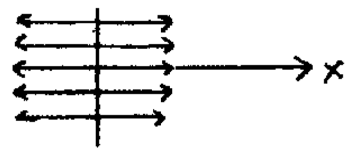
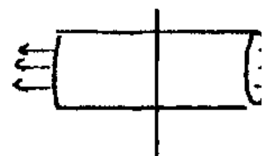
19.29 $\Phi_E = EA\cos\theta$ $\qquad A = \pi r^2 = \pi(0.200)^2 = 0.126\ \text{m}^2$

$5.20 \times 10^5 = E(0.126)\cos 0°$ $\qquad E = 4.14 \times 10^6\ \text{N/C} = \boxed{4.14\ \text{MN/C}}$

X2: The field looks like this:



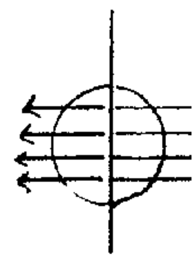
(a) Orient the cylinder along x. Then there is outward flux from both ends of the can

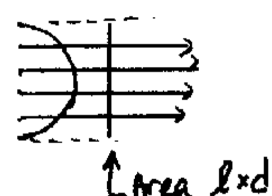


$$\Phi = \int \vec{E}\cdot d\vec{A} = (300\ \text{N/C})\cdot \tfrac{\pi}{4}d^2 + (300\ \text{N/C})\tfrac{\pi}{4}d^2$$

$$= (2)(300\ \text{N/C})\tfrac{\pi}{4}(0.05\text{m})^2 \qquad \boxed{\Phi = 1.18\ \text{N}\cdot\text{m}^2/\text{C}}$$

(b) With the cylinder turned there is flux out through the sides of the can. Here $\vec{E}$ is not ⊥ to the surface so we need to be careful. The simplest thing is to notice that the flux through either half of the can is the same as through a rectangle of dimensions $l \times d$ ⇒





$$\Phi = (300\ \text{N/C} \times l \times d) \times 2$$

$$= (300\ \text{N/C})(0.20\text{m})(0.05\text{m})(2) \Rightarrow \boxed{\Phi = 6.0\ \text{N}\cdot\text{m}^2/\text{C}}$$

19.31 (a) $\Phi_E = \dfrac{q_{in}}{\epsilon_0} = \dfrac{(+5.00\ \mu\text{C} - 9.00\ \mu\text{C} + 27.0\ \mu\text{C} - 84.0\ \mu\text{C})}{8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2} = -6.89 \times 10^6\ \text{N}\cdot\text{m}^2/\text{C}^2$

$\Phi_E = \boxed{-6.89\ \text{MN}\cdot\text{m}^2/\text{C}}$

(b) Since the net electric flux is negative, more lines enter than leave the surface.

***19.32** $\Phi_E = \frac{q_{in}}{\epsilon_0} = \frac{170 \times 10^{-6} \text{ C}}{8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2} = 1.92 \times 10^7 \text{ N} \cdot \text{m}^2/\text{C}$

(a) $(\Phi_E)_{\text{one face}} = \frac{1}{6}\Phi_E = \frac{1.92 \times 10^7 \text{ N} \cdot \text{m}^2/\text{C}}{6}$ $\quad (\Phi_E)_{\text{one face}} = \boxed{3.20 \text{ MN} \cdot \text{m}^2/\text{C}}$

(b) $\Phi_E = \boxed{19.2 \text{ MN} \cdot \text{m}^2/\text{C}}$

(c) The answer to (a) would change because the flux through each face of the cube would not be equal with an asymmetric charge distribution. The sides of the cube nearer the charge would have more flux and the ones farther away would have less. The answer to (b) would remain the same, since the overall flux would remain the same.

19.34 (a) $E = \frac{k_e Q r}{a^3} = \boxed{0}$

(b) $E = \frac{k_e Q r}{a^3} = \frac{(8.99 \times 10^9)(26.0 \times 10^{-6})(0.100)}{(0.400)^3} = \boxed{365 \text{ kN/C}}$

(c) $E = \frac{k_e Q}{r^2} = \frac{(8.99 \times 10^9)(26.0 \times 10^{-6})}{(0.400)^2} = \boxed{1.46 \text{ MN/C}}$

(d) $E = \frac{k_e Q}{r^2} = \frac{(8.99 \times 10^9)(26.0 \times 10^{-6})}{(0.600)^2} = \boxed{649 \text{ kN/C}}$

The direction for each electric field is $\boxed{\text{radially outward}}$.

***19.35** (a) $\mathbf{E} = \boxed{0}$

(b) $E = \frac{k_e Q}{r^2} = \frac{(8.99 \times 10^9)(32.0 \times 10^{-6})}{(0.200)^2} = 7.19 \text{ MN/C}$ $\quad \mathbf{E} = \boxed{7.19 \text{ MN/C radially outward}}$

19.44 (a) Inside surface: consider a cylindrical surface within the metal. Since E inside the conducting shell is zero, the total charge inside the gaussian surface must be zero, so the inside charge/length $= -\lambda$.

