter 6 we saw that the electric potential energy of a system of two particles is given by the equation

$$U_{\text{el}} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

(a) What is the electric potential energy of two protons separated by a distance of 9 nm (9×10^{-9} m)? **(b)** What is the electric potential energy of a proton and an electron separated by the same distance?

•P25 A proton that initially is traveling at a speed of 300 m/s enters a region where there is an electric field. Under the influence of the electric field the proton slows down and comes to a stop. What is the change in kinetic energy of the proton?

Section 16.3

•P26 You move from location i at $\langle 2,7,5\rangle$ m to location f at $\langle 5,6,12\rangle$ m. All along this path there is a nearly uniform electric field of $\langle 1000,200,-510\rangle$ N/C. Calculate $V_f - V_i$, including sign and units.

•P27 A capacitor with a gap of 1 mm has a potential difference from one plate to the other of 36 V. What is the magnitude of the electric field between the plates?

•P28 An electron starts from rest in a vacuum, in a region of strong electric field. The electron moves through a potential difference of 35 V. **(a)** What is the kinetic energy of the electron in electron volts (eV)? **(b)** What would happen if the particle were a proton?

•P29 Locations A, B, and C are in a region of uniform electric field, as shown in the diagram in Figure 16.65. Location A is at $\langle -0.5,0,0\rangle$ m. Location B is at $\langle 0.5,0,0\rangle$ m. In the region the electric field has the value $\langle 750,0,0\rangle$ N/C. For a path starting at B and ending at A, calculate: **(a)** the displacement vector $\Delta\vec{l}$, **(b)** the change in electric potential, **(c)** the potential energy change for the system when a proton moves from B to A, **(d)** the potential energy change for the system when an electron moves from B to A.

Figure 16.65

•P30 Locations A, B, and C are in a region of uniform electric field, as shown in Figure 16.65. Location A is at $\langle -0.5,0,0\rangle$ m. Location B is at $\langle 0.5,0,0\rangle$ m. In the region the electric field has the value $\langle 750,0,0\rangle$ N/C. **(a)** For a path starting at B and ending at C, calculate: (1) the displacement vector $\Delta\vec{l}$, (2) the change in electric potential, (3) the potential energy change for the system when a proton moves from B to C, (4) the potential energy change for the system when an electron moves from B to C, **(b)** Which of the following statements are true in this situation? Choose all that are correct. (1) the potential difference cannot be zero because the electric field is not zero along this path, (2) when a proton moves along this path, the electric force does zero net work on the proton, (3) $\Delta\vec{l}$ is perpendicular to $\vec{E}$.

•P31 Locations A, B, and C are in a region of uniform electric field, as shown in Figure 16.66. Location A is at $\langle -0.3,0,0\rangle$ m. Location B is at $\langle 0.4,0,0\rangle$ m. In the region the electric field has the value $\langle -850,400,0\rangle$ N/C. For a path starting at A and ending at B, calculate:

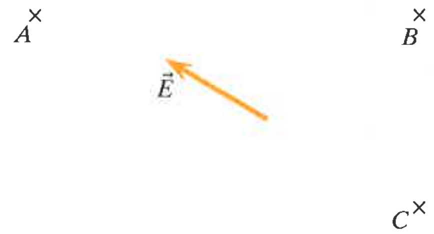

Figure 16.66

(a) the displacement vector $\Delta\vec{l}$, **(b)** the change in electric potential, **(c)** the potential energy change for the system when a proton moves from A to B, **(d)** the potential energy change for the system when an electron moves from A to B.

•P32 Locations A, B, and C are in a region of uniform electric field, as shown in Figure 16.66. Location A is at $\langle -0.3,0,0\rangle$ m. Location B is at $\langle 0.4,0,0\rangle$ m. In the region the electric field has the value $\langle -850,400,0\rangle$ N/C. For a path starting at C and ending at A, calculate: **(a)** the displacement vector $\Delta\vec{l}$, **(b)** the change in electric potential, **(c)** the potential energy change for the system when a proton moves from C to A, **(d)** the potential energy change for the system when an electron moves from C to A.

•P33 Locations A and B are in a region of uniform electric field, as shown in Figure 16.67. Along a path from B to A, the change in potential is -2200 V. The distance from A to B is 0.28 m. What is the magnitude of the electric field in this region?

Figure 16.67

•P34 An electron starts from rest in a vacuum, in a region of strong electric field. The electron moves through a potential difference of 44 V. **(a)** What is the kinetic energy of the electron in electron volts (eV)? **(b)** Which of the following statements would be true if the particle were a proton? Choose both if they are both correct. (1) The kinetic energy of the proton would be negative. (2) The proton would move in the opposite direction from the electron.

•P35 If the electric field exceeds about 3×10^6 N/C in air, a spark occurs. Approximately, what is the absolute value of the maximum possible potential difference between the plates of a capacitor whose gap is 3 mm, without causing a spark in the air between them?

•P36 A capacitor with a gap of 2 mm has a potential difference from one plate to the other of 30 V. What is the magnitude of the electric field between the plates?

•P37 You move from location i at $\langle 2,5,4\rangle$ m to location f at $\langle 3,5,9\rangle$ m. All along this path there is a nearly uniform electric field whose value is $\langle 1000, 200, -500\rangle$ N/C. Calculate $\Delta V = V_f - V_i$, including sign and units.

•P38 In a particular region there is a uniform electric field of $\langle -760, 380, 0\rangle$ V/m. Location A is $\langle 0.2, 0.1, 0\rangle$ m, location B is $\langle 0.7, 0.1, 0\rangle$, and location C is $\langle 0.7, -0.4, 0\rangle$ m. **(a)** What is the change in potential along a path from B to A? **(b)** What is the change in potential along a path from A to C? **(c)** An alpha particle (two protons and two neutrons) moves from A to C. What is the change in potential energy of the system (alpha + source charges)?

••P39 The potential difference from one end of a 1-cm-long wire to the other in a circuit is $\Delta V = V_B - V_A = 1.5$ V, as shown in Figure 16.68. Which end of the wire is at the higher potential? What are the magnitude and direction of the electric field E inside the wire?

