CHAPTER 16

1. The number of electrons is
   $N = Q/e = (-30.0 \times 10^{-6}\ \mathrm{C})/(-1.60 \times 10^{-19}\ \mathrm{C/electrons}) =$ 1.88×10^{14} electrons.

2. The magnitude of the Coulomb force is
   $F = kQ_1Q_2/r^2$.
   If we divide the expressions for the two forces, we have
   $F_2/F_1 = (r_1/r_2)^2$;
   $F_2/(4.2 \times 10^{-2}\ \mathrm{N}) = (8)^2$, which gives $F_2 =$ 2.7 N.

3. The magnitude of the Coulomb force is
   $F = kQ_1Q_2/r^2$.
   If we divide the expressions for the two forces, we have
   $F_2/F_1 = (r_1/r_2)^2$;
   $3 = [(20.0\ \mathrm{cm})/r_2]^2$, which gives $r_2 =$ 11.5 cm.

4. The magnitude of the Coulomb force is
   $F = kQ_1Q_2/r^2$.
   If we divide the expressions for the two forces, we have
   $F_2/F_1 = (r_1/r_2)^2$;
   $F_2/(0.0200\ \mathrm{N}) = (150\ \mathrm{cm}/30.0\ \mathrm{cm})^2$, which gives $F_2 =$ 0.500 N.

5. The magnitude of the Coulomb force is
   $F = kQ_1Q_2/r^2$
   $= (9.0 \times 10^9\ \mathrm{N \cdot m^2/C^2})(26)(1.60 \times 10^{-19}\ \mathrm{C})(1.60 \times 10^{-19}\ \mathrm{C})/(1.5 \times 10^{-12}\ \mathrm{m})^2 =$ 2.7×10^{-3} N.

6. The magnitude of the Coulomb force is
   $F = kQ_1Q_2/r^2$
   $= (9.0 \times 10^9\ \mathrm{N \cdot m^2/C^2})(1.60 \times 10^{-19}\ \mathrm{C})(1.60 \times 10^{-19}\ \mathrm{C})/(5.0 \times 10^{-15}\ \mathrm{m})^2 =$ 9.2 N.

7. The magnitude of the Coulomb force is
   $F = kQ_1Q_2/r^2$
   $= (9.0 \times 10^9\ \mathrm{N \cdot m^2/C^2})(15 \times 10^{-6}\ \mathrm{C})(3.00 \times 10^{-3}\ \mathrm{C})/(0.40\ \mathrm{m})^2 =$ 2.5×10^3 N.

8. The number of excess electrons is
   $N = Q/e = (-60 \times 10^{-6}\ \mathrm{C})/(-1.60 \times 10^{-19}\ \mathrm{C/electrons}) =$ 3.8×10^{14} electrons.
   The mass increase is
   $Æm = Nm_e = (3.8 \times 10^{14}\ \mathrm{electrons})(9.11 \times 10^{-31}\ \mathrm{kg/electron}) =$ 3.4×10^{-16} kg.

9. Because the charge on the Earth can be considered to be at the center, we can use the expression for the force between two point charges. For the Coulomb force to be equal to the weight, we have
   $kQ^2/R^2 = mg$;

$(9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)Q^2/(6.38 \times 10^6 \text{ m})^2 = (1050 \text{ kg})(9.80 \text{ m/s}^2)$, which gives $Q =$ 6.8×10^3 C.

10. The number of molecules in 1.0 kg is

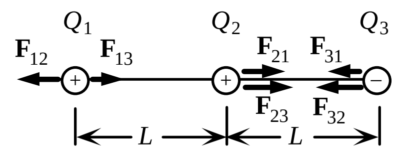
$N = [(1.0 \text{ kg})(10^3 \text{ g/kg})/(18 \text{ g/mol})](6.02 \times 10^{23} \text{ molecules/mol}) = 3.34 \times 10^{25}$ molecules.