$0 = \lambda\ell + q_{\text{in}}$ so $\dfrac{q_{\text{in}}}{\ell} = \boxed{-\lambda}$

Outside surface: The total charge on the metal cylinder is $2\lambda\ell = q_{\text{in}} + q_{\text{out}}$

$q_{\text{out}} = 2\lambda\ell + \lambda\ell$ so the outside charge/length is $\boxed{3\lambda}$

(b) $E = \dfrac{2k_e(3\lambda)}{r} = \dfrac{6k_e\lambda}{r} = \boxed{\dfrac{3\lambda}{2\pi\epsilon_0 r} \text{ radially outward}}$

***19.45** (a) $\mathbf{E} = \boxed{0}$

(b) $E = \dfrac{k_e Q}{r^2} = \dfrac{(8.99\times10^9)(8.00\times10^{-6})}{(0.0300)^2} = 7.99\times10^7 \text{ N/C}$ $\quad \mathbf{E} = \boxed{79.9 \text{ MN/C radially outward}}$

(c) $\mathbf{E} = \boxed{0}$

(d) $E = \dfrac{k_e Q}{r^2} = \dfrac{(8.99\times10^9)(4.00\times10^{-6})}{(0.0700)^2} = 7.34\times10^6 \text{ N/C}$ $\quad \mathbf{E} = \boxed{7.34 \text{ MN/C radially outward}}$

20.1 (a) Energy of the proton-field system is conserved as the proton moves from high to low potential, which can be defined for this problem as moving from 120 V down to 0 V.

$$K_i + U_i + \Delta E_{\text{mech}} = K_f + U_f \qquad 0 + qV + 0 = \tfrac{1}{2}mv_p^2 + 0$$

$$\left(1.60\times10^{-19}\ \text{C}\right)(120\ \text{V})\left(\frac{1\ \text{J}}{1\ \text{V}\cdot\text{C}}\right) = \tfrac{1}{2}\left(1.67\times10^{-27}\ \text{kg}\right)v_p^2$$

$$v_p = \boxed{1.52\times10^{5}\ \text{m/s}}$$

(b) The electron will gain speed in moving the other way,

from $V_i = 0$ to $V_f = 120$ V: $K_i + U_i + \Delta E_{\text{mech}} = K_f + U_f$

$$0 + 0 + 0 = \tfrac{1}{2}mv_e^2 + qV$$

$$0 = \tfrac{1}{2}\left(9.11\times10^{-31}\ \text{kg}\right)v_e^2 + \left(-1.60\times10^{-19}\ \text{C}\right)(120\ \text{J/C})$$

$$v_e = \boxed{6.49\times10^{6}\ \text{m/s}}$$

20.2 $\Delta V = -14.0$ V and $Q = -N_A e = -\left(6.02\times10^{23}\right)\left(1.60\times10^{-19}\right) = -9.63\times10^{4}$ C

$\Delta V = \dfrac{W}{Q}$, so $W = Q\Delta V = \left(-9.63\times10^{4}\ \text{C}\right)(-14.0\ \text{J/C}) = \boxed{1.35\ \text{MJ}}$

20.5 (a) We follow the path from (0, 0) to (20.0 cm, 0) to (20.0 cm, 50.0 cm).

$\Delta U = -$ (work done)

$\Delta U = -$ (work from origin to (20.0 cm, 0)) $-$ (work from (20.0 cm, 0) to (20.0 cm, 50.0 cm))

Note that the last term is equal to 0 because the force is perpendicular to the displacement.

$$\Delta U = -(qE_x)\Delta x = -\left(12.0\times10^{-6}\ \text{C}\right)(250\ \text{V/m})(0.200\ \text{m}) = \boxed{-6.00\times10^{-4}\ \text{J}}$$

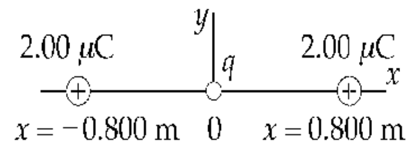
(b) $$\Delta V = \frac{\Delta U}{q} = -\frac{6.00\times10^{-4}\ \text{J}}{12.0\times10^{-6}\ \text{C}} = -50.0\ \text{J/C} = \boxed{-50.0\ \text{V}}$$

20.8 (a) $|\Delta V| = Ed = (5.90\times10^{3}\ \text{V/m})(0.0100\ \text{m}) = \boxed{59.0\ \text{V}}$