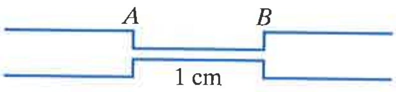

Figure 16.68

••P40 In the cathode ray tube found in old television sets, which contains a vacuum, electrons are boiled out of a very hot metal filament placed near a negative metal plate. These electrons start out nearly at rest and are accelerated toward a positive metal plate. They pass through a hole in the positive plate on their way toward the picture screen, as shown in the diagram in Figure 16.69. If the high-voltage supply in the television set maintains a potential difference of 15,000 V between the two plates, what speed do the electrons reach?

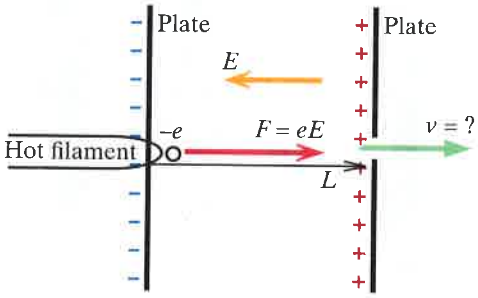

Figure 16.69

••P41 Two very large disks of radius R are carrying uniformly distributed charges Q_A and Q_B. The plates are parallel and 0.1 mm apart, as shown in Figure 16.70. The potential difference between the plates is $V_B - V_A = -10$ V. **(a)** What is the direction of the electric field between the disks? **(b)** Invent values of Q_A, Q_B, and R that would make $V_B - V_A = -10$ V.

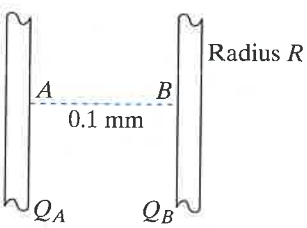

Figure 16.70

••P42 A particular oscilloscope, shown in Figure 16.71, has an 18,000-V power supply for accelerating electrons to a speed adequate to make the front phosphor-coated screen glow when the electrons hit it. Once the electron has emerged from the accelerating region, it coasts through a vacuum at nearly constant speed.

One can apply a potential difference of plus or minus 40 V across the deflection plates to steer the electron beam up or down on the screen to paint a display (other deflection plates not shown in the diagram are used to steer the beam horizontally).

Each of the two deflection plates is a thin metal plate of length $L = 8$ cm and width (into the diagram) 4 cm. The distance between the deflection plates is $s = 3$ mm. The distance from the deflection plates to the screen is $d = 30$ cm.

When there is a 40-V potential difference between the deflection plates, what is the deflection y of the electron beam where it hits the screen? An approximate treatment is fine, but state your assumptions. As is usually the case, it pays to carry out all of your calculations algebraically and only evaluate the final algebraic result numerically. Note the exaggerated vertical scale: the deflection is actually small compared to the distance to the screen.

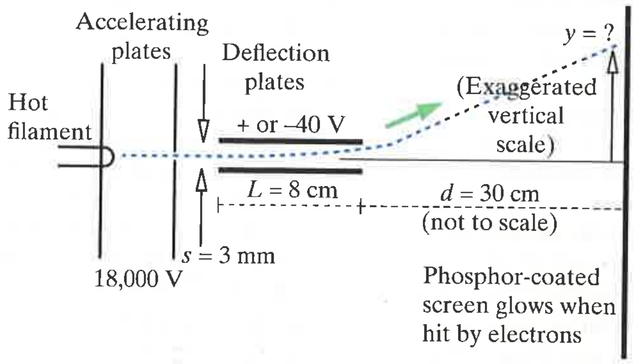

Figure 16.71

Section 16.5

•P43 Location C is 0.02 m from a small sphere that has a charge of 4 nC uniformly distributed on its surface. Location D is 0.06 m from the sphere. What is the change in potential along a path from C to D?

•P44 What is the change in potential ΔV in going from a location 3×10^{-10} m from a proton to a location 4×10^{-10} m from the proton?

•P45 An electron is initially at rest. It is moved from a location 4×10^{-10} m from a proton to a location 6×10^{-10} m from the proton. What is the change in electric potential energy of the system of proton and electron?

•P46 How much work is required to move a proton and an electron at rest a distance 3×10^{-8} m apart to be at rest a distance 7×10^{-8} m apart?

••P47 As shown in Figure 16.72, three large, thin, uniformly charged plates are arranged so that there are two adjacent regions of uniform electric field. The origin is at the center of the central plate. Location A is $\langle -0.4, 0, 0\rangle$ m, and location B is $\langle 0.2, 0, 0\rangle$ m. The electric field $\vec{E}_1$ has the value $\langle 725, 0, 0\rangle$ V/m, and $\vec{E}_2$ is $\langle -425, 0, 0\rangle$ V/m.

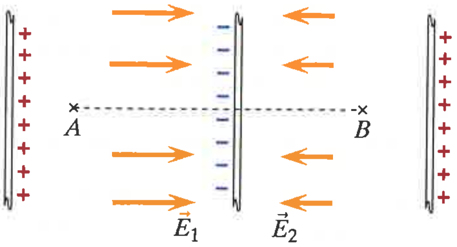

Figure 16.72

(a) Consider a path from A to B. Along this path, what is the change in electric potential? **(b)** What is the change in electric potential along a path from B to A? **(c)** There is a tiny hole in the central plate, so a moving particle can pass through the hole. If an electron moved from A to B along the path shown, what would be the change in its kinetic energy? **(d)** What is the minimum kinetic energy the electron must have at location A in order to ensure that it reaches location B?

••P48 If throughout a particular region of space the potential can be expressed as $V = 4xz + 2y - 5z$, what are the vector components of the electric field at location $\langle x,y,z \rangle$?

••P49 A dipole is oriented along the x axis. The dipole moment is p ($= qs$). **(a)** Calculate exactly the potential V (relative to infinity) at a location $\langle x,0,0 \rangle$ on the x axis and at a location $\langle 0,y,0 \rangle$ on the y axis, by superposition of the individual $1/r$ contributions to the potential. **(b)** What are the approximate values of V at the locations in part (a) if these locations are far from the dipole? **(c)** Using the approximate results of part (b), calculate the gradient of the potential along the x axis, and show that the negative gradient is equal to the x component E_x of the electric field. **(d)** Along the y axis, $dV/dy = 0$. Why isn't this equal to the magnitude of the electric field E along the y axis?

