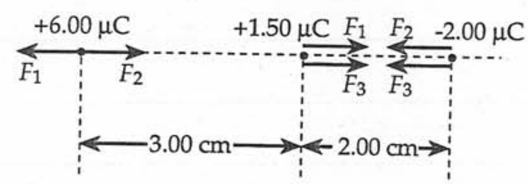
# SOLUTIONS CHAPTER 15

2. To avoid making a spark. Rubber-soled shoes acquire a charge by friction with the floor and could discharge with a spark, possibly causing an explosive burning situation, where the burning is enhanced by the oxygen.

10. She is not shocked. She becomes part of the dome of the Van de Graaff, and charges flow onto her body. They do not jump to her body via a spark, however, so she is not shocked.

**15.10** The forces are as shown in the sketch at the right.




$$F_1 = \frac{k_e q_1 q_2}{r_{12}^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(6.00\times10^{-6}\ \text{C})(1.50\times10^{-6}\ \text{C})}{(3.00\times10^{-2}\ \text{m})^2} = 89.9\ \text{N}$$

$$F_2 = \frac{k_e q_1 |q_3|}{r_{13}^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(6.00\times10^{-6}\ \text{C})(2.00\times10^{-6}\ \text{C})}{(5.00\times10^{-2}\ \text{m})^2} = 43.2\ \text{N}$$

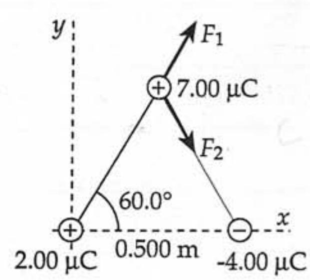
$$F_3 = \frac{k_e q_2 |q_3|}{r_{23}^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(1.50\times10^{-6}\ \text{C})(2.00\times10^{-6}\ \text{C})}{(2.00\times10^{-2}\ \text{m})^2} = 67.4\ \text{N}$$

The net force on the $6\,\mu\text{C}$ charge is $F_6 = F_1 - F_2 = \boxed{46.7\ \text{N (to the left)}}$.

The net force on the $1.5\,\mu\text{C}$ charge is $F_{1.5} = F_1 + F_3 = \boxed{157\ \text{N (to the right)}}$.

The net force on the $-2\,\mu\text{C}$ charge is $F_{-2} = F_2 + F_3 = \boxed{111\ \text{N (to the left)}}$.

**15.13** The forces on the 7.00 $\mu$C charge are shown at the right.




$$F_1 = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(7.00\times10^{-6}\ \text{C})(2.00\times10^{-6}\ \text{C})}{(0.500\ \text{m})^2}$$
$$= 0.503\ \text{N}$$

$$F_2 = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(7.00\times10^{-6}\ \text{C})(4.00\times10^{-6}\ \text{C})}{(0.500\ \text{m})^2}$$
$$= 1.01\ \text{N}$$

Thus, $\Sigma F_x = (F_1 + F_2)\cos 60.0° = 0.755 \text{ N}$,

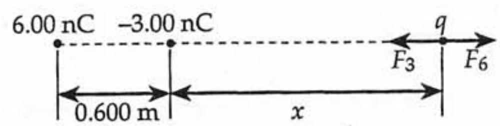
and $\Sigma F_y = (F_1 - F_2)\sin 60.0° = -0.436 \text{ N}$

The resultant force on the 7.00 $\mu$C charge is

$$F_R = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2} = 0.872 \text{ N at } \theta = \tan^{-1}\left(\frac{\Sigma F_y}{\Sigma F_x}\right) = -30.0°,$$

or $\mathbf{F}_R = \boxed{0.872 \text{ N at } 30.0° \text{ below the } +x \text{ axis}}$

**15.16** The required position is shown in the sketch at the right. Note that this places $q$ closer to the smaller charge, which will allow the two forces to cancel. Requiring that




$F_6 = F_3$ gives

$$\frac{k_e(6.00 \text{ nC})q}{(x+0.600 \text{ m})^2} = \frac{k_e(3.00 \text{ nC})q}{x^2}, \text{ or } 2x^2 = (x+0.600 \text{ m})^2$$

Solving for $x$ gives the equilibrium position as

$$x = \frac{0.600 \text{ m}}{\sqrt{2}-1} = \boxed{1.45 \text{ m beyond the -3.00 nC charge}}$$

**15.19** We shall treat the concentrations as point charges. Then, the resultant field consists of two contributions, one due to each concentration.