(b) $\frac{1}{2}mv_f^2 = |q\Delta V|$: $\quad\frac{1}{2}(9.11\times10^{-31})v_f^2 = (1.60\times10^{-19})(59.0)$

$v_f = \boxed{4.55\times10^{6}\ \text{m/s}}$

20.11 (a) Since the charges are equal and placed symmetrically, $\boxed{F=0}$

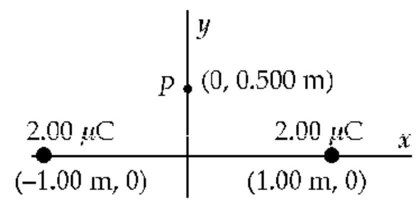


(b) Since $F = qE = 0$, $\boxed{E=0}$

(c) $V = 2k_e\dfrac{q}{r} = 2(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)\left(\dfrac{2.00\times10^{-6}\ \text{C}}{0.800\ \text{m}}\right)$

$V = 4.50\times10^{4}\ \text{V} = \boxed{45.0\ \text{kV}}$

***20.16** (a) $V = \dfrac{k_eq_1}{r_1} + \dfrac{k_eq_2}{r_2} = 2\left(\dfrac{k_eq}{r}\right)$

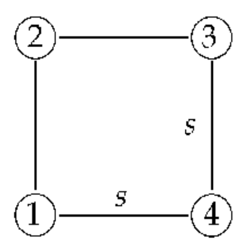


$V = 2\left(\dfrac{(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)(2.00\times10^{-6}\ \text{C})}{\sqrt{(1.00\ \text{m})^2+(0.500\ \text{m})^2}}\right)$

$V = 3.22\times10^{4}\ \text{V} = \boxed{32.2\ \text{kV}}$

(b) $U = qV = (-3.00\times10^{-6}\ \text{C})\left(3.22\times10^{4}\ \dfrac{\text{J}}{\text{C}}\right) = \boxed{-9.65\times10^{-2}\ \text{J}}$

20.17 $U = U_1 + U_2 + U_3 + U_4$



$U = 0 + U_{12} + (U_{13} + U_{23}) + (U_{14} + U_{24} + U_{34})$

$U = 0 + \dfrac{k_eQ^2}{s} + \dfrac{k_eQ^2}{s}\left(\dfrac{1}{\sqrt{2}} + 1\right) + \dfrac{k_eQ^2}{s}\left(1 + \dfrac{1}{\sqrt{2}} + 1\right)$

$U = \dfrac{k_eQ^2}{s}\left(4 + \dfrac{2}{\sqrt{2}}\right) = \boxed{5.41\dfrac{k_eQ^2}{s}}$

An alternate way to get the term $(4 + 2/\sqrt{2})$ is to recognize that there are 4 side pairs and 2 face diagonal pairs.

***20.21** Using conservation of energy for the alpha particle-nucleus system,

we have $K_f + U_f = K_i + U_i$

But $U_i = \dfrac{k_e q_\alpha q_{\text{gold}}}{r_i}$

and $r_i \cong \infty$

Thus, $U_i = 0$

Also $K_f = 0 \quad (v_f = 0 \text{ at turning point}),$

so $U_f = K_i$

or $\dfrac{k_e q_\alpha q_{\text{gold}}}{r_{\min}} = \frac{1}{2} m_\alpha v_\alpha^{\ 2}$

$$r_{\min} = \frac{2k_e q_\alpha q_{\text{gold}}}{m_\alpha v_\alpha^{\ 2}} = \frac{2\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)(2)(79)\left(1.60\times10^{-19}\ \text{C}\right)^2}{\left(6.64\times10^{-27}\ \text{kg}\right)\left(2.00\times10^7\ \text{m/s}\right)^2} = 2.74\times10^{-14}\ \text{m} = \boxed{27.4\ \text{fm}}$$

*20.22 In an empty universe, the 20-nC charge can be placed at its location with no energy investment. At a distance of 4 cm, it creates a potential

$$V_1 = \frac{k_e q_1}{r} = \frac{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(20\times10^{-9}\ \text{C}\right)}{0.04\ \text{m}} = 4.50\ \text{kV}$$

To place the 10-nC charge there we must put in energy

$$U_{12} = q_2 V_1 = \left(10\times10^{-9}\ \text{C}\right)\left(4.5\times10^3\ \text{V}\right) = 4.50\times10^{-5}\ \text{J}$$