••P50 A capacitor consists of two large metal disks placed a distance s apart. The radius of each disk is R ($R \gg s$), and the thickness of each disk is t, as shown in Figure 16.73. The disk on the left has a net charge of $+Q$, and the disk on the right has a net charge of $-Q$. Calculate the potential difference $V_2 - V_1$, where location 1 is inside the left disk at its center, and location 2 is in the center of the air gap between the disks. Explain briefly.

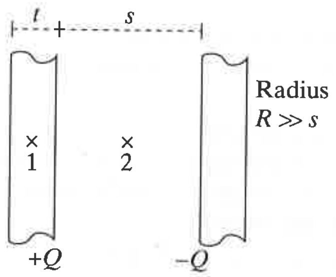

Figure 16.73

••P51 The diagram in Figure 16.74 shows three very large metal disks (seen edgewise), carrying charges as indicated. On each surface the charges are distributed approximately uniformly. Each disk has a very large radius R and a small thickness t. The distances between the disks are a and b, as shown; they also are small compared to R. Calculate $V_2 - V_1$, and explain your calculation briefly.

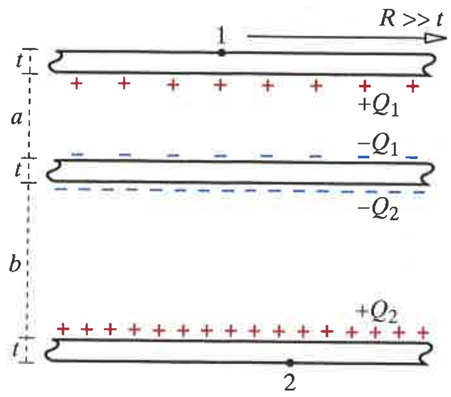

Figure 16.74

••P52 Three charged metal disks are arranged as shown in Figure 16.75 (cutaway view). The disks are held apart by insulating supports not shown in the diagram. Each disk has an area of 2.5 m^2 (this is the area of one flat surface of the disk). The charge $Q_1 = 5 \times 10^{-8}$ C and the charge $Q_2 = 4 \times 10^{-7}$C.

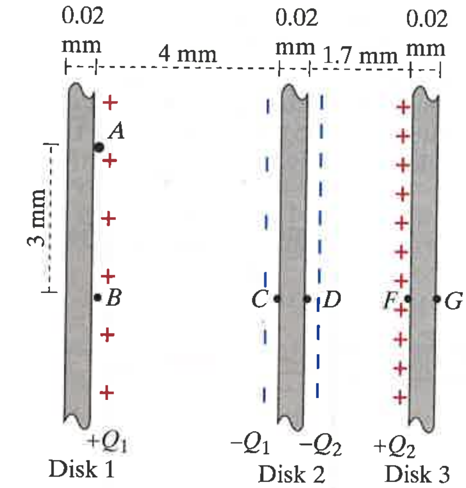

Figure 16.75

(a) What is the electric field (magnitude and direction) in the region between disks 1 and 2? **(b)** Which of the following statements are true? Choose all that apply. (1) Along a path from A to B, $\vec{E} \perp \Delta \vec{l}$. (2) $V_B - V_A = 0$. (3) $V_B - V_A = -\frac{Q_1/2.5}{\varepsilon_0} *$ (0.003) V. **(c)** To calculate $V_C - V_B$, where should the path start and where should it end? **(d)** Should $V_C - V_B$ be positive or negative? Why? (1) Positive, because $\Delta \vec{l}$ is opposite to the direction of $\vec{E}$. (2) Negative, because $\Delta \vec{l}$ is in the same direction as $\vec{E}$. (3) Zero, because $\Delta \vec{l} \perp \vec{E}$. **(e)** What is the potential difference $V_C - V_B$? **(f)** What is the potential difference $V_D - V_C$? **(g)** What is the potential difference $V_F - V_D$? **(h)** What is the potential difference $V_G - V_F$? **(i)** What is the potential difference $V_G - V_A$? **(j)** The charged disks have tiny holes that allow a particle to pass through them. An electron that is traveling at a fast speed approaches the plates from the left side. It travels along a path from A to G. Since no external work is done on the system of plates + electron, $\Delta K + \Delta U = W_{ext} = 0$. Consider the following states: initial, electron at location A; final, electron at location G. (1) What is the change in potential energy of the system? (2) What is the change in kinetic energy of the electron?

••P53 The long rod shown in Figure 16.76 has length L and carries a uniform charge $-Q$. Calculate the potential difference $V_A - V_C$. All of the distances are small compared to L. Explain your work carefully.

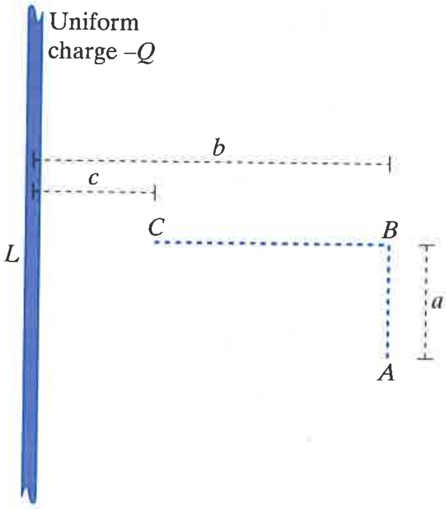

Figure 16.76

••P54 Three very large charged metal plates are arranged as shown in Figure 16.77. The radius of each plate is 4 m, and each plate is $w = 0.05$ mm thick. The separation d_1 is 6 mm, and the separation d_2 is 2 mm. Each plate has a tiny hole in it, so it is possible for a small charged particle to pass through all the plates.

