The spherically symmetric charge distributions behave as if all their charge was located at the center of the spheres. Therefore, the force is (using Eq. 1-1)

\[ F_e = \frac{k_e |q_1||q_2|}{r^2} = \frac{8.99 \times 10^9 \text{ Nm}^2/\text{C}^2 (1.2 \times 10^{-8} \text{ C})(-1.8 \times 10^{-8} \text{ C})}{(0.30 \text{ m})^2} \]

\[ = 2.2 \times 10^{-5} \text{ N} \]

Note that since we have unlike charges, this force will be attractive.

When the spheres are connected by a conducting wire, the charge will equalize for an individual charge on each of

\[ q^* = \frac{q_1 + q_2}{2} = \frac{(+1.2 \times 10^{-8} \text{ C}) + (-1.8 \times 10^{-8} \text{ C})}{2} \]

\[ = -3.0 \times 10^{-9} \text{ C} \] (both charges are now negative)

The new force is

\[ F_e = \frac{k_e |q^*||q^*|}{r^2} = \frac{8.99 \times 10^9 \text{ Nm}^2/\text{C}^2 (-3.0 \times 10^{-9} \text{ C})(3.0 \times 10^{-9} \text{ C})}{(0.30 \text{ m})^2} \]

\[ = 9.0 \times 10^{-7} \text{ N} \]

Since we now have like charges, this force will be repulsive.
a) Find $|E|$, 1.00 cm to left of middle charge (point A in diagram).

Let $q_1 = 6.00 \mu C$, $q_2 = 1.50 \mu C$, $q_3 = -2.00 \mu C$ Above are the directions of the $E$-fields from each charge.

Then the $E$-field at point A is

$$E_A = E_1 - E_2 + E_3$$

$$= \frac{kq_1}{r_1^2} - \frac{kq_2}{r_2^2} + \frac{kq_3}{r_3^2}$$

$$= \left(8.99 \times 10^9 \text{ Nm}^2/\text{C}^2\right) \left[\frac{6.00 \times 10^{-6} \text{ C}}{(0.0200 \text{ m})^2} - \frac{1.50 \times 10^{-6} \text{ C}}{(0.0200 \text{ m})^2} + \frac{2.00 \times 10^{-6} \text{ C}}{(0.0300 \text{ m})^2}\right] = +2.00 \times 10^7 \text{ N/C} \text{ (to the right)}$$

b) Force if $q = -2.00 \mu C$ placed at A:

$$F = qE_A = (-2.00 \times 10^{-6} \text{ C}) \times +2.00 \times 10^7 \text{ N/C} = -40.0 \text{ N}$$

(points towards the left)
3. 

a) 16 lines away from each charge

b) 20 lines into each charge

2 lines out of +1 \( \mu \text{C} \)  
16 lines into -2 \( \mu \text{C} \)
The surface area of the Gaussian surface is

\[ A = 4\pi r^2. \]

Since the E-field is along \( \hat{r} \) and the area normal line follows \( \hat{r} \), \( \theta = 0 \) so

\[ \Phi_E = EA \cos \theta = E (4\pi r^2) \cos 0^\circ = 4\pi r^2 E \]

a) For \( r > a \) (i.e., outside the shell), the total charge enclosed by the Gaussian surface is

\[ Q = +q - q = 0 \]

Thus Gauss's law gives

\[ \Phi_E = \frac{Q}{\varepsilon_0} = 4\pi r^2 E = 0, \]

or \( E = 0. \)

b) For \( r < a \) (i.e., inside the shell), \( Q = +q \), and

\[ \Phi_E = \frac{Q}{\varepsilon_0} = \frac{q}{\varepsilon_0} = 4\pi r^2 E, \]

or

\[ E = \frac{q}{4\pi \varepsilon_0 r^2} = \frac{\vec{E} \cdot \hat{r}}{r^2} \]

directed radially outward.
Here, we can't use the gravitational form of the 1-D equations of motion (i.e., $a = gt$) since there will be a 2nd force (the E-field) acting on the body.

