ELECTRIC POTENTIAL

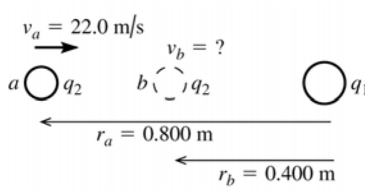
23

23.5. **(a) IDENTIFY:** Use conservation of energy:

$$K_a + U_a + W_{\text{other}} = K_b + U_b$$

U for the pair of point charges is given by Eq.(23.9).

SET UP:



Let point a be where q_2 is 0.800 m from q_1 and point b be where q_2 is 0.400 m from q_1, as shown in Figure 23.5a.

Figure 23.5a

EXECUTE: Only the electric force does work, so $W_{\text{other}} = 0$ and $U = \dfrac{1}{4\pi\epsilon_0}\dfrac{q_1 q_2}{r}$.

$$K_a = \tfrac{1}{2}mv_a^2 = \tfrac{1}{2}(1.50\times10^{-3}\text{ kg})(22.0\text{ m/s})^2 = 0.3630\text{ J}$$

$$U_a = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_a} = (8.988\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2)\frac{(-2.80\times10^{-6}\text{ C})(-7.80\times10^{-6}\text{ C})}{0.800\text{ m}} = +0.2454\text{ J}$$

$$K_b = \tfrac{1}{2}mv_b^2$$

$$U_b = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_b} = (8.988\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2)\frac{(-2.80\times10^{-6}\text{ C})(-7.80\times10^{-6}\text{ C})}{0.400\text{ m}} = +0.4907\text{ J}$$

The conservation of energy equation then gives $K_b = K_a + (U_a - U_b)$

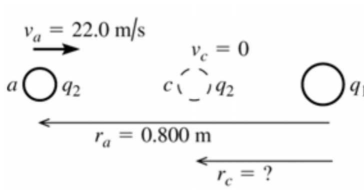
$$\tfrac{1}{2}mv_b^2 = +0.3630\text{ J} + (0.2454\text{ J} - 0.4907\text{ J}) = 0.1177\text{ J}$$

$$v_b = \sqrt{\frac{2(0.1177\text{ J})}{1.50\times10^{-3}\text{ kg}}} = 12.5\text{ m/s}$$

EVALUATE: The potential energy increases when the two positively charged spheres get closer together, so the kinetic energy and speed decrease.

(b) IDENTIFY: Let point c be where q_2 has its speed momentarily reduced to zero. Apply conservation of energy to points a and c: $K_a + U_a + W_{\text{other}} = K_c + U_c$.

SET UP: Points a and c are shown in Figure 23.5b.



EXECUTE: $K_a = +0.3630$ J (from part (a))
$U_a = +0.2454$ J (from part (a))

Figure 23.5b

$K_c = 0$ (at distance of closest approach the speed is zero)

$$U_c = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_c}$$

Thus conservation of energy $K_a + U_a = U_c$ gives $\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_c} = +0.3630 \text{ J} + 0.2454 \text{ J} = 0.6084 \text{ J}$

$$r_c = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{0.6084 \text{ J}} = (8.988\times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)\frac{(-2.80\times 10^{-6} \text{ C})(-7.80\times 10^{-6} \text{ C})}{+0.6084 \text{ J}} = 0.323 \text{ m.}$$

EVALUATE: $U \to \infty$ as $r \to 0$ so q_2 will stop no matter what its initial speed is.

23.9. IDENTIFY: $U = k\left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right)$

SET UP: In part (a), $r_{12} = 0.200$ m, $r_{23} = 0.100$ m and $r_{13} = 0.100$ m. In part (b) let particle 3 have coordinate *x*, so $r_{12} = 0.200$ m, $r_{13} = x$ and $r_{23} = 0.200 - x$.

EXECUTE: **(a)** $U = k\left(\frac{(4.00 \text{ nC})(-3.00 \text{ nC})}{(0.200 \text{ m})} + \frac{(4.00 \text{ nC})(2.00 \text{ nC})}{(0.100 \text{ m})} + \frac{(-3.00 \text{ nC})(2.00 \text{ nC})}{(0.100 \text{ m})}\right) = 3.60\times 10^{-7} \text{ J}$

(b) If $U = 0$, then $0 = k\left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{x} + \frac{q_2 q_3}{r_{12} - x}\right)$. Solving for *x* we find:

$0 = -60 + \frac{8}{x} - \frac{6}{0.2 - x} \Rightarrow 60x^2 - 26x + 1.6 = 0 \Rightarrow x = 0.074$ m, 0.360 m. Therefore, $x = 0.074$ m since it is the only value between the two charges.