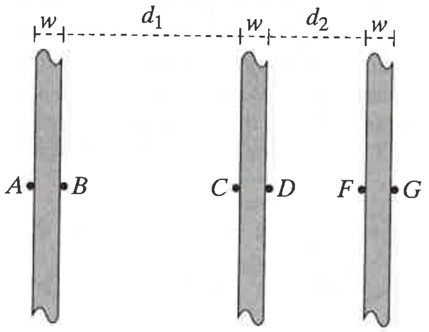

Figure 16.77

You are able to adjust the apparatus by varying the electric field in the region between location D and location F. You need to adjust this setting so that a fast-moving electron moving to the right, entering at location A, will have lost exactly 5.2×10^{-18} J of kinetic energy by the time it reaches location G. Using a voltmeter, you find that the potential difference $V_C - V_B = -16$ V. Based on this measurement, you adjust the electric field between D and F to the appropriate value. **(a)** Consider the system of (electron + plates). Neglecting the small amount of work done by the gravitational force on the electron, during this process (electron going from A to G), what is $\Delta K + \Delta U$? **(b)** What is the change in potential energy for the system during this process? **(c)** What is $V_G - V_A$? **(d)** What is $V_F - V_D$? **(e)** What is the electric field (magnitude and direction) in the region between locations D and F?

••P55 In the Van de Graaff generator shown in Figure 16.78, a rubber belt carries electrons up through a small hole in a large hollow spherical metal shell. The electrons come off the upper part of the belt and drift through a wire to the outer surface of the metal shell, so that the metal shell acquires a sizable negative charge, approximately uniformly distributed over the sphere. At a time when the sphere has acquired a sizable charge $-Q$, approximately how much work must be done by the motor to move one more electron from the base (a distance h below the sphere) to the upper pulley (located a distance $R/2$ from the center of the hollow sphere)? Explain your work, and state explicitly what approximations you had to make.

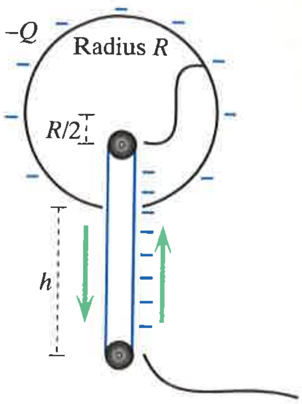

Figure 16.78

••P56 A thin spherical shell made of plastic carries a uniformly distributed negative charge $-Q_1$. As shown in Figure 16.79, two large thin disks made of glass carry uniformly distributed positive and negative charges $+Q_2$ and $-Q_2$. The radius R_1 of the plastic spherical shell is very small compared to the radius R_2 of the glass disks. The distance from the center of the spherical shell to the positive disk is d, and d is much smaller than R_2. **(a)** Find the potential difference $V_2 - V_1$ in terms of the given quantities (Q_1, Q_2, R_1, R_2, and d). Point 1 is at the center of the plastic sphere, and point 2 is just outside the sphere. **(b)** Find the potential difference $V_3 - V_2$. Point 2 is just below the sphere, and point 3 is right beside the positive glass disk.

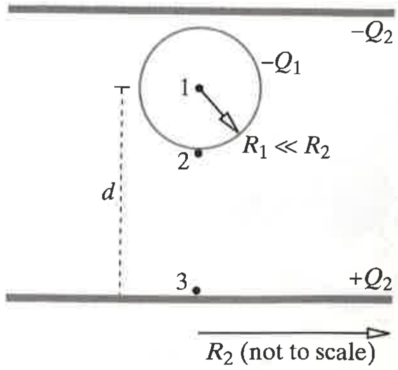

Figure 16.79

(c) Suppose that the plastic shell is replaced by a solid metal sphere with radius R_1 carrying charge $-Q_1$. State whether the absolute magnitudes of the potential differences would be greater than, less than, or the same as they were with the plastic shell in place. Explain briefly, including an appropriate diagram.

••P57 A thin spherical shell of radius R_1 made of plastic carries a uniformly distributed negative charge $-Q_1$. A thin spherical shell of radius R_2 made of glass carries a uniformly distributed positive charge $+Q_2$. The distance between centers is L, as shown in Figure 16.80. **(a)** Find the potential difference $V_B - V_A$. Location A is at the center of the glass sphere, and location B is just outside the glass sphere. **(b)** Find the potential difference $V_C - V_B$. Location B is just outside the glass sphere, and location C is a distance d to the right of B. **(c)** Suppose the glass shell is replaced by a solid metal sphere with radius R_2 carrying charge $+Q_2$. Would the magnitude of the potential difference $V_B - V_A$ be greater than, less than, or the same as it was with the glass shell in place? Explain briefly, including an appropriate physics diagram.

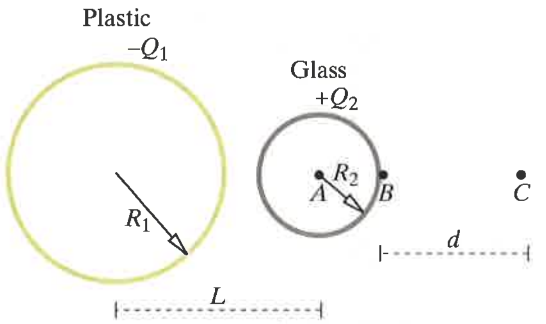

Figure 16.80

••P58 As shown in Figure 16.81, a solid metal sphere of radius r_1 has a charge $+Q$. It is surrounded by a concentric spherical metal shell with inner radius r_2 and outer radius r_3 that has a charge $-Q$ on its inner surface and $+Q$ on its outer surface. In the diagram, point A is located at a distance r_4 from the center of the spheres. Points B and C are inside the metal shell, very near the outer and inner surfaces, respectively. Point E is just inside the surface of the solid sphere. Point D is halfway between C and E. Point F is a distance $r_1/2$ from the center. **(a)** Is each of the following potential differences greater than zero, equal to zero, or less than zero? Briefly explain why in terms of the directions of the electric field and of the path: (1) $V_B - V_A$, (2) $V_C - V_B$, (3) $V_D - V_C$, (4) $V_F - V_E$. **(b)** Calculate V_F, the potential at location F. Explain your work.