Given:
- $g = 9.80 \text{ m/s}^2$
- $m = 2.00 \text{ kg}$
- $q = 5.00 \mu \text{C} = 5.00 \times 10^{-6} \text{ C}$
- $v_0 = 20.1 \text{ m/s}$
- $t_f = 4.10 \text{ s}$

Since the E-field is uniform, we can use Eq. (II-6) to calculate the potential difference:

$$\Delta V = -Ed = -E(y_0 - y_{max}) = E y_{max}$$

To determine $y_{max}$, use $v_{y_{max}}^2 = v_{y_0}^2 + 2a y_{max}$, where $v_{y_0} = v_0$ is the velocity at $y_{max}$, so

$$y_{max} = \frac{-v_{y_0}^2}{2a} \quad (1)$$

The acceleration can be determined by a second 1-D equation of motion:

$$y = y_0 + v_0 t + \frac{1}{2} a t^2$$

If we use data from the entire flight, $y = y_0$. 

$$\Delta V = V_{top} - V_o$$

$\Delta V$ \hspace{1cm} $t_0 = 0$

$\text{GROUND}$ \hspace{1cm} $V_o$

$\text{\uparrow}$ \hspace{1cm} $\text{\downarrow}\vec{E}$ \hspace{1cm} $\text{\uparrow} y$

$\text{\uparrow} \vec{g}$
and \( t = t_f \), so
\[
0 = v_0 t_f + \frac{1}{2} a t_f^2
\]
or
\[
a = -\frac{2v_0}{t_f}
\]  \hspace{2cm} (2)

Plugging this into Eq. (1) gives
\[
y_{\text{max}} = -\frac{v_0^2}{2} \left( -\frac{t_f}{2v_0} \right) = \frac{v_0 t_f}{4}
\]
\[
= \frac{(20.1 \text{ m/s})(4.10 \text{ s})}{4} = 20.6 \text{ m}
\]

We next need to find the E-field strength. Using Newton's 2nd law, we can write
\[
a = \frac{\sum F}{m} = -\frac{mg - qE}{m} = -\left( g + \frac{qE}{m} \right)
\]

Setting this equation equal to Eq. (2) gives
\[
-g - \frac{qE}{m} = -\frac{2v_0}{t_f}
\]
\[
\frac{qE}{m} = -g + \frac{2v_0}{t_f}
\]

\[
E = \left( \frac{q}{4} \right) \left[ \frac{2v_0}{t_f} - g \right] = \left( \frac{2.00 \text{ dyn}}{5.00 \times 10^{-6} \text{ C}} \right) \left[ \frac{2(20.1 \text{ m/s})}{4.10 \text{ s}} - 9.80 \text{ m/s}^2 \right]
\]
\[
= 1.95 \times 10^3 \text{ N/C} = 1.95 \times 10^3 \text{ V/m}
\]

Hence
\[
\Delta V = E y_{\text{max}} = (1.95 \times 10^3 \text{ V/m})(20.6 \text{ m}) = 40.2 \text{ V}
\]
$$\mathbf{q} = 7.00 \, \text{mC} = 7.00 \times 10^{-9} \, \text{C}$$

Calculate $V$ at $P$.

$$V = V_1 + V_2 + V_3 = \kappa \left( \frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} \right)$$

$q_1 = +7.00 \times 10^{-9} \, \text{C}$, $q_2 = -7.00 \times 10^{-9} \, \text{C} = q_3$