EVALUATE: U_{13} is positive and both U_{23} and U_{12} are negative. If $U = 0$, then $|U_{13}| = |U_{23}| + |U_{12}|$. For $x = 0.074$ m, $U_{13} = +9.7\times 10^{-7}$ J, $U_{23} = -4.3\times 10^{-7}$ J and $U_{12} = -5.4\times 10^{-7}$ J. It is true that $U = 0$ at this *x*.

23.17. IDENTIFY: Apply the equation that precedes Eq.(23.17): $W_{a\to b} = q'\int_a^b \vec{E}\cdot d\vec{l}$.

SET UP: Use coordinates where $+y$ is upward and $+x$ is to the right. Then $\vec{E} = E\hat{j}$ with $E = 4.00\times 10^4$ N/C.

(a) The path is sketched in Figure 23.17a.

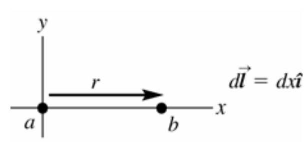


Figure 23.17a

EXECUTE: $\vec{E}\cdot d\vec{l} = (E\hat{j})\cdot(dx\hat{i}) = 0$ so $W_{a\to b} = q'\int_a^b \vec{E}\cdot d\vec{l} = 0$.

EVALUATE: The electric force on the positive charge is upward (in the direction of the electric field) and does no work for a horizontal displacement of the charge.

(b) SET UP: The path is sketched in Figure 23.17b.

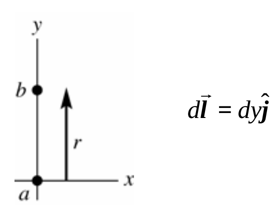


Figure 23.17b

EXECUTE: $\vec{E}\cdot d\vec{l} = (E\hat{j})\cdot(dy\hat{j}) = E\,dy$

$$W_{a\to b} = q'\int_a^b \vec{E}\cdot d\vec{l} = q'E\int_a^b dy = q'E(y_b - y_a)$$

$y_b - y_a = +0.670$ m, positive since the displacement is upward and we have taken $+y$ to be upward.

$$W_{a\to b} = q'E(y_b - y_a) = (+28.0\times 10^{-9} \text{ C})(4.00\times 10^4 \text{ N/C})(+0.670 \text{ m}) = +7.50\times 10^{-4} \text{ J.}$$

EVALUATE: The electric force on the positive charge is upward so it does positive work for an upward displacement of the charge.

(c) SET UP: The path is sketched in Figure 23.17c.

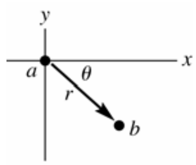


Figure 23.17c

$y_a = 0$

$y_b = -r\sin\theta = -(2.60 \text{ m})\sin 45° = -1.838 \text{ m}$

The vertical component of the 2.60 m displacement is 1.838 m downward.

EXECUTE: $d\vec{l} = dx\hat{i} + dy\hat{j}$ (The displacement has both horizontal and vertical components.)

$\vec{E} \cdot d\vec{l} = (E\hat{j}) \cdot (dx\hat{i} + dy\hat{j}) = E\,dy$ (Only the vertical component of the displacement contributes to the work.)

$$W_{a\to b} = q'\int_a^b \vec{E} \cdot d\vec{l} = q'E\int_a^b dy = q'E(y_b - y_a)$$

$$W_{a\to b} = q'E(y_b - y_a) = (+28.0\times10^{-9}\text{C})(4.00\times10^4 \text{ N/C})(-1.838 \text{ m}) = -2.06\times10^{-3} \text{ J.}$$

EVALUATE: The electric force on the positive charge is upward so it does negative work for a displacement of the charge that has a downward component.

23.21. IDENTIFY: $V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

SET UP: The locations of the changes and points A and B are sketched in Figure 23.21.

