(Q8) $\bullet$ = positively charged ball

(Since the ball is not a conductor, the charge should be considered permanent.)

□ = conductor (initially neutral)

Step 1
Bring them close.

Negatively charged electrons are pulled to the left, exposing positively charged ion on the right. The ions try to pull the electrons back limiting how many are able to move.

Ground the conductor

The ground connection allows more electrons to flow in and cancel the exposed positive charges.

$\blacksquare$ The conductor has not negative charge.

(2) Take the ball away and then break the ground connection.

With the ball gone, there is nothing holding the negative charges on the conductor and they flow back to ground. The conductor is neutral.

(6) Break the ground connection and then take the ball away.

With no connection to ground, the negative charges (electrons) are stuck on the conductor. The conductor is negatively charged.
Charged plastic  
(Charges are not free to move)

Neutral copper  
(Internal, but still contains electrons which are free to move)

The electrons in the copper will be repelled by the plastic onto the right side of the copper. Only a few (billion) make it over, however. The electrons on the right side the uncharged positive charge on the left soon exert a counter-force which cancels the force from the charged plastic.

Note that a positive charge appears on the left side, but no positive charges (the atomic nuclei) ever moved.
1) Given: \( q_1 = 26.0 \mu C \)
\( q_2 = -47.0 \mu C \)

Find: \( r \) so \( F_{12} = 5.70 N \)

\[ F = F_{12} = F_{21} = 5.70 N \]

\[ 1F_1 = \frac{k|q_1 q_2|}{r^2} \quad \Rightarrow \quad r = \sqrt{\frac{k|q_1 q_2|}{F}} \]

\[ = \left[ \frac{8.99 \times 10^9 N \cdot m^2}{c^2} \left( 26.0 \times 10^{-6} C \right) \left( 47.0 \times 10^{-6} C \right) \right] \]
\[ \frac{1}{5.70 N} \]
\[ = 1.37 m \sqrt{\text{✓}} \]

4) Initially (Fig 22-20a) let the charge on each sphere be \( q_1 = q_2 = q \) and the distance between them be \( d \). Then \( F = F_{12} = F_{21} = \frac{kq^2}{d^2} \) (Fig 22-20b)

Now \( q_1 = q_3 = \frac{q}{2} \). \( q_2 = q \) still.

(Fig 22-20c) Now \( q_2 = q_3 = \frac{\frac{q}{2} + \frac{q}{2}}{2} = \frac{3}{4} q \). \( q_1 = \frac{q}{2} \) still.

(Fig 22-20d) \( F' = \frac{kq_1 q_2}{d^2} = \frac{k \left( \frac{q}{2} \right) \left( \frac{3}{4} q \right)}{d^2} = \frac{kq^2}{d^2} \left( \frac{3}{8} \right) \)
\[ = \frac{3}{8} F \sqrt{\text{✓}} \]
5) Given: \( \theta = 1.0 \times 10^{-7} \text{C} \)
\( q = 5.0 \text{cm} \)

Find: \( F_x \) and \( F_y \) for \( \theta_2 \), the circled charge.

\[
F_x = |F_{32}| \cos 45^\circ + |F_{34}| \\
= \frac{K (2\theta) (\theta)}{(\sqrt{2} q)^2} \left( \frac{1}{\sqrt{2}} \right) + \frac{K (2\theta) (\theta)}{q^2} \\
= \frac{K \theta^2}{q^2} \left( \frac{1}{\sqrt{2}} + 4 \right) = \frac{(8.0 \times 10^7 \text{N m}^2/\text{C}^2)(10 \times 10^{-7} \text{C})}{(0.050 \text{m})^2} \times 4.71 = 0.17 \text{N} \sqrt{ \text{m}}
\]

\[
F_y = -|F_{31}| + |F_{32}| \sin 45^\circ \\
= -\frac{K (2\theta) (\theta)}{q^2} + \frac{K (2\theta) (\theta)}{(\sqrt{2} q)^2} \left( \frac{1}{\sqrt{2}} \right) = \frac{K \theta^2}{q^2} \left( -2 + \frac{1}{\sqrt{2}} \right) = -0.046 \text{N} \sqrt{ \text{m}}
\]
6) Given: \( \chi_1 = -\alpha \)
\( \chi_2 = \alpha \)

Find: (a) A relation between \( \chi_1 + \chi_2 \) so \( F_\phi = 0 \) when \( \chi_\phi = \frac{\alpha}{2} \)
(b) \( ... \) when \( \chi_\phi = \frac{3\alpha}{2} \)

\[ \frac{\chi_1}{\chi_2} \]

We want \( F_\phi = F_{\chi_1} + F_{\chi_2} = 0 \), so \( F_{\chi_1} = -F_{\chi_2} \).
Thus \( \chi_1, \chi_2 \) must have the same sign.