Each molecule of H_2O contains 2(1) + 8 = 10 electrons. The charge of the electrons in 1.0 kg is

$q = (3.34 \times 10^{25} \text{ molecules})(10 \text{ electrons/molecule})(-1.60 \times 10^{-19} \text{ C/electron})$

$= -5.4 \times 10^7$ C.

11. Using the symbols in the figure, we find the magnitudes of the three individual forces:



$F_{12} = F_{21} = kQ_1Q_2/r_{12}^2 = kQ_1Q_2/L^2$

$= (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(70 \times 10^{-6} \text{ C})(48 \times 10^{-6} \text{ C})/(0.35 \text{ m})^2$

$= 2.47 \times 10^2$ N.

$F_{13} = F_{31} = kQ_1Q_3/r_{12}^2 = kQ_1Q_3/(2L)^2$

$= (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(70 \times 10^{-6} \text{ C})(80 \times 10^{-6} \text{ C})/[2(0.35 \text{ m})]^2$

$= 1.03 \times 10^2$ N.

$F_{23} = F_{32} = kQ_2Q_3/r_{12}^2 = kQ_2Q_3/L^2$

$= (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(48 \times 10^{-6} \text{ C})(80 \times 10^{-6} \text{ C})/(0.35 \text{ m})^2$

$= 2.82 \times 10^2$ N.

The directions of the forces are determined from the signs of the charges and are indicated on the diagram. For the net forces, we get

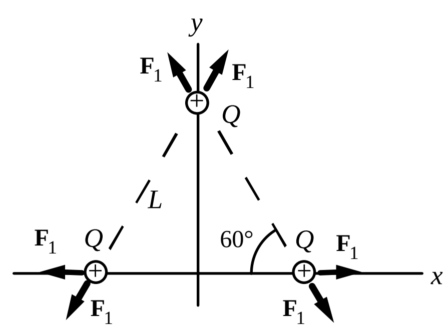
$F_1 = F_{13} - F_{12} = 1.03 \times 10^2 \text{ N} - 2.47 \times 10^2 \text{ N} =$ -1.4×10^2 N (left).

$F_2 = F_{21} - F_{23} = 2.47 \times 10^2 \text{ N} + 2.82 \times 10^2 \text{ N} =$ $+5.3 \times 10^2$ N (right).

$F_3 = -F_{31} - F_{32} = -1.03 \times 10^2 \text{ N} - 2.82 \times 10^2 \text{ N} =$ -3.9×10^2 N (left).

Note that the sum for the three charges is zero.

12. Because all the charges and their separations are equal, we find the magnitude of the individual forces:



$F_1 = kQQ/L^2 = kQ^2/L^2$

$= (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(11.0 \times 10^{-6} \text{ C})^2/(0.150 \text{ m})^2$

$= 48.4$ N.

The directions of the forces are determined from the signs of the charges and are indicated on the diagram.
For the forces on the top charge, we see that the horizontal components will cancel. For the net force, we have

$F = F_1 \cos 30° + F_1 \cos 30° = 2F_1 \cos 30°$

$= 2(48.4 \text{ N}) \cos 30°$

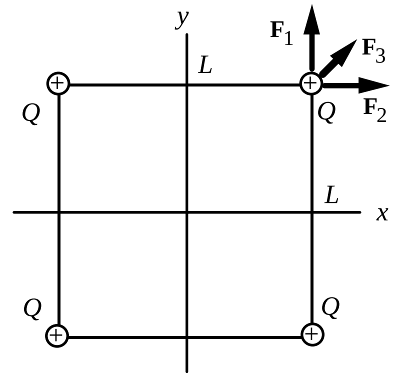
$= 83.8$ N up, or away from the center of the triangle.

From the symmetry each of the other forces will have the same magnitude and a direction away from the center: The net force on each charge is 83.8 N away from the center of the triangle.
Note that the sum for the three charges is zero.