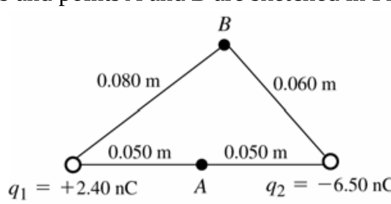


Figure 23.21

EXECUTE: **(a)** $V_A = \frac{1}{4\pi\epsilon_0}\left(\frac{q_1}{r_{A1}} + \frac{q_2}{r_{A2}}\right)$

$$V_A = (8.988\times10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)\left(\frac{+2.40\times10^{-9} \text{ C}}{0.050 \text{ m}} + \frac{-6.50\times10^{-9} \text{ C}}{0.050 \text{ m}}\right) = -737 \text{ V}$$

(b) $V_B = \frac{1}{4\pi\epsilon_0}\left(\frac{q_1}{r_{B1}} + \frac{q_2}{r_{B2}}\right)$

$$V_B = (8.988\times10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)\left(\frac{+2.40\times10^{-9} \text{ C}}{0.080 \text{ m}} + \frac{-6.50\times10^{-9} \text{ C}}{0.060 \text{ m}}\right) = -704 \text{ V}$$

(c) IDENTIFY and **SET UP:** Use Eq.(23.13) and the results of parts (a) and (b) to calculate W.

EXECUTE: $W_{B\to A} = q'(V_B - V_A) = (2.50\times10^{-9} \text{ C})(-704 \text{ V} - (-737 \text{ V})) = +8.2\times10^{-8} \text{ J}$

EVALUATE: The electric force does positive work on the positive charge when it moves from higher potential (point B) to lower potential (point A).

23.25. IDENTIFY: For a point charge, $V = \frac{kq}{r}$. The total potential at any point is the algebraic sum of the potentials of the two charges.

SET UP: **(a)** The positions of the two charges are shown in Figure 23.25a.

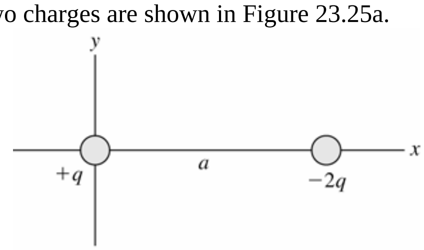


Figure 23.25a

(b) $x > a: V = \frac{kq}{x} - \frac{2kq}{x-a} = \frac{-kq(x+a)}{x(x-a)}$. $0 < x < a: V = \frac{kq}{x} - \frac{2kq}{a-x} = \frac{kq(3x-a)}{x(x-a)}$.

$x < 0: V = \frac{-kq}{x} + \frac{2kq}{x-a} = \frac{kq(x+a)}{x(x-a)}$. A general expression valid for any *y* is $V = k\left(\frac{q}{|x|} - \frac{2q}{|x-a|}\right)$.

(c) The potential is zero at $x = -a$ and $a/3$.

(d) The graph of *V* versus *x* is sketched in Figure 23.25b.