Next, to bring up the –20-nC charge requires energy

$$U_{23}+U_{13} = q_3V_2 + q_3V_1 = q_3\left(V_2+V_1\right) = -20\times10^{-9}\ \text{C}\left(8.89\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(\frac{10\times10^{-9}\ \text{C}}{0.04\ \text{m}} - \frac{20\times10^{-9}\ \text{C}}{0.08\ \text{m}}\right)$$

$$= -4.50\times10^{-5}\ \text{J} - 4.50\times10^{-5}\ \text{J}$$

The total energy of the three charges is

$$U_{12}+U_{23}+U_{13} = \boxed{-4.50\times10^{-5}\ \text{J}}$$

(b) The three fixed charges create this potential at the location where the fourth is released:

$$V = V_1+V_2+V_3 = \left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(\frac{20\times10^{-9}}{\sqrt{0.04^2+0.03^2}} + \frac{10\times10^{-9}}{0.03} - \frac{20\times10^{-9}}{0.05}\right)\text{C/m}$$

$$V = 3.00\times10^3\ \text{V}$$

Energy of the system of four charged objects is conserved as the fourth charge flies away:

$$\left(\tfrac{1}{2}mv^2+qV\right)_i = \left(\tfrac{1}{2}mv^2+qV\right)_f$$

$$0+\left(40\times10^{-9}\ \text{C}\right)\left(3.00\times10^3\ \text{V}\right) = \tfrac{1}{2}\left(2.00\times10^{-13}\ \text{kg}\right)v^2+0$$

$$v = \sqrt{\frac{2\left(1.20\times10^{-4}\ \text{J}\right)}{2\times10^{-13}\ \text{kg}}} = \boxed{3.46\times10^4\ \text{m/s}}$$

20.23 $V = a+bx = 10.0\ \text{V} + (-7.00\ \text{V/m})x$

(a) At $x = 0$, $V = \boxed{10.0\ \text{V}}$

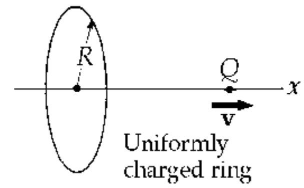
At $x = 3.00$ m, $V = \boxed{-11.0\ \text{V}}$

At $x = 6.00$ m, $V = \boxed{-32.0\ \text{V}}$

(b) $E = -\frac{dV}{dx} = -b = -(-7.00\ \text{V/m}) = \boxed{7.00\ \text{N/C in the } +x \text{ direction}}$

20.26 $$\Delta V = V_{2R} - V_0 = \frac{k_e Q}{\sqrt{R^2 + (2R)^2}} - \frac{k_e Q}{R} = \frac{k_e Q}{R}\left(\frac{1}{\sqrt{5}} - 1\right) = \boxed{-0.533 \frac{k_e Q}{R}}$$

***20.61** From Example 20.5, the potential at the center of the ring is $V_i = k_e Q / R$ and the potential at an infinite distance from the ring is $V_f = 0$. Thus, the initial and final potential energies of the point charge-ring system are:



$$U_i = QV_i = \frac{k_e Q^2}{R}$$

and $$U_f = QV_f = 0$$

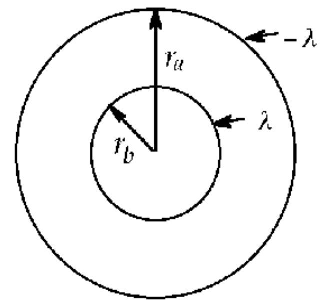
From conservation of energy,

$$K_f + U_f = K_i + U_i$$

or $$\tfrac{1}{2} M v_f^2 + 0 = 0 + \frac{k_e Q^2}{R}$$

giving $$v_f = \boxed{\sqrt{\frac{2 k_e Q^2}{MR}}}$$

***20.72** (a) $V_B - V_A = -\int_A^B \mathbf{E} \cdot d\mathbf{s}$ and the field at distance r from a uniformly charged rod (where $r >$ radius of charged rod) is



$$E = \frac{\lambda}{2\pi\epsilon_0 r} = \frac{2k_e\lambda}{r}$$

In this case, the field between the central wire and the coaxial cylinder is directed perpendicular to the line of charge so that

$$V_B - V_A = -\int_{r_a}^{r_b} \frac{2k_e\lambda}{r} dr = 2k_e\lambda \ln\left(\frac{r_a}{r_b}\right),$$

or $$\boxed{\Delta V = 2k_e\lambda \ln\left(\frac{r_a}{r_b}\right)}$$

(b) From part (a), when the outer cylinder is considered to be at zero potential, the potential at a distance r from the axis is

$$V = 2k_e\lambda \ln\left(\frac{r_a}{r}\right)$$

The field at r is given by

$$E = -\frac{\partial V}{\partial r} = -2k_e\lambda\left(\frac{r}{r_a}\right)\left(-\frac{r_a}{r^2}\right) = \frac{2k_e\lambda}{r}$$

But, from part (a), $2k_e\lambda = \dfrac{\Delta V}{\ln(r_a/r_b)}$.

Therefore, $$\boxed{E = \frac{\Delta V}{\ln(r_a/r_b)}\left(\frac{1}{r}\right)}$$