13. We find the magnitudes of the individual forces on the charge at the upper right corner:

$F_1 = F_2 = kQQ/L^2 = kQ^2/L^2$
$= (9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2)(6.00 \times 10^{-3}\ \text{C})^2/(1.00\ \text{m})^2$
$= 3.24 \times 10^5\ \text{N}.$

$F_3 = kQQ/(L\tilde{A}2)^2 = kQ^2/2L^2$
$= (9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2)(6.00 \times 10^{-3}\ \text{C})^2/2(1.00\ \text{m})^2$
$= 1.62 \times 10^5\ \text{N}.$



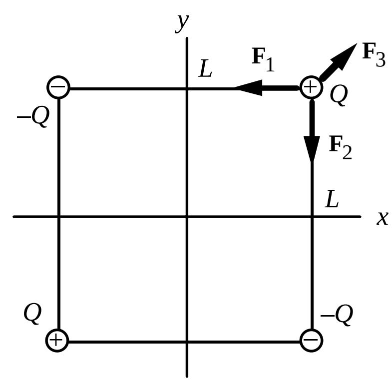
The directions of the forces are determined from the signs of the charges and are indicated on the diagram.
For the forces on the top charge, we see that the net force will be along the diagonal. For the net force, we have

$F = F_1 \cos 45° + F_2 \cos 45° + F_3$
$= 2(3.24 \times 10^5\ \text{N}) \cos 45° + 1.62 \times 10^5\ \text{N}$
$= 6.20 \times 10^5$ N along the diagonal, or away from the center of the square.

From the symmetry, each of the other forces will have the same magnitude and a direction away from the center: The net force on each charge is 6.20×10^5 N away from the center of the square.
Note that the sum for the three charges is zero.

14. Because the magnitudes of the charges and the distances have not changed, we have the same magnitudes of the individual forces on the charge at the upper right corner:

$F_1 = F_2 = kQQ/L^2 = 3.24 \times 10^5\ \text{N}.$
$F_3 = kQ^2/2L^2 = 1.62 \times 10^5\ \text{N}.$



The directions of the forces are determined from the signs of the charges and are indicated on the diagram.
For the forces on the top charge, we see that the net force will be along the diagonal. For the net force, we have

$F = - F_1 \cos 45° - F_2 \cos 45° + F_3$
$= - 2(3.24 \times 10^5\ \text{N}) \cos 45° + 1.62 \times 10^5\ \text{N}$
$= - 2.96 \times 10^5$ N along the diagonal, or toward the center of the square.

From the symmetry, each of the other forces will have the same magnitude and a direction toward the center: The net force on each charge is 2.96×10^5 N toward the center of the square.
Note that the sum for the three charges is zero.

15. For the two forces, we have

$F_{\text{electric}} = kq_1q_2/r_{12}^2 = ke^2/r^2$
$= (9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2)(1.6 \times 10^{-19}\ \text{C})^2/(0.53 \times 10^{-10}\ \text{m})^2 = 8.2 \times 10^{-8}\ \text{N}.$

$F_{\text{gravitational}} = Gm_1m_2/r^2$
$= (6.67 \times 10^{-11}\ \text{N} \cdot \text{m}^2/\text{kg}^2)(9.11 \times 10^{-31}\ \text{kg})(1.67 \times 10^{-27}\ \text{kg})/(0.53 \times 10^{-10}\ \text{m})^2$
$= 3.6 \times 10^{-47}\ \text{N}.$

The ratio of the forces is

$F_{\text{electric}}/F_{\text{gravitational}} = (8.2 \times 10^{-8}\ \text{N})/(3.6 \times 10^{-47}\ \text{N}) = 2.3 \times 10^{39}.$

16. Because the electrical attraction must provide the same force as the gravitational attraction, we equate the two forces:

$kQQ/r^2 = Gm_1m_2/r^2$;

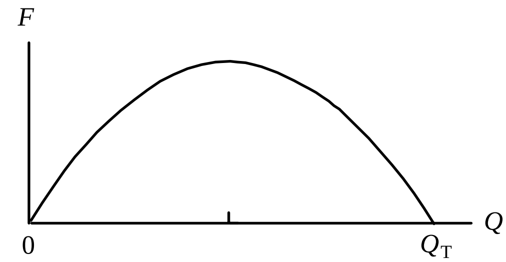
$(9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)Q^2 = (6.67 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(5.97 \times 10^{24}\ \text{kg})(7.35 \times 10^{22}\ \text{kg})$, which gives

$Q = 5.71 \times 10^{13}$ C.