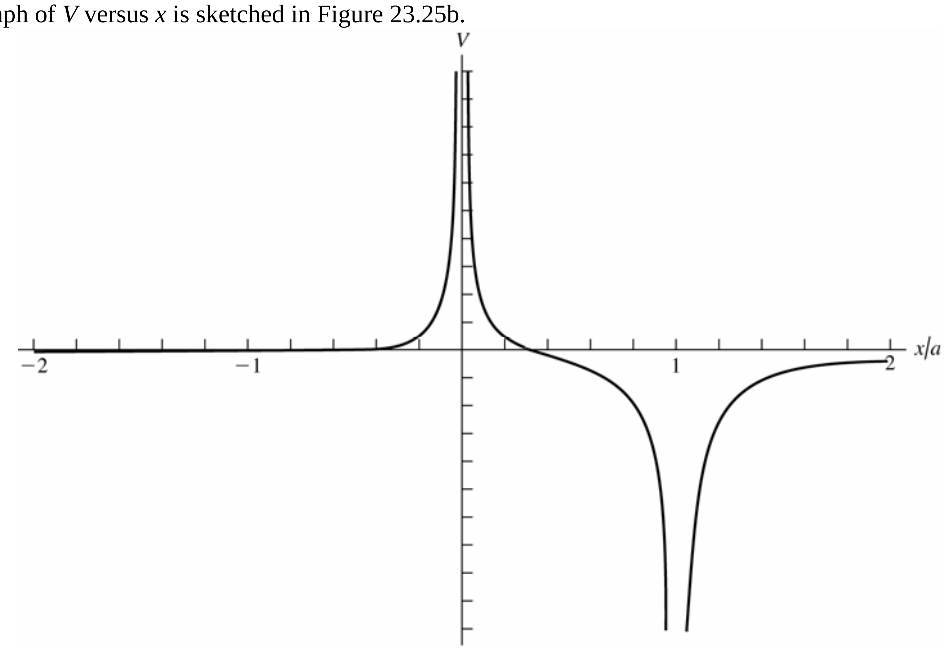


Figure 23.25b

EVALUATE: **(e)** For $x >> a: V \approx \frac{-kqx}{x^2} = \frac{-kq}{x}$, which is the same as the potential of a point charge –*q*. Far from the two charges they appear to be a point charge with a charge that is the algebraic sum of their two charges.

23.29. **(a) IDENTIFY** and **SET UP:** The direction of $\vec{E}$ is always from high potential to low potential so point *b* is at higher potential.

(b) Apply Eq.(23.17) to relate $V_b - V_a$ to *E*.

EXECUTE: $V_b - V_a = -\int_a^b \vec{E} \cdot d\vec{l} = \int_a^b E\,dx = E(x_b - x_a)$.

$$E = \frac{V_b - V_a}{x_b - x_a} = \frac{+240\text{ V}}{0.90\text{ m} - 0.60\text{ m}} = 800\text{ V/m}$$

(c) $W_{b \to a} = q(V_b - V_a) = (-0.200 \times 10^{-6}\text{ C})(+240\text{ V}) = -4.80 \times 10^{-5}\text{ J}$.

EVALUATE: The electric force does negative work on a negative charge when the negative charge moves from high potential (point *b*) to low potential (point *a*).

23.33. **(a) IDENTIFY** and **SET UP:** The electric field on the ring's axis is calculated in Example 21.10. The force on the electron exerted by this field is given by Eq.(21.3).

EXECUTE: When the electron is on either side of the center of the ring, the ring exerts an attractive force directed toward the center of the ring. This restoring force produces oscillatory motion of the electron along the axis of the ring, with amplitude 30.0 cm. The force on the electron is *not* of the form $F = -kx$ so the oscillatory motion is not simple harmonic motion.

(b) IDENTIFY: Apply conservation of energy to the motion of the electron.

SET UP: $K_a + U_a = K_b + U_b$ with *a* at the initial position of the electron and *b* at the center of the ring. From Example 23.11, $V = \frac{1}{4\pi\epsilon_0}\frac{Q}{\sqrt{x^2+R^2}}$, where *R* is the radius of the ring.

EXECUTE: $x_a = 30.0\text{ cm}, x_b = 0$.

$K_a = 0$ (released from rest), $K_b = \frac{1}{2}mv^2$

Thus $\frac{1}{2}mv^2 = U_a - U_b$

And $U = qV = -eV$ so $v = \sqrt{\dfrac{2e(V_b - V_a)}{m}}$.

$$V_a = \frac{1}{4\pi\epsilon_0}\frac{Q}{\sqrt{x_a^2 + R^2}} = (8.988\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{24.0\times10^{-9}\ \text{C}}{\sqrt{(0.300\ \text{m})^2 + (0.150\ \text{m})^2}}$$

$$V_a = 643\ \text{V}$$

$$V_b = \frac{1}{4\pi\epsilon_0}\frac{Q}{\sqrt{x_b^2 + R^2}} = (8.988\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{24.0\times10^{-9}\ \text{C}}{0.150\ \text{m}} = 1438\ \text{V}$$

$$v = \sqrt{\frac{2e(V_b - V_a)}{m}} = \sqrt{\frac{2(1.602\times10^{-19}\ \text{C})(1438\ \text{V} - 643\ \text{V})}{9.109\times10^{-31}\ \text{kg}}} = 1.67\times10^7\ \text{m/s}$$

EVALUATE: The positively charged ring attracts the negatively charged electron and accelerates it. The electron has its maximum speed at this point. When the electron moves past the center of the ring the force on it is opposite to its motion and it slows down.