$r_2 = 1.00 \, \text{cm} = 10^{-2} \, \text{m} = r_3$

Note that $r_1^2 + r_2^2 = l^2$

$$r_1 = \sqrt{l^2 - r_2^2} = \sqrt{(4.00 \, \text{cm})^2 - (1.00 \, \text{cm})^2} = 3.87 \, \text{cm} = 3.87 \times 10^{-2} \, \text{m}$$

$$V = \left( 8.99 \times 10^9 \, \frac{\text{Nm}^2}{\text{C}^2} \right) \left( \frac{-7.00 \times 10^{-9} \, \text{C}}{1.00 \times 10^{-2} \, \text{m}} - \frac{7.00 \times 10^{-9} \, \text{C}}{1.00 \times 10^{-2} \, \text{m}} + \frac{7.00 \times 10^{-9} \, \text{C}}{3.87 \times 10^{-2} \, \text{m}} \right)$$

$$= -1.10 \times 10^4 \, \text{V} = -11.0 \, \text{keV}$$
\[ A = 21.0 \times 10^{-12} \text{ m}^2 \]  and  \[ C = 60.0 \times 10^{-15} \text{ F} \], use Eq. (II-14):

\[ C = \varepsilon_0 \frac{A}{d} \quad \text{or} \quad d = \frac{\varepsilon_0 A}{C} = \frac{\left(8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2\right)(21.0 \times 10^{-12} \text{ m}^2)}{60.0 \times 10^{-15} \text{ F}} \]

Note that \( \frac{C^2}{N \text{m}^2} \cdot \text{m}^2 = \frac{C^2}{N} \) and \( F = \frac{C}{V} \) and \( \frac{V}{C} = \frac{V}{N} = V \cdot \frac{C}{N} = V \cdot \frac{m}{V} = m \)

So

\[ \frac{C^2}{N \text{m}^2} \cdot \frac{\text{m}^2}{F} = \frac{C^2}{N} = \frac{V}{C} \cdot \frac{C^2}{N} = \frac{VC}{N} = V \cdot \frac{C}{N} = V \cdot \frac{m}{V} = m \]

Finally,

\[ d = 3.10 \times 10^{-9} \text{ m} \times \frac{1 \text{ A}}{10^{-10} \text{ m}} = \sqrt{31.0 \text{ A}} \]

\[ C_1 = 15.0 \mu\text{F} \quad C_2 = 3.00 \mu\text{F} \quad C_4 = 20.0 \mu\text{F} \]

8. 

![Diagram](image)

\[ C_3 = 6.00 \mu\text{F} \]

a) First reduce the \( C_1 \) and \( C_2 \) series capacitors to \( C_A \):

\[ \frac{1}{C_A} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{15.0 \mu\text{F}} + \frac{1}{3.00 \mu\text{F}} \]
\[ \frac{1}{C_A} = \frac{1}{15.0\,\mu F} + \frac{5}{15.0\,\mu F} = \frac{6}{15.0\,\mu F} \]

\[ C_A = \frac{15.0\,\mu F}{6} = 2.50\,\mu F \]

\[ C_A = 2.50\,\mu F \]

Now reduce the 11 capacitor \( C_A \) \& \( C_3 \):

\[ C_B = C_A + C_3 = 2.50\,\mu F + 6.00\,\mu F = 8.50\,\mu F \]

\[ C_B = 8.50\,\mu F \quad C_4 = 20.0\,\mu F \]

Finally determine the equivalent capacitance from these final 2 series capacitors:

\[ \frac{1}{C_{eq}} = \frac{1}{C_B} + \frac{1}{C_4} = \frac{1}{8.50\,\mu F} + \frac{1}{20.0\,\mu F} \]

\[ = 0.118\,\mu F^{-1} + 0.05\,\mu F^{-1} = 0.168\,\mu F^{-1} \]

\[ C_{eq} = 5.96\,\mu F \]
b) To determine the charge, note that in Figure (3) that
\[ Q_8 = Q_4 = V_{ab} C_4 = (15.0 \, \text{V})(5.96 \, \mu\text{F}) = 89.5 \, \mu\text{C} \]

Thus the charge on capacitor 4 \( (20.0\, \mu\text{F}) \) is
\[ Q_4 = 89.5 \, \mu\text{C} \]