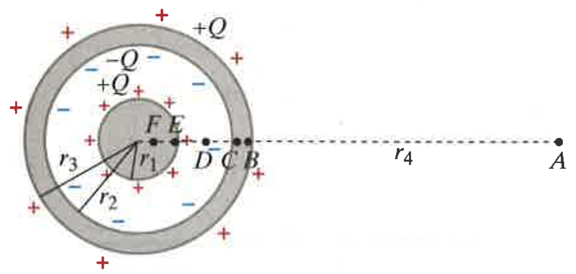

Figure 16.81

••P59 In a region with an uniform electric field, you measure a potential difference of 74 V from the origin to a position of $\langle 0,0,10\rangle$ m. Now we add a uniformly charged, thin spherical plastic shell centered at the origin. The spherical shell has a radius of 5 m and a charge of −3530 nC. Draw a diagram to help answer the following questions: **(a)** What is the potential difference from the origin to a position of $\langle 0,0,5\rangle$ m (at the surface of the spherical shell)? **(b)** What is the potential difference from the position of $\langle 0,0,5\rangle$ m to a position of $\langle 0,0,10\rangle$ m?

••P60 A dipole is centered at the origin, with its axis along the y axis, so that at locations on the y axis, the electric field due to the dipole is given by

$$\vec{E} = \left\langle 0, \frac{1}{4\pi\varepsilon_0}\frac{2qs}{y^3}, 0\right\rangle \frac{\text{V}}{\text{m}}$$

The charges making up the dipole are +3 nC and −3 nC, and the dipole separation is 2 mm (Figure 16.82). What is the potential difference along a path starting at location $\langle 0,0.03,0\rangle$ m and ending at location $\langle 0,0.04,0\rangle$ m?

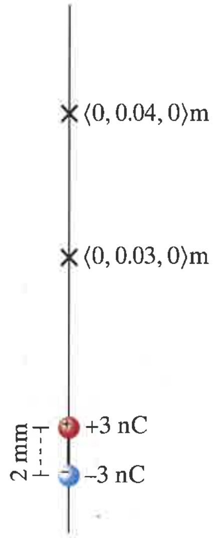

Figure 16.82

••P61 A thin spherical glass shell of radius R carries a uniformly distributed charge $+Q$, and a thin spherical plastic shell of radius R carries a uniformly distributed charge $-Q$. The surfaces of the spheres are a distance $L + 2d$ from each other, and locations A and B are a distance d from the surfaces of the spheres, as shown in Figure 16.83. Calculate the potential difference $V_B - V_A$.

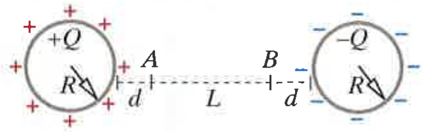

Figure 16.83

••P62 An HCl molecule (Figure 16.84) in the gas phase has an internuclear separation s. For the purposes of this problem, assume that

- The molecule can be considered as two point charges, H^+ and Cl^-, located at the centers of the nuclei (i.e., ignore polarization of one ion by the other, sharing of electrons, etc.).
- The molecule remains fixed in position.
- The distances a and b shown in the diagram are much greater than shown ($a > b \gg s$).

(a) Draw vectors showing the relative magnitude and direction of the electric field at each of the three points indicated by a square box. Your drawing should be accurate enough to show clearly whether one vector is equal in magnitude, greater in magnitude, or less in magnitude than another vector, but need not be more accurate than that. **(b)** What is the potential difference $\Delta V = V_B - V_A$ in terms of the given quantities? **(c)** An electron passes point A traveling along the x axis in the negative x direction, toward the Cl^-. Its kinetic energy is K_A. What is its kinetic energy at point B?

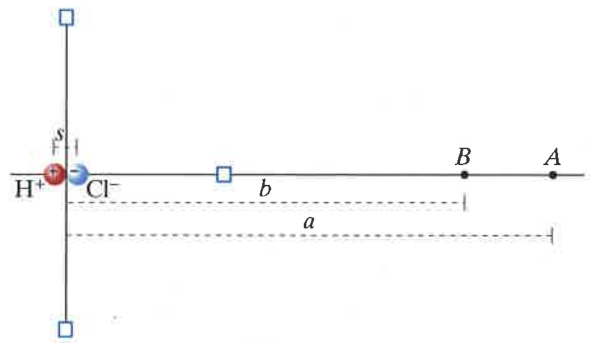

Figure 16.84

••**P63** A very long, thin glass rod of length $2R$ carries a uniformly distributed charge $+q$, as shown in Figure 16.85. A very large plastic disk of radius R, carrying a uniformly distributed charge $-Q$, is located a distance d from the rod, where $d \ll R$. Calculate the potential difference $V_B - V_A$ from the center of the surface of the disk (location A) to a location a distance h from the center of the disk (location B). If you have to make any approximations, state what they are.

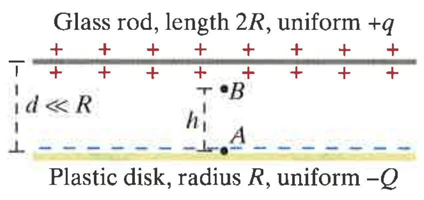

Figure 16.85

•••**P64** A long thin metal wire with radius r and length L is surrounded by a concentric long narrow metal tube of radius R, where $R \ll L$, as shown in Figure 16.86. Insulating spokes hold the wire in the center of the tube and prevent electrical contact between the wire and the tube. A variable power supply is connected to the device as shown. There is a charge $+Q$ on the inner wire and a charge $-Q$ on the outer tube. As we will see when we study Gauss's law in a later chapter, the electric field inside the tube is contributed solely by the wire, and the field outside the wire is the same as though the wire were infinitely thin; the outer tube does not contribute as long as we are not near the ends of the tube. **(a)** In terms of the charge Q, length L, inner radius r, and outer radius R, what is the potential difference $V_{\text{tube}} - V_{\text{wire}}$ between the inner wire and the outer tube? Explain, and include checks on your answer. **(b)** The power-supply voltage is slowly increased until you see a glow in the air very near the inner wire. Calculate this power-supply voltage (give a numerical value), and explain your calculation. The length $L = 80$ cm, the inner radius $r = 0.7$ mm, and the outer radius $R = 3$ cm. This device is called a "Geiger–Müller tube" and was one of the first electronic particle detectors. The voltage is set just below the threshold for making the air glow near the wire. A charged particle that passes near the center wire can trigger breakdown in the air, leading to a large current that can be easily measured.