23.40. **IDENTIFY** and **SET UP:** For oppositely charged parallel plates, $E = \sigma/\epsilon_0$ between the plates and the potential difference between the plates is $V = Ed$.

EXECUTE: **(a)** $E = \dfrac{\sigma}{\epsilon_0} = \dfrac{47.0\times10^{-9}\ \text{C/m}^2}{\epsilon_0} = 5310\ \text{N/C}.$

(b) $V = Ed = (5310\ \text{N/C})(0.0220\ \text{m}) = 117\ \text{V}.$

(c) The electric field stays the same if the separation of the plates doubles. The potential difference between the plates doubles.

EVALUATE: The electric field of an infinite sheet of charge is uniform, independent of distance from the sheet. The force on a test charge between the two plates is constant because the electric field is constant. The potential difference is the work per unit charge on a test charge when it moves from one plate to the other. When the distance doubles the work, which is force times distance, doubles and the potential difference doubles.

23.41. **IDENTIFY** and **SET UP:** Use the result of Example 23.9 to relate the electric field between the plates to the potential difference between them and their separation. The force this field exerts on the particle is given by Eq.(21.3). Use the equation that precedes Eq.(23.17) to calculate the work.

EXECUTE: **(a)** From Example 23.9, $E = \dfrac{V_{ab}}{d} = \dfrac{360\ \text{V}}{0.0450\ \text{m}} = 8000\ \text{V/m}$

(b) $F = |q|E = (2.40\times10^{-9}\ \text{C})(8000\ \text{V/m}) = +1.92\times10^{-5}\ \text{N}$

(c) The electric field between the plates is shown in Figure 23.41.

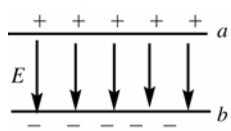


Figure 23.41

The plate with positive charge (plate *a*) is at higher potential. The electric field is directed from high potential toward low potential (or, $\vec{E}$ is from + charge toward − charge), so $\vec{E}$ points from *a* to *b*. Hence the force that $\vec{E}$ exerts on the positive charge is from *a* to *b*, so it does positive work.

$W = \int_a^b \vec{F}\cdot d\vec{l} = Fd$, where *d* is the separation between the plates.

$W = Fd = (1.92\times10^{-5}\ \text{N})(0.0450\ \text{m}) = +8.64\times10^{-7}\ \text{J}$

(d) $V_a - V_b = +360\ \text{V}$ (plate *a* is at higher potential)

$\Delta U = U_b - U_a = q(V_b - V_a) = (2.40\times10^{-9}\ \text{C})(-360\ \text{V}) = -8.64\times10^{-7}\ \text{J}.$

EVALUATE: We see that $W_{a\to b} = -(U_b - U_a) = U_a - U_b.$

23.54. **IDENTIFY:** The electric force between the electron and proton is attractive and has magnitude $F = \dfrac{ke^2}{r^2}$. For circular motion the acceleration is $a_{\text{rad}} = v^2/r$. $U = -k\dfrac{e^2}{r}$.

SET UP: $e = 1.60\times10^{-19}\ \text{C}$. $1\ \text{eV} = 1.60\times10^{-19}\ \text{J}$.

EXECUTE: **(a)** $\dfrac{mv^2}{r} = \dfrac{ke^2}{r^2}$ and $v = \sqrt{\dfrac{ke^2}{mr}}$.

(b) $K = \frac{1}{2}mv^2 = \frac{1}{2}\frac{ke^2}{r} = -\frac{1}{2}U$

(c) $E = K + U = \frac{1}{2}U = -\frac{1}{2}\frac{ke^2}{r} = -\frac{1}{2}\frac{k(1.60\times10^{-19}\text{ C})^2}{5.29\times10^{-11}\text{ m}} = -2.17\times10^{-18}\text{ J} = -13.6\text{ eV}$.

EVALUATE: The total energy is negative, so the electron is bound to the proton. Work must be done on the electron to take it far from the proton.

23.60. **IDENTIFY:** Apply $\sum F_x = 0$ and $\sum F_y = 0$ to the sphere. The electric force on the sphere is $F_e = qE$. The potential difference between the plates is $V = Ed$.

SET UP: The free-body diagram for the sphere is given in Figure 23.56.