For series capacitors, the voltages add, so
\[ V_{ab} = V_B + V_4 \quad \text{or} \quad V_3 = V_{ab} - V_4 \]
\[ V_B = V_{ab} - V_4 = V_{ab} - \frac{Q_4}{C_4} = 15.0 \, \text{V} - \left( \frac{89.5 \, \mu\text{C}}{20.0 \, \mu\text{F}} \right) \]
\[ = 10.53 \, \text{V} \]

In parallel, the voltages across capacitors are equal, therefore (from comparing Fig. (3) \& (2))
\[ V_B = V_A = V_3 = 10.53 \, \text{V} \]

Thus the charge on capacitor 3 \( (6.00\, \mu\text{F}) \) is
\[ Q_3 = V_3 C_3 = (10.53 \, \text{V})(6.00 \, \mu\text{F}) = 63.2 \, \mu\text{C} \]

From Fig. (1), \( C_1 \) \& \( C_2 \) are in series, so \( Q_1 = Q_2 \) and
\[ Q_1 = Q_2 = V_A C_A = (10.53 \, \text{V})(2.50 \, \mu\text{F}) = 26.3 \, \mu\text{C} \]
\[ Q_1 = 26.3 \, \mu\text{C} \]
\[ Q_2 = 26.3 \, \mu\text{C} \]
Period: \( T = \frac{2\pi}{\omega} \)

Current: \( I = \frac{\text{charge}}{\text{time}} = \frac{\text{charge}}{\text{period}} = \frac{q}{T} = \frac{q}{2\pi/\omega} \)

\[
I = \frac{q \omega}{2\pi}
\]

10. \( L = 2.0 \text{ m} = 2.0 \times 10^{-2} \text{ m} \)

\[\rho = 5.6 \times 10^{-8} \Omega \text{ m} \]

\[R = 0.050 \Omega \] (Table 17.1)

\[
R = \frac{\rho L}{A} \Rightarrow A = \frac{\pi D^2}{4} = \frac{\rho L}{R}, \text{ or}
\]

\[
D = \sqrt{\frac{4\rho L}{\pi R}} = \sqrt{\frac{4 (5.6 \times 10^{-8} \Omega \text{ m}) (2.0 \times 10^{-2} \text{ m})}{\pi (0.050 \Omega)}}
\]

\[
= 1.7 \times 10^{-4} \text{ m} = 0.17 \text{ mm}
\]
11. \( T_0 = 20^\circ C, \quad T = 80^\circ C, \quad \Delta T = T - T_0 = 60^\circ C \)

\[ R = R_o \left[ 1 + \alpha (T - T_0) \right] \]

\[ I = \frac{\Delta V}{R} = \frac{\Delta V}{R_o \left[ 1 + \alpha (\Delta T) \right]} \]

\[ I = \frac{5.0 V}{(200 \Omega) \left[ 1 + (-0.5 \times 10^{-3} \text{ C}^{-1}) \times 60^\circ C \right]} = 2.6 \times 10^{-2} A \]

\[ I = 26 \text{ mA} \]

12. \( \Delta V = 120 \text{ V}, \quad I = 2.00 \text{ A}, \quad \rho = 0.500 \text{ kg}, \quad T_{\text{room}} = 23.0^\circ C \)

The energy required to bring the water to the boiling point is

\[ E = \rho v \Delta T = (0.500 \text{ kg})(4186 \text{ J/kg}^\circ C) \times (100^\circ C - 23.0^\circ C) = 1.61 \times 10^5 \text{ J} \]

The power input from the heating element is

\[ P = (\Delta V)I = (120 \text{ V})(2.00 \text{ A}) = 240 \text{ W} = 240 \text{ J/s} \]

Time required is

\[ t = \frac{E}{P} = \frac{1.61 \times 10^5 \text{ J}}{240 \text{ J/s}} = 672 \text{ s} = 11.2 \text{ min} \]