The contribution due to the positive charge at 3000 m altitude is

$$E_+ = k_e\frac{|q|}{r^2} = \left(8.99\times10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(40.0 \text{ C})}{(1000 \text{ m})^2} = 3.60\times10^5 \text{ N/C} \quad \text{(downward)}$$

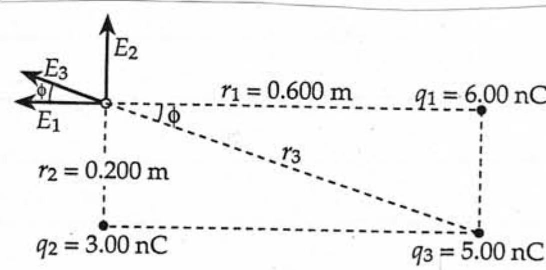
The contribution due to the negative charge at 1000 m altitude is

$$E_- = k_e\frac{|q|}{r^2} = \left(8.99\times10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(40.0 \text{ C})}{(1000 \text{ m})^2} = 3.60\times10^5 \text{ N/C} \quad \text{(downward)}$$

The resultant field is then

$$\mathbf{E} = \mathbf{E}_+ + \mathbf{E}_- = \boxed{7.20\times10^5 \text{ N/C (downward)}}$$

**15.24** From the geometry of the rectangle,




$$r_3^2 = (0.600\text{ m})^2 + (0.200\text{ m})^2 = 0.400\text{ m}^2,$$

and

$$\phi = \tan^{-1}\left(\frac{0.200\text{ m}}{0.600\text{ m}}\right) = 18.4°$$

The resultant field at the vacant corner is

$$\mathbf{E}_R = \mathbf{E}_1 + \mathbf{E}_2 + \mathbf{E}_3$$

$$E_x = \Sigma E_x = -\frac{k_e|q_1|}{r_1^2} - \frac{k_e|q_3|}{r_3^2}\cos\phi$$

$$= -\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left[\frac{6.00\times10^{-9}\text{ C}}{(0.600\text{ m})^2} + \frac{5.00\times10^{-9}\text{ C}}{0.400\text{ m}^2}\cos18.4°\right] = -256\text{ N/C}$$

$$E_y = \Sigma E_y = \frac{k_e|q_2|}{r_2^2} + \frac{k_e|q_3|}{r_3^2}\sin\phi$$

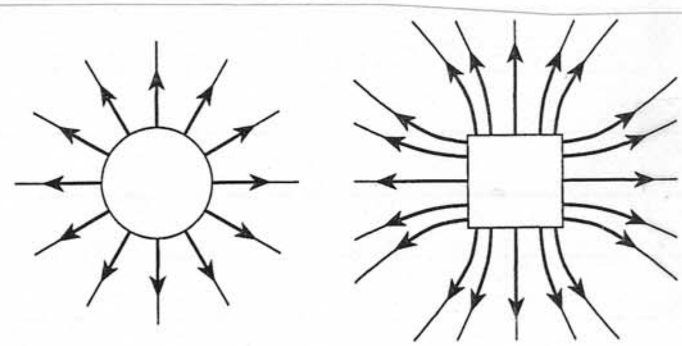
$$= \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left[\frac{3.00\times10^{-9}\text{ C}}{(0.200\text{ m})^2} + \frac{5.00\times10^{-9}\text{ C}}{0.400\text{ m}^2}\sin18.4°\right] = 710\text{ N/C}$$

Thus, $E_R = \sqrt{(E_x)^2 + (E_y)^2} = 755\text{ N/C}$. With $E_x < 0$ and $E_y > 0$, the resultant field lies in the second quadrant. Its angle with the $+x$ axis is

$$\theta = \tan^{-1}\left(\frac{E_y}{E_x}\right) = \tan^{-1}\left(\frac{710}{-256}\right) = 110°,$$

so $\mathbf{E}_R =$ **755 N/C at 110° counterclockwise from $+x$ axis**

**15.32** (a) In the sketch for (a) at the right, note that there are no lines inside the sphere. On the outside of the sphere, the field lines are uniformly spaced and radially outward.



(a) (b)

(b) In the sketch for (b) above, note that the lines are perpendicular to the surface at the points where they emerge. They should also be symmetrical about the symmetry axes of the cube. The field is zero inside the cube.

**15.43** We choose a spherical gaussian surface, concentric with the charged spherical shell and of radius *r*. Then, $\Sigma EA\cos\theta = E\left(4\pi r^2\right)\cos 0° = 4\pi r^2 E$.

(a) For $r > R$ (i.e., outside the shell), the total charge enclosed by the gaussian surface is $Q = +q - q = 0$. Thus, Gauss's law gives $4\pi r^2 E = 0$, or $E = \boxed{0}$.

(b) Inside the shell, $r < R$, and the enclosed charge is $Q = +q$.

Therefore, from Gauss's law, $4\pi r^2 E = \frac{q}{\epsilon_0}$, or $E = \frac{q}{4\pi\epsilon_0 r^2} = \frac{k_e q}{r^2}$

The field for $r < R$ is $\boxed{\mathbf{E} = \frac{k_e q}{r^2} \text{ directed radially outward}}$.

**15.45** $E = 0$ at all points inside the conductor, and $\cos\theta = \cos 90° = 0$ on the cylindrical surface. Thus, the only flux through the gaussian surface is on the outside end cap and Gauss's law reduces to $\Sigma EA\cos\theta = EA_{cap} = \frac{Q}{\epsilon_o}$.

The charge enclosed by the gaussian surface is $Q = \sigma A$, where *A* is the cross-sectional area of the cylinder and also the area of the end cap, so Gauss's law becomes

$$EA = \frac{\sigma A}{\epsilon_o}, \text{ or } E = \boxed{\frac{\sigma}{\epsilon_o}}$$