EXECUTE: $T\cos\theta = mg$ and $T\sin\theta = F_e$ gives $F_e = mg\tan\theta = (1.50\times10^{-3}\text{ kg})(9.80\text{ m/s}^2)\tan(30°) = 0.0085\text{ N}$.

$F_e = Eq = \frac{Vq}{d}$ and $V = \frac{Fd}{q} = \frac{(0.0085\text{ N})(0.0500\text{ m})}{8.90\times10^{-6}\text{ C}} = 47.8\text{ V}.$

EVALUATE: $E = V/d = 956\text{ V/m}$. $E = \sigma/\epsilon_0$ and $\sigma = E\epsilon_0 = 8.46\times10^{-9}\text{ C/m}^2$.

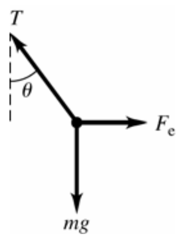


Figure 23.60

23.61. **(a) IDENTIFY:** The potential at any point is the sum of the potentials due to each of the two charged conductors.

SET UP: From Example 23.10, for a conducting cylinder with charge per unit length λ the potential outside the cylinder is given by $V = (\lambda/2\pi\epsilon_0)\ln(r_0/r)$ where *r* is the distance from the cylinder axis and r_0 is the distance from the axis for which we take $V = 0$. Inside the cylinder the potential has the same value as on the cylinder surface. The electric field is the same for a solid conducting cylinder or for a hollow conducting tube so this expression for *V* applies to both. This problem says to take $r_0 = b$.

EXECUTE: For the hollow tube of radius *b* and charge per unit length $-\lambda$: outside $V = -(\lambda/2\pi\epsilon_0)\ln(b/r)$; inside $V = 0$ since $V = 0$ at $r = b$.

For the metal cylinder of radius *a* and charge per unit length λ:

outside $V = (\lambda/2\pi\epsilon_0)\ln(b/r)$, inside $V = (\lambda/2\pi\epsilon_0)\ln(b/a)$, the value at $r = a$.

(i) $r < a$; inside both $V = (\lambda/2\pi\epsilon_0)\ln(b/a)$

(ii) $a < r < b$; outside cylinder, inside tube $V = (\lambda/2\pi\epsilon_0)\ln(b/r)$

(iii) $r > b$; outside both the potentials are equal in magnitude and opposite in sign so $V = 0$.

(b) For $r = a$, $V_a = (\lambda/2\pi\epsilon_0)\ln(b/a)$.

For $r = b$, $V_b = 0$.

Thus $V_{ab} = V_a - V_b = (\lambda/2\pi\epsilon_0)\ln(b/a)$.

(c) IDENTIFY and **SET UP:** Use Eq.(23.23) to calculate *E*.

EXECUTE: $E = -\frac{\partial V}{\partial r} = -\frac{\lambda}{2\pi\epsilon_0}\frac{\partial}{\partial r}\ln\left(\frac{b}{r}\right) = -\frac{\lambda}{2\pi\epsilon_0}\left(\frac{r}{b}\right)\left(-\frac{b}{r^2}\right) = \frac{V_{ab}}{\ln(b/a)}\frac{1}{r}.$

(d) The electric field between the cylinders is due only to the inner cylinder, so V_{ab} is not changed, $V_{ab} = (\lambda/2\pi\epsilon_0)\ln(b/a)$.

EVALUATE: The electric field is not uniform between the cylinders, so $V_{ab} \neq E(b-a)$.

23.67. **(a) IDENTIFY:** Use $V_a - V_b = \int_a^b \vec{E}\cdot d\vec{l}.$

SET UP: From Problem 22.48, $E(r) = \frac{\lambda r}{2\pi\epsilon_0 R^2}$ for $r \le R$ (inside the cylindrical charge distribution) and $E(r) = \frac{\lambda r}{2\pi\epsilon_0 r}$ for $r \ge R$. Let $V = 0$ at $r = R$ (at the surface of the cylinder).