17. If the separation is r and one charge is Q_1, the other charge will be $Q_2 = Q_T - Q_1$.

For the repulsive force, we have

$F = kQ_1Q_2/r^2 = kQ_1(Q_T - Q_1)/r^2$.



(*a*) If we plot the force as a function of Q_1, we see that the maximum occurs when

$Q_1 = !Q_T$,

which we would expect from symmetry, since we could interchange the two charges without changing the force.

(*b*) We see from the plot that the minimum occurs when either charge is zero:

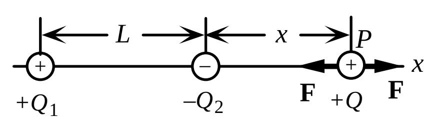
Q_1 (or Q_2) = 0.

18. The attractive Coulomb force provides the centripetal acceleration of the electron:

$ke^2/r^2 = mv^2/r$, or $r = ke^2/mv^2$;

$r = (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.60 \times 10^{-19}\ \text{C})^2/(9.11 \times 10^{-31}\ \text{kg})(1.1 \times 10^6\ \text{m/s})^2 = 2.1 \times 10^{-10}$ m.

19. If we place a positive charge, it will be repelled by the positive charge and attracted by the negative charge. Thus the third charge must be placed along the line of the charges, but not between them. For the net force to be zero, the magnitudes of the individual forces must be equal:



$F = kQ_1Q/r_1^2 = kQ_2Q/r_2^2$, or $Q_1/(L + x)^2 = Q_2/x^2$;

$(5.7\ \mu\text{C})/(0.25\ \text{m} + x)^2 = (3.5\ \mu\text{C})/x^2$, which gives $x = 0.91$ m, – 0.11 m.

The negative result corresponds to the position between the charges where the magnitudes and the directions are the same. Thus the third charge should be placed 0.91 m beyond the negative charge.

Note that we would have the same analysis if we used a negative charge.

20. If one charge is Q_1, the other charge will be $Q_2 = Q - Q_1$. For the force to be repulsive, the two charges must have the same sign. Because the total charge is positive, each charge will be positive. We account for this by considering the force to be positive:

$F = kQ_1Q_2/r^2 = kQ_1(Q - Q_1)/r^2$;

$12.0\ \text{N} = (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)Q_1(80.0 \times 10^{-6}\ \text{C} - Q_1)/(1.06\ \text{m})^2$, which is a quadratic equation:

$Q_1^2 - (80.0 \times 10^{-6}\ \text{C})Q_1 + 1.50 \times 10^{-9}\ \text{C}^2 = 0$, which gives $Q_1 = 50.0 \times 10^{-6}$ C, 30.0×10^{-6} C.

Note that, because the labels are arbitrary, we get the value of both charges.

For an attractive force, the charges must have opposite signs, so their product will be negative. We account for this by considering the force to be negative:

$F = kQ_1Q_2/r^2 = kQ_1(Q - Q_1)/r^2$;

$-12.0\ \text{N} = (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)Q_1(80.0 \times 10^{-6}\ \text{C} - Q_1)/(1.06\ \text{m})^2$, which is a quadratic equation:

$Q_1^2 - (80.0 \times 10^{-6}\ \text{C})Q_1 - 1.50 \times 10^{-9}\ \text{C}^2 = 0$, which gives $Q_1 = -15.7 \times 10^{-6}$ C, 95.7×10^{-6} C.

21. The acceleration is produced by the force from the electric field:
    $F = qE = ma$;
    $(1.60 \times 10^{-19}\ \text{C})(600\ \text{N/C}) = (9.11 \times 10^{-31}\ \text{kg})a$, which gives $a =$ $1.05 \times 10^{14}\ \text{m/s}^2$.
    Because the charge on the electron is negative, the direction of force, and thus the acceleration, is opposite to the direction of the electric field.
    The direction of the acceleration is independent of the velocity.