Now, \( |F_{\chi_1}| = |F_{\chi_2}| \) or \( F_{\chi_1} = F_{\chi_2} \) so

\[
\left| \frac{\chi_1 \chi_2}{(\frac{\alpha}{2})^2} \right| = \left| \frac{\chi_1 \chi_2}{(\frac{3\alpha}{2})^2} \right| \Rightarrow \left| \frac{\chi_1}{\chi_2} \right| = \frac{\chi_1}{\chi_2} = \frac{\alpha}{3\alpha} = \frac{1}{3} \Rightarrow \chi_1 = -3\chi_2
\]

Now \( \chi_1, \chi_2 \) must have opposite signs.
We still have \( F_{\chi_1} = F_{\chi_2} \):

\[
\left| \frac{\chi_1 \chi_2}{(\frac{\alpha}{2})^2} \right| = \left| \frac{\chi_1 \chi_2}{(\frac{3\alpha}{2})^2} \right| \Rightarrow \left| \frac{\chi_1}{\chi_2} \right| = 2.5 \Rightarrow \chi_1 = -2.5\chi_2
\]
10) Given: $q_1 = 1.0 \mu C$
\[ q_2 = -3.0 \mu C \]
\[ d = 10 cm \]

Find: $x$ = position of a third charge so that it experiences no net force.

$q_3$ has to be on the line joining $q_1$ and $q_2$.

It can't be in region II because the forces from $q_1$ and $q_2$ will be in the same direction. In regions I and III, the forces are opposite and will cancel if they are equal in magnitude.

\[ |F_{31}| = |F_{32}| \]

\[ \frac{kq_3q_1}{x^2} = \frac{kq_3q_2}{(x-d)^2} \]

\[ (x-d)^2 = \frac{q_2^2}{q_1} \]

\[ \frac{x-d}{x} = \pm \frac{q_2}{q_1} \]

\[ x = \frac{d}{1 + \frac{q_2}{q_1}^{1/2}} = \frac{0.10 m}{1 + \sqrt{3}} \]

\[ x = -0.14 m \quad \text{Region I} \]

\[ x = +0.037 m \quad \text{Region II} \]

We exclude the first answer because it is in region I.
11) Find: The positive charge $Q$ to place on the Earth and on the moon so that their electrostatic repulsion cancels their gravitational attraction.

\[ \frac{kQ^2}{r^2} = \frac{G M_{\text{Earth}} M_{\text{Moon}}}{r^2} \]

We want $F_E = F_M$

\[ Q = \left( \frac{G}{k} \frac{M_{\text{Earth}} M_{\text{Moon}}}{r^2} \right)^{1/2} \]

\[ = \left( \frac{6.67 \times 10^{-11} \frac{\text{m}^3}{\text{kg} \cdot \text{s}^2}}{6.67 \times 10^{-9} \frac{\text{m}^3}{\text{kg}^2 \cdot \text{s}^2}} \right)^{1/2} \left( \frac{5.98 \times 10^{24} \text{kg}}{7.36 \times 10^{24} \text{kg}} \right)^{1/2} \]

\[ = 5.7 \times 10^{13} \text{C} \checkmark \]

Find: Mass of hydrogen required to provide $2Q$.

Each hydrogen atom can contribute 1 proton of charge e.

Mass required = \((\text{Hydrogen}) \times \text{# of Hydrogens} = M_{\text{Hydrogen}} \frac{2Q}{e}\)

\[ = (1.67 \times 10^{-27} \text{kg}) \times \left( \frac{5.7 \times 10^{13} \text{C}}{1.6 \times 10^{-19} \text{C}} \right) = 1.2 \times 10^5 \text{kg} \checkmark \]
19) Find: Charge $q$ of $m = 75.0 \text{ kg}$ of electrons.

$$q = (\text{charge per electron})(\text{# of electrons})$$

$$= (1.60 \times 10^{-19} \text{ C})(\frac{75.0 \text{ kg}}{9.11 \times 10^{-31} \text{ kg}})$$

$$= 1.32 \times 10^{13} \text{ C} \checkmark$$

(It would take $2.7 \times 10^5 \text{ kg}$ or 300 tons of Carbon to supply 75 kg of electrons.)

21) Given: $d = 5.0 \times 10^{-10} \text{ m}$

$F = 3.7 \times 10^{-9} \text{ N}$

Find: $+q$, number $N$ of missing electrons required to create $+q$.

$$F = \frac{k q^2}{d^2} \Rightarrow q = \sqrt{\frac{d^2 F}{k}} = \sqrt{\left[\frac{(5.0 \times 10^{-10})^2}{(9.0 \times 10^9 \text{ N m}^2/\text{C}^2)} \right] \frac{(3.7 \times 10^{-9} \text{ N})}{9.0 \times 10^9 \text{ N m}^2/\text{C}^2}}$$

$$= 3.2 \times 10^{-19} \text{ C} \checkmark$$

$$N = \left|\frac{q}{e}\right| = \frac{3.2 \times 10^{-19} \text{ C}}{1.6 \times 10^{-19} \text{ C}} = 2 \checkmark$$