Chapter 16: Questions

(4) 6 points A positively charged rod is brought close to a neutral piece of paper, which it attracts. Draw a diagram showing the separation of charge and explain why attraction occurs.

The positively charged rod slightly polarizes the molecules in the paper. The negative charges in the paper are slightly attracted to the part of the paper closest to the rod, while the positive charges in the paper are slightly repelled from the part of the paper closest to the rod. Since the opposite charges are now closer together and the like charges are not farther apart, there is a net attractive force between the rod and the paper.

(8) 6 points When an electroscope is charged, its two leaves repel each other and remain at an angle. What balances the electric force of repulsion so that the leaves don’t separate further?

In addition to the electric force, there is also a gravitational force acting on each of the leaves. This downward force tends to return the leaves to the vertical position.

(17) 6 points Consider the electric field at points A, B, and C in the figure below. First draw an arrow at each point indicating the direction of the net force that a positive test charge would experience if placed at that point, then list the points in order of decreasing field strength (strongest first).

At point A, the net force acting on a positive test charge would be down and to the left, parallel to the nearby electric field lines. At point B, the net force acting on a positive test charge would be up and to the right, parallel to the nearby electric field lines. At point C, the net force acting on a positive test charge would be zero. In order of decreasing field strength, the points would be ordered A, B, C.

(18) 6 points Why can electric field lines never cross?

Electric field lines show the direction of the force on a test charge placed at a given location. The electric force has a unique direction at each point. If two field lines cross, it would indicate that the electric force is pointing in two directions at once, which is not possible.

Chapter 16: Problems

(12) 8 points (II) Particles of charge +75, +48, and -85 µC are placed in a line (Fig. 16-49). The center one is 0.35 m from the others. Calculate the net force on each charge due to the other two.

For simplicity, we will label the charges as \( q_1 = +75 \) µC, \( q_2 = +48 \) µC, and \( q_3 = -85 \) µC. Furthermore, by convention, we will assume that a vector pointing to the right is positive, while a vector pointing to the left is negative. With that assumption (and, remembering that like charges repel, while opposite charges attract), we find that the net force exerted on charge \( q_1 \) is

\[
\bar{F}_1 = k_e \left( - \frac{|q_1||q_2|}{r_{12}^2} + \frac{|q_1||q_3|}{r_{13}^2} \right)
= (9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \left[ -\frac{(7.5 \times 10^{-5} \text{ C})(4.8 \times 10^{-5} \text{ C})}{(0.35 \text{ m})^2} + \frac{(7.5 \times 10^{-5} \text{ C})(8.5 \times 10^{-5} \text{ C})}{(0.70 \text{ m})^2} \right]
= -147.2 \text{ N} \approx -1.5 \times 10^2 \text{ N}.
\]

Likewise, the net force exerted on charge \( q_2 \) is

\[
\bar{F}_2 = k_e \left( + \frac{|q_2||q_1|}{r_{21}^2} + \frac{|q_2||q_3|}{r_{23}^2} \right)
= (9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \left[ +\frac{(4.8 \times 10^{-5} \text{ C})(7.5 \times 10^{-5} \text{ C})}{(0.35 \text{ m})^2} + \frac{(4.8 \times 10^{-5} \text{ C})(8.5 \times 10^{-5} \text{ C})}{(0.35 \text{ m})^2} \right]
= 563.5 \text{ N} \approx 5.6 \times 10^2 \text{ N}.
\]
Finally, the net force exerted on charge \( q_3 \) is

\[
\mathbf{F}_{1} = k_e \left( \frac{|q_3| |q_1|}{r_{31}^2} - \frac{|q_3| |q_2|}{r_{32}^2} \right) = (9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \left[ -\frac{(8.5 \times 10^{-5} \text{ C})(7.5 \times 10^{-5} \text{ C})}{(0.70 \text{ m})^2} - \frac{(8.5 \times 10^{-5} \text{ C})(4.8 \times 10^{-5} \text{ C})}{(0.35 \text{ m})^2} \right] = -416.3 \text{ N} \approx -4.2 \times 10^2 \text{ N}.
\]

(14) 12 points  (II) A charge of 6.00 mC is placed at each corner of a square 0.100 m on each side. Determine the magnitude and direction of the electric field at a point midway between the charges.

Determine the force on one of the charges (say, the upper right charge), and then use the symmetry of the configuration to determine the force on the other three charges. The force acting on the upper right charge is the vector sum of the forces due to the other three charges. Let the variable \( Q \) represent the 6.00 mC charge at each corner.