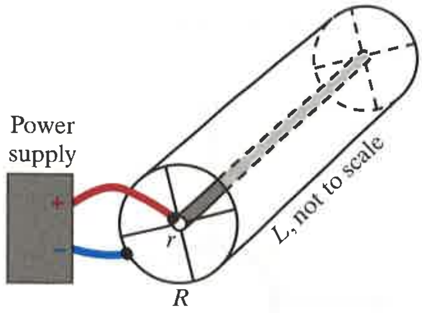

Figure 16.86

Section 16.6

•**P65** In the region of space depicted in Figure 16.87 there are several stationary charged objects that are not shown in the diagram. Along a path $A \Rightarrow B \Rightarrow C \Rightarrow D$ you measure the following potential differences: $V_B - V_A = 12$ V; $V_C - V_B = -5$ V; $V_D - V_C = -15$ V. What is the potential difference $V_A - V_D$?

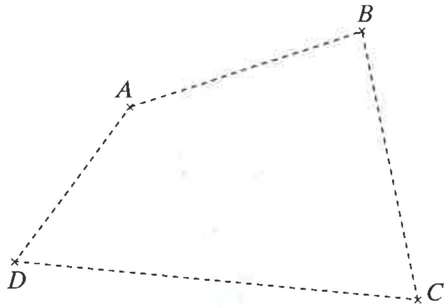

Figure 16.87

••**P66** A capacitor consists of two charged disks of radius R separated by a distance s, where $R \gg s$. The magnitude of the charge on each disk is Q. Consider points A, B, C, and D inside the capacitor, as shown in Figure 16.88. **(a)** Show that $\Delta V = V_C - V_A$ is the same for these paths by evaluating ΔV along each path: (1) Path 1: $A \Rightarrow B \Rightarrow C$, (2) Path 2: $A \Rightarrow C$, (3) Path 3: $A \Rightarrow D \Rightarrow B \Rightarrow C$. **(b)** If $Q = 43\ \mu$C, $R = 4.0$ m, $s_1 = 1.5$ mm, and $s_2 = 0.7$ mm, what is the value of $\Delta V = V_C - V_A$? **(c)** Choose two different paths from point A back to point A again, and show that $\Delta V = 0$ for a round trip along both of these paths.

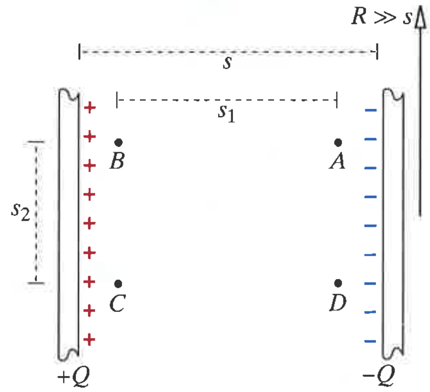

Figure 16.88

••**P67** A uniform spherical shell of charge $+Q$ is centered at point B, as shown in Figure 16.89. Show that $\Delta V = V_C - V_A$ is independent of path by calculating ΔV for each of these two paths (actually do the integrals): **(a)** Path 1: $A \Rightarrow B \Rightarrow C$ (along a straight line through the shell). **(b)** Path 2: $A \Rightarrow D \Rightarrow C$ (along a circular arc around point B).

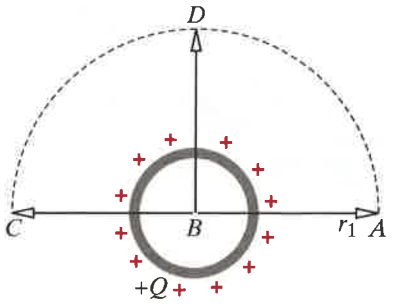

Figure 16.89

••P68 Four voltmeters are connected to a circuit as shown in Figure 16.90. As is usual with voltmeters, the reading on the voltmeter is positive if the negative lead (black wire, usually labeled COM) is connected to a location at lower potential, and the positive lead (red) is connected to a location at higher potential. The circuit contains two devices whose identity is unknown, and a rod (green) of length 9 cm made of a conducting material. At a particular moment, the readings observed on the voltmeters are: voltmeter A: -1.6 V; voltmeter B: -6 V; voltmeter C: -3.5 V. **(a)** At this moment, what is the reading on voltmeter D, both magnitude and sign? **(b)** What are the magnitude and direction of the electric field inside the rod?

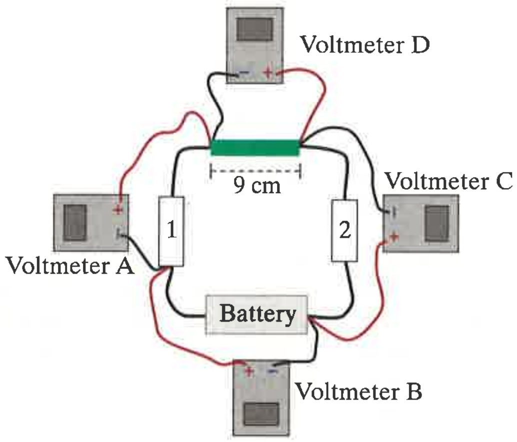

Figure 16.90

Section 16.7

•P69 A particle with charge $+q_1$ and a particle with charge $-q_2$ are located as shown in Figure 16.91. What is the potential (relative to infinity) at location A?

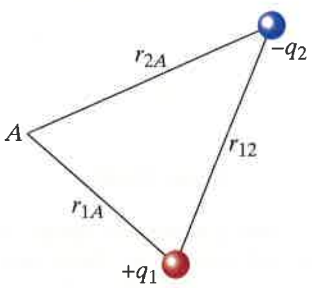

Figure 16.91

•P70 What is the electric potential at a location 2.5×10^{-9} m from an electron?

•P71 Calculate the potential at location A in Figure 16.92.