EXECUTE: $r > R$

Take point *a* to be at *R* and point *b* to be at *r*, where $r > R$. Let $d\vec{l} = d\vec{r}$. $\vec{E}$ and $d\vec{r}$ are both radially outward, so $\vec{E}\cdot d\vec{r} = E\,dr$. Thus $V_R - V_r = \int_R^r E\,dr$. Then $V_R = 0$ gives $V_r = -\int_R^r E\,dr$. In this interval $(r > R)$, $E(r) = \lambda/2\pi\epsilon_0 r$, so

$$V_r = -\int_R^r \frac{\lambda}{2\pi\epsilon_0 r}dr = -\frac{\lambda}{2\pi\epsilon_0}\int_R^r \frac{dr}{r} = -\frac{\lambda}{2\pi\epsilon_0}\ln\left(\frac{r}{R}\right).$$

EVALUATE: This expression gives $V_r = 0$ when $r = R$ and the potential decreases (becomes a negative number of larger magnitude) with increasing distance from the cylinder.

EXECUTE: $r < R$

Take point *a* at *r*, where $r < R$, and point *b* at *R*. $\vec{E}\cdot d\vec{r} = E\,dr$ as before. Thus $V_r - V_R = \int_r^R E\,dr$. Then $V_R = 0$ gives $V_r = \int_r^R E\,dr$. In this interval $(r < R)$, $E(r) = \lambda r/2\pi\epsilon_0 R^2$, so

$$V_r = \int_r^R \frac{\lambda}{2\pi\epsilon_0 R^2}dr = \frac{\lambda}{2\pi\epsilon_0 R^2}\int_r^R r\,dr = \frac{\lambda}{2\pi\epsilon_0 R^2}\left(\frac{R^2}{2} - \frac{r^2}{2}\right).$$

$$V_r = \frac{\lambda}{4\pi\epsilon_0}\left(1 - \left(\frac{r}{R}\right)^2\right).$$

EVALUATE: This expression also gives $V_r = 0$ when $r = R$. The potential is $\lambda/4\pi\epsilon_0$ at $r = 0$ and decreases with increasing *r*.

(b) EXECUTE: Graphs of *V* and *E* as functions of *r* are sketched in Figure 23.67.

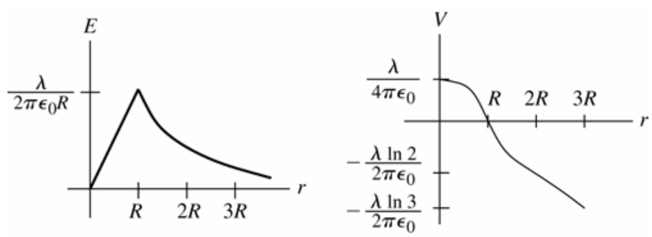


Figure 23.67

EVALUATE: *E* at any *r* is the negative of the slope of $V(r)$ at that *r* (Eq.23.23).

23.78. IDENTIFY: $V_a - V_b = \int_a^b \vec{E}\cdot d\vec{l}$

SET UP: $\vec{E}$ is radially outward, so $\vec{E}\cdot d\vec{l} = E\,dr$. Problem 22.42 shows that $E(r) = 0$ for $r \le a$, $E(r) = kq/r^2$ for $a < r < b$, $E(r) = 0$ for $b < r < c$ and $E(r) = kq/r^2$ for $r > c$.

EXECUTE: **(a)** At $r = c$: $V_c = -\int_\infty^c \frac{kq}{r^2}dr = \frac{kq}{c}$.

(b) At $r = b$: $V_b = -\int_\infty^c \vec{E}\cdot d\vec{r} - \int_c^b \vec{E}\cdot d\vec{r} = \frac{kq}{c} - 0 = \frac{kq}{c}$.

(c) At $r = a$: $V_a = -\int_\infty^c \vec{E}\cdot d\vec{r} - \int_c^b \vec{E}\cdot d\vec{r} - \int_b^a \vec{E}\cdot d\vec{r} = \frac{kq}{c} - kq\int_b^a \frac{dr}{r^2} = kq\left[\frac{1}{c} - \frac{1}{b} + \frac{1}{a}\right]$

(d) At $r = 0$: $V_0 = kq\left[\frac{1}{c} - \frac{1}{b} + \frac{1}{a}\right]$ since it is inside a metal sphere, and thus at the same potential as its surface.

EVALUATE: The potential difference between the two conductors is $V_a - V_b = kq\left[\frac{1}{a} - \frac{1}{b}\right]$.