For notational purposes, the corners will be numerically labeled, starting with the upper left corner and proceeding in a counter clockwise fashion around the square (i.e \( Q_1 \) represents the charge in the upper left corner, \( Q_2 \) represents the charge in the lower left corner, etc.). The force exerted on charge \( Q_4 \) by charge \( Q_1 \) only acts in the \( x \)-direction:

\[
F_{14x} = \frac{k_e Q^2}{d^2} \quad \text{and} \quad F_{14y} = 0.
\]

Similarly, the force exerted on charge \( Q_4 \) by charge \( Q_3 \) only acts in the \( y \)-direction:

\[
F_{34x} = 0 \quad \text{and} \quad F_{34y} = \frac{k_e Q^2}{d^2}.
\]

Finally, the force exerted on charge \( Q_4 \) by charge \( Q_2 \) acts equally in the \( x \)- and \( y \)-directions

\[
F_{24x} = \frac{k_e Q^2}{2d^2} \cos(45^\circ) = \frac{\sqrt{2}}{4} \frac{k_e Q^2}{d^2} \quad \text{and} \quad F_{24y} = \frac{\sqrt{2}}{4} k_e Q^2.
\]

Therefore,

\[
F_{4x} = F_{14x} + F_{24x} + F_{34x} = \frac{k_e Q^2}{d^2} \left( 1 + \frac{\sqrt{2}}{4} \right) = F_{4y},
\]

so, the magnitude of the net force acting on the charge \( Q_4 \) is

\[
F_4 = (F_{4x}^2 + F_{4y}^2)^{1/2} = \frac{k_e Q^2}{d^2} \left( \frac{\sqrt{2}}{4} + \frac{1}{2} \right) = (9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(6.00 \times 10^{-3} \text{ C})^2 \left( \frac{\sqrt{2}}{4} + \frac{1}{2} \right) = 6.20 \times 10^7 \text{ N}.
\]

This force is directed at an angle of 45\(^\circ\) above the \( x \)-direction. For each charge, the net force acting on it will be the magnitude determined above, and will lie along the line from the center of the square out towards the charge.

(28) 6 points  (II) What are the magnitude and direction of the electric field at a point midway between a -8.0 \( \mu \text{C} \) and a +7.0 \( \mu \text{C} \) charge 8.0 cm apart. Assume no other charges are nearby.

The electric field due to the negative charge will point toward the negative charge, while the electric field due to the positive charge will point away from the positive charge. Thus both fields point in the same direction, towards the negative charge so:

\[
E = E_1 + E_2 = \frac{k_e |Q_1|}{(d/2)^2} + \frac{k_e |Q_2|}{(d/2)^2} = \frac{4k_e}{d^2} (|Q_1| + |Q_2|) = \frac{4(9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(8.0 \times 10^{-6} \text{ C} + 7.0 \times 10^{-6} \text{ C})}{(8.0 \times 10^{-2} \text{ m})^2} = 8.4 \times 10^7 \text{ N/C}.
\]
A cube of side $\ell$ is placed in a uniform field $E = 6.50 \times 10^3 \, \text{N/C}$ with edges parallel to the field lines. (a) What is the net flux through the cube? (b) What is the flux through each of its six faces?

(a) Since all of the electric field lines that enter the cube also leave the cube, we conclude that the net flux through the cube is zero.

(b) There are four faces that have no flux through them, since their surfaces are parallel to the field (as a result, none of the field lines past through those faces). There is an electric flux through the remaining two faces. The electric flux through the face that the field lines enter the cube through is

$$\Phi_{\text{enter}} = -EA = -(6.50 \times 10^3 \, \text{N/C}) \ell^2.$$ 

The electric flux through the face opposite this one (through which the electric field lines leave the cube) is

$$\Phi_{\text{exit}} = EA = (6.50 \times 10^3 \, \text{N/C}) \ell^2.$$ 

A large electroscope is made with “leaves” that are 78-cm-long wires with tiny 24-g spheres at the ends. When charged, nearly all of the charge resides on the spheres. If the wires each make a $30^\circ$ angle with the vertical, what total charge $Q$ must have been applied to the electroscope? Ignore the mass of the wires.