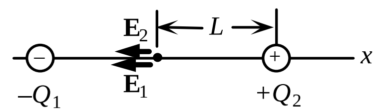
22. If we take the positive direction to the east, we have
    $F = qE = (-1.60 \times 10^{-19}\ \text{C})(+3500\ \text{N/C}) = -5.6 \times 10^{-16}\ \text{N}$, or 5.6×10^{-16} N (west).

23. If we take the positive direction to the south, we have
    $F = qE$;
    $3.2 \times 10^{-14}\ \text{N} = (+1.60 \times 10^{-19}\ \text{C})E$, which gives $E =$ $+2.0 \times 10^{5}$ N/C (south).

24. If we take the positive direction up, we have
    $F = qE$;
    $+8.4\ \text{N} = (-8.8 \times 10^{-6}\ \text{C})E$, which gives $E =$ $+9.5 \times 10^{5}$ N/C (up).

25. The electric field above a positive charge will be away from the charge, or up.
    We find the magnitude from
    $E = kQ/r^2$
    $= (9.0 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)(33.0 \times 10^{-6}\ \text{C})/(0.300\ \text{m})^2 =$ 3.30×10^{6} N/C (up).

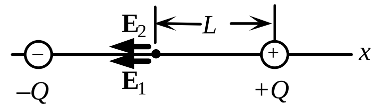
26. The directions of the fields are determined from the signs of the charges and are indicated on the diagram. The net electric field will be to the left. We find its magnitude from



    $E = kQ_1/L^2 + kQ_2/L^2 = k(Q_1 + Q_2)/L^2$
    $= (9.0 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)(8.0 \times 10^{-6}\ \text{C} + 6.0 \times 10^{-6}\ \text{C})/(0.020\ \text{m})^2$
    $= 3.2 \times 10^{8}\ \text{N/C}$.
    Thus the electric field is 3.2×10^{8} N/C toward the negative charge.

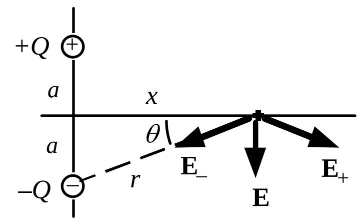
27. The acceleration is produced by the force from the electric field:
    $F = qE = ma$;
    $(-1.60 \times 10^{-19}\ \text{C})E = (9.11 \times 10^{-31}\ \text{kg})(125\ \text{m/s}^2)$, which gives $E = -7.12 \times 10^{-10}\ \text{N/C}$.
    Because the charge on the electron is negative, the direction of force, and thus the acceleration, is opposite to the direction of the electric field, so the electric field is 7.12×10^{-10} N/C (south).

28. The directions of the fields are determined from the signs of the charges and are in the same direction, as indicated on the diagram.
    The net electric field will be to the left. We find its magnitude from



    $E = kQ_1/L^2 + kQ_2/L^2 = k(Q + Q)/L^2 = 2kQ/L^2$
    $1750\ \text{N/C} = 2(9.0 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)Q/(0.080\ \text{m})^2$, which gives
    $Q = 6.2 \times 10^{-10}$ C.

29. From the diagram, we see that the electric fields produced by the charges will have the same magnitude, and the resultant field will be down. The distance from the origin is x, so we have



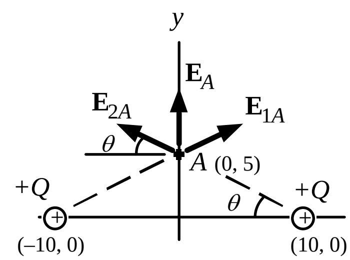
$E_+ = E_- = kQ/r^2 = kQ/(a^2 + x^2)$.

From the symmetry, for the magnitude of the electric field we have

$E = 2E_+ \sin\theta = 2[kQ/(a^2 + x^2)][a/(a^2 + x^2)^{1/2}]$

$= 2kQa/(a^2 + x^2)^{3/2}$ parallel to the line of the charges.