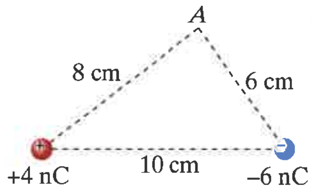

Figure 16.92

•P72 Two capacitors have the same size of plates and the same distance (2 mm) between plates. The potentials of the two plates in capacitor 1 are -10 V and $+10$ V. The potentials of the two plates in capacitor 2 are 350 V and 370 V. What is the electric field inside capacitor 1? Inside capacitor 2?

•P73 Suppose that the potential at $z = 3.15$ m is 37 V, and the potential at $z = 3.27$ m is -36 V. What is the approximate value of E_z in this region? Include the appropriate sign.

•P74 Four point charges, q_1, q_2, q_3, and q_4, are located at the corners of a square with side d, as shown in Figure 16.93. What is the potential (relative to infinity) at location A, at the center of the square? What is the potential at location B, in the middle of one side?

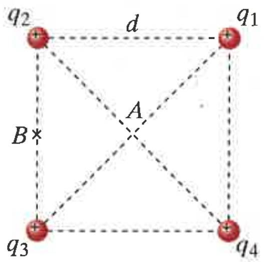

Figure 16.93

•P75 What is the potential (relative to infinity) at location B, a distance h from a ring of radius a with charge $-Q$, as shown in Figure 16.94?

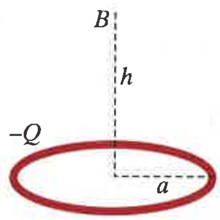

Figure 16.94

••P76 What is the maximum possible potential (relative to infinity) of a metal sphere of 10-cm radius in air? What is the maximum possible potential of a metal sphere of only 1-mm radius? These results hint at the reason why a highly charged piece of metal (with uniform potential throughout) tends to spark at places where the radius of curvature is small or at places where there are sharp points. Remember that the breakdown electric field strength for air is roughly 3×10^6 V/m.

••P77 A small solid glass ball of radius r is irradiated by a beam of positive ions and gains a charge $+q$ distributed uniformly throughout its volume. What is the potential (relative to infinity) at location A, inside the ball, a distance $r/2$ from the center of the ball?

••P78 A small metal sphere of radius r initially has a charge q_0. Then a long copper wire is connected from this small sphere to a distant, large, uncharged metal sphere of radius R. Calculate the final charge q on the small sphere and the final charge Q on the large sphere. You may neglect the small amount of charge on the wire. What other approximations did you make? (Think about potential ....)

••P79 A metal sphere of radius r_1 carries a positive charge of amount Q. A concentric spherical metal shell with inner radius r_2 and outer radius r_3 surrounds the inner sphere and carries a total positive charge of amount $4Q$, with some of this charge on the outer surface (at r_3) and some on the inner surface (at r_2). **(a)** How is the charge of $4Q$ distributed on the two surfaces of the outer shell? Prove this! **(b)** What is the potential (relative to infinity) just outside r_3, halfway between r_2 and r_3, just inside r_2, just outside r_1, and at the center?

••P80 A thin plastic spherical shell of radius a is rubbed all over with wool and gains a charge of $-Q$. What is the potential relative to infinity at location B, a distance $a/3$ from the center of the sphere, as shown in Figure 16.95?

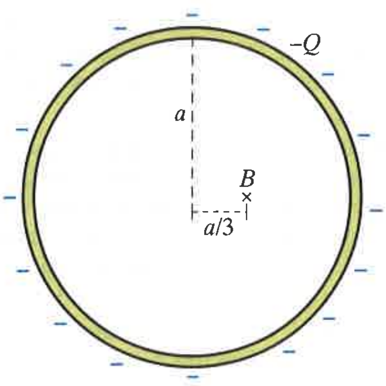

Figure 16.95

••P81 A solid plastic sphere of radius R has charge $-Q$ distributed uniformly over its surface. It is far from all other objects. **(a)** Sketch the molecular polarization in the interior of the sphere and explain briefly. **(b)** Calculate the potential relative to infinity at the center of the sphere.

•••P82 A nucleus contains Z protons that on average are uniformly distributed throughout a tiny sphere of radius R. **(a)** Calculate the potential (relative to infinity) at the center of the nucleus. Assume that there are no electrons or other charged particles in the vicinity of this bare nucleus. **(b)** Graph the potential as a function of distance from the center of the nucleus. **(c)** Suppose that in an accelerator experiment a positive pion is produced at rest at the center of a nucleus containing Z protons. The pion decays into a positive muon (essentially a heavy positron) and a neutrino. The muon has initial kinetic energy K_i. How much kinetic energy does the muon have by the time it has been repelled very far away from the nucleus? (The muon interacts with the nucleus only through Coulomb's law and is unaffected by nuclear forces. The massive nucleus hardly moves and gets negligible kinetic energy.) **(d)** If the nucleus is gold, with 79 protons, what is the numerical value of $K_f - K_i$ in electron volts?

Section 16.9

••P83 An isolated large-plate capacitor (not connected to anything) originally has a potential difference of 1000 V with an air gap of 2 mm. Then a plastic slab 1 mm thick, with dielectric constant 5, is inserted into the middle of the air gap as shown in Figure 16.96. Calculate the following potential differences, and explain your work.

$$V_1 - V_2 = ? \qquad V_2 - V_3 = ?$$
$$V_3 - V_4 = ? \qquad V_1 - V_4 = ?$$

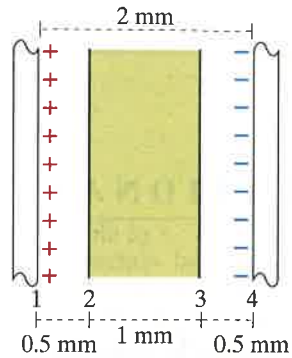

Figure 16.96

••P84 An isolated parallel-plate capacitor of area A_1 with an air gap of length s_1 is charged up to a potential difference ΔV_1. A second parallel-plate capacitor, initially uncharged, has an area A_2 and a gap of length s_2 filled with plastic whose dielectric constant is K. You connect a wire from the positive plate of the first capacitor to one of the plates of the second capacitor, and you connect another wire from the negative plate of the first capacitor to the other plate of the second capacitor. What is the final potential difference across the first capacitor?