The key to solving this problem is realizing that the spheres are in equilibrium; the net force acting on each sphere is zero. Therefore

$$\sum F_x = F_e - T \sin \theta = 0,$$

and

$$\sum F_y = T \cos \theta - mg = 0,$$

where $T$ is the tension in the cord, $\theta = 30^\circ$ and $F_e$ is the magnitude of the electrostatic force between the charged spheres. There are two unknowns in these equations ($F_e$ and $T$); eliminating $T$ and solving for $F_e$ yields

$$F_e = mg \tan \theta.$$ 

Denoting the distance between the spheres as $d$:

$$F_e = \frac{k_e Q^2}{4d^2}$$

where we used the fact that the charge on each sphere is $Q/2$. Because the wires form an equilateral triangle, $d = 78$ cm. Substituting this expression into the one above for $F_e$ and solving for $Q$ yields

$$Q = 2d \left( \frac{mg \tan \theta}{k_e} \right)^{1/2} = 2(7.8 \times 10^{-1} \, \text{m}) \left( \frac{(2.4 \times 10^{-2} \, \text{kg})(9.80 \, \text{m/s}^2) \tan 30^\circ}{(9.0 \times 10^9 \, \text{N} \cdot \text{m}^2/\text{C}^2)} \right)^{1/2} = 6.1 \times 10^{-6} \, \text{C}.$$
Physlet Explorations

(23.2) 8 points  The animation shows two fixed charges and a test charge (position is given in meters and
time is given in seconds). The electric field lines due to the fixed charges and the force
vector on the test charge are shown. The test charge will move under the action of the
electric field when the animation is played.

a. Using Configuration A, drag the test charge to the approximate position of (-0.8 m, 0
m). Write down a prediction for the path the charge will follow after being released at
this point. After you have made your prediction, play the animation. Was your prediction
correct? If not, what caused your error?

After being placed at this position, the test charge will oscillate back and forth between the two positive
charges.

b. Reset the applet and then drag the test charge to the approximate position of (1 m,
0.35 m). As before, write down a prediction for the path the charge will follow after being
released. If your prediction was incorrect, explain the flaw in your reasoning.

The charge will begin moving upward and to the left. Due to the changing electric field, the curve is
follows is not straight.

c. Repeat using Configuration B with the charge being released from the point (-0.5 m, 0.5
m).

The charge begins by moving upward and to the right. As it nears the negative charge, it experiences a
large attractive force which causes it to be pulled downward.

d. Repeat using Configuration B with the charge being released from the point (0 m, 1.3
m).

The charge continually oscillates halfway around the negative charge.

Physlet Problems

(23.7) 10 points  An electron is shot through a region of constant electric field (time is given in µsec (10^{-6}
s) and position is given in centimeters).

a. Which vector most closely shows the direction of the electric field?
Vector F (which points down and to the left) most closely shows the direction of the electric field.

b. What is the magnitude of the electric field?
Since the electric field is constant in the region, the electron’s acceleration is also constant. Therefore, we
can use the constant acceleration equations from PHY 120 to solve for the magnitude of this acceleration.
We note that the electron enters the electric field at a position of (0, 15.00) cm at time \( t = 1.30 \, \mu s \) with
an initial velocity of (0, -50.0) cm/\( \mu s \) and leaves the electric field at a position of (165, 15.00) cm at
time \( t = 4.63 \, \mu s \) with a final velocity of (100, 50.0) cm/\( \mu s \). Therefore, using \( \Delta \vec{x} = \vec{v}_i t + \frac{1}{2} \vec{a} t^2 \), we find
that the electron’s acceleration in the \( x \) direction is

\[
a_x = \frac{2(\Delta x + v_{ix}t)}{t^2}
= \frac{2(1.65 \, \text{m})}{(3.33 \times 10^{-6} \, \text{s})^2}
= 3.00 \times 10^{11} \, \text{m/s}^2.
\]
Similarly, the electron’s acceleration in the $y$ direction is

\[
a_y = \frac{2(\Delta y + v_{iy}t)}{t^2}
\]

\[
= \frac{2(-5.0 \times 10^5 \text{ m/s})}{(3.33 \times 10^{-6} \text{ s})} = 3.00 \times 10^{11} \text{ m/s}^2.
\]

Therefore, the magnitude of the electron’s acceleration is $a = \sqrt{a_x^2 + a_y^2} = 4.25 \times 10^{11} \text{ m/s}^2$. Finally, given the electron’s acceleration, we can find the magnitude of the responsible electric field using $F = ma = qE$

\[
E = \frac{m_e a}{q_e}
\]

\[
= \frac{(9.11 \times 10^{-31} \text{ kg})(4.25 \times 10^{11} \text{ m/s}^2)}{1.60 \times 10^{-19} \text{ C}} = 2.42 \text{ N/C}.
\]