Section 16.11

••P85 Refer to Section 16.7 for the potential relative to infinity along the axis of a ring of radius R carrying a charge Q. Let the axis of the ring be the z axis of the coordinate system, and determine E_z at any location z along the axis. (If the charge is nearly uniformly distributed around the ring, at these locations there is no E_x or E_y, due to the symmetry of the situation.) Compare with the result obtained in the previous chapter by integration.

••P86 A rod uniformly charged with charge $-q$ is bent into a semicircular arc of radius b, as shown in Figure 16.97. What is the potential relative to infinity at location A, at the center of the arc?

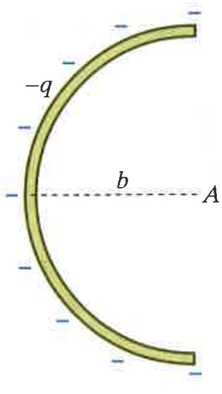

Figure 16.97

••**P87** We know the magnitude of the electric field of a dipole at a location on the x axis and at a location on the y axis, if we are far from the dipole. **(a)** Find $\Delta V = V_B - V_A$ along a line perpendicular to the axis of the dipole shown in Figure 16.98. Do it two ways: from the superposition of V due to the two charges and from the integral of the electric field. **(b)** Find $\Delta V = V_C - V_D$ along the axis of the dipole, as shown in Figure 16.99. Include the correct sign. Do it two ways: from the superposition of V due to the two charges and from the integral of the electric field. **(c)** What is the change in potential energy ΔU in moving an electron from D to C?

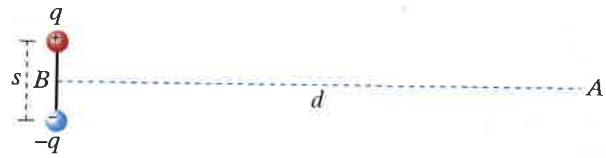

Figure 16.98

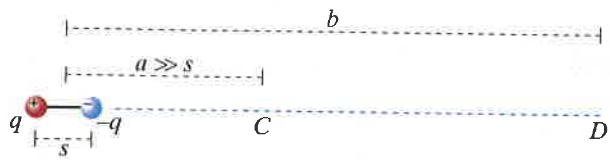

Figure 16.99

COMPUTATIONAL PROBLEMS

More detailed and extended versions of some computational modeling problems may be found in the lab activities included in the *Matter & Interactions* resources for instructors.

•**P88** Modify the program from Section 16.8 to calculate the potential difference $V_C - V_D$ near the dipole, where $C = \langle -0.03, -0.02, 0\rangle$ m and $D = \langle -0.05, -0.07, 0\rangle$ m.

••**P89** Replace the dipole in the program from Section 16.8 with a uniformly charged thin rod. The rod is centered at the origin, and its axis is aligned along the y axis. The rod is 0.05 m long, and its net charge is -2×10^{-8} C. Calculate the potential difference $V_B - V_A$, where $A = \langle 0.02, 0.02, 0\rangle$ m, and $B = \langle 0.12, 0.08, 0\rangle$ m. Explain how you decided how many point charges to use in modeling the rod.

••**P90** Replace the dipole in the program from Section 16.8 with a uniformly charged thin ring. The ring is centered at the origin, and its axis is aligned with the z axis. The radius of the ring is 0.04 m, and its net charge is -3×10^{-8} C. Calculate the potential difference $V_B - V_A$, where $A = \langle 0.02, 0, 0.02\rangle$ m, and $B = \langle 0.12, 0, 0.08\rangle$ m. Explain how you decided how many point charges to use in modeling the ring.

••**P91** Consider a uniformly charged cylinder 0.3 m long, with a radius of 1 mm, carrying a total charge of 4×10^{-8} C. The cylinder lies along the x axis, with its center at the origin. Calculate the potential difference along a path going from $\langle 0, 0.05, 0\rangle$ to $\langle 0.15, 0.05, 0\rangle$. Explain how you decided how many point charges to use in modeling the cylinder.

•••**P92** As in Problem P91, consider a uniformly charged cylinder 0.3 m long, with a radius of 1 mm, carrying a total charge of 4×10^{-8} C. The cylinder lies along the x axis, with its center at the origin. Compute the potential difference along a path from $\langle 0, 0.05, 0\rangle$ to $\langle 0.15, 0.05, 0\rangle$ by calculating and displaying (with arrows) $\vec{E}$ and $\Delta\vec{l}$ at many steps along the path and adding up the contributions $-\vec{E} \bullet \Delta\vec{l}$. The VPython function `dot(A,B)` gives the dot product of the two vectors `A` and `B`. See optional Section 16.13 for suggestions on how to structure the program.

ANSWERS TO CHECKPOINTS

1 (a) 7.65×10^{-21} J; **(b)** 2.12×10^{-20} J; **(c)** 1.36×10^{-20} J
2 (a) -1.68×10^{-18} J; **(b)** 1.68×10^{-18} J; **(c)** 4.45×10^4 m/s; **(d)** 1.68×10^{-18} J; -1.68×10^{-18} J
3 (a) 300 V; **(b)** 4.8×10^{-17} J; **(c)** -4.8×10^{-17} J; **(d)** 0; **(e)** 0; **(f)** 0
4 −150 V/m
5 (a) To the left, positive; **(b)** To the right, negative
6 (a) −380 V; **(b)** +380 V
7 (a) +1 V; **(b)** −1 V
8 $\Delta V_1 = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r_2} - \frac{Q}{r_1}\right)$
$\Delta V_2 = 0$
$\Delta V_3 = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r_1} - \frac{Q}{r_2}\right)$
$\Delta V_4 = 0$
$\Delta V_{\text{round trip}} = 0$
9 0.025 V/m (a very small field)
10 If $z \gg R$, $\sqrt{z^2 + R^2} \approx z$, and $V \approx \frac{1}{4\pi\varepsilon_0}\frac{Q}{z}$.
11 4.8 V
12 1.5×10^6 V/m; 39.8 J
13 Since each little charge dQ is a distance R from the center, the potential at the center is $\sum \frac{1}{4\pi\varepsilon_0}\frac{dQ}{R} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$.