30. At point A, from the diagram, we see that the electric fields produced by the charges will have the same magnitude, and the resultant field will be up. We find the angle θ from



$\tan\theta = (0.050 \text{ m})/(0.100 \text{ m}) = 0.500$, or $\theta = 26.6°$.

For the magnitudes of the individual fields we have

$E_{1A} = E_{2A} = kQ/r_A^2$

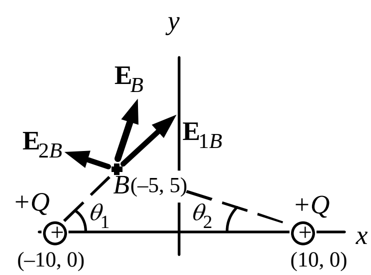
$= (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(9.0 \times 10^{-6} \text{ C})/[(0.100 \text{ m})^2 + (0.050 \text{ m})^2]$

$= 6.48 \times 10^6 \text{ N/C}$.

From the symmetry, the resultant electric field is

$E_A = 2E_{1A} \sin\theta = 2(6.48 \times 10^6 \text{ N/C}) \sin 26.6° =$ 5.8×10^6 N/C up.

For point B we find the angles for the directions of the fields from



$\tan\theta_1 = (0.050 \text{ m})/(0.050 \text{ m}) = 1.00$, or $\theta_1 = 45.0°$.

$\tan\theta_2 = (0.050 \text{ m})/(0.150 \text{ m}) = 0.333$, or $\theta_2 = 18.4°$.

For the magnitudes of the individual fields we have

$E_{1B} = kQ/r_{1B}^2$

$= (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(9.0 \times 10^{-6} \text{ C})/[(0.050 \text{ m})^2 + (0.050 \text{ m})^2]$

$= 1.62 \times 10^7 \text{ N/C}$.

$E_{2B} = kQ/r_{2B}^2$

$= (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(9.0 \times 10^{-6} \text{ C})/[(0.150 \text{ m})^2 + (0.050 \text{ m})^2]$

$= 3.24 \times 10^6 \text{ N/C}$.

For the components of the resultant field we have

$E_{Bx} = E_{1B} \cos\theta_1 - E_{2B} \cos\theta_2 = (1.62 \times 10^7 \text{ N/C}) \cos 45.0° - (3.24 \times 10^6 \text{ N/C}) \cos 18.4° = 8.38 \times 10^6 \text{ N/C}$;

$E_{By} = E_{1B} \sin\theta_1 - E_{2B} \sin\theta_2 = (1.62 \times 10^7 \text{ N/C}) \sin 45.0° - (3.24 \times 10^6 \text{ N/C}) \sin 18.4° = 1.25 \times 10^7 \text{ N/C}$.

We find the direction from

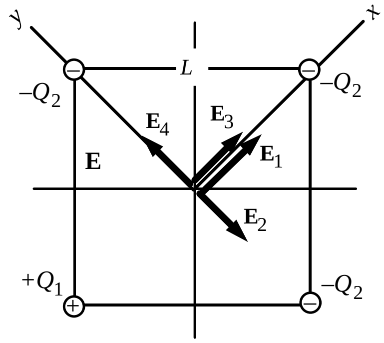
$\tan\theta_B = E_{By}/E_{Bx} = (1.25 \times 10^7 \text{ N/C})/(8.38 \times 10^6 \text{ N/C}) = 1.49$, or $\theta_1 = 56.2°$.

We find the magnitude from

$E_B = E_{Bx}/\cos\theta_B = (8.38 \times 10^6 \text{ N/C})/\cos 56.2° = 1.51 \times 10^7 \text{ N/C}$.

Thus the field at point B is 1.5×10^7 N/C 56° above the horizontal.

31. The directions of the individual fields will be along the diagonals of the square, as shown. We find the magnitudes of the individual fields:



$E_1 = kQ_1/(L/\text{Ã}2)^2 = 2kQ_1/L^2$
$= 2(9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(45.0 \times 10^{-6}\ \text{C})/(0.60\ \text{m})^2$
$= 2.25 \times 10^6\ \text{N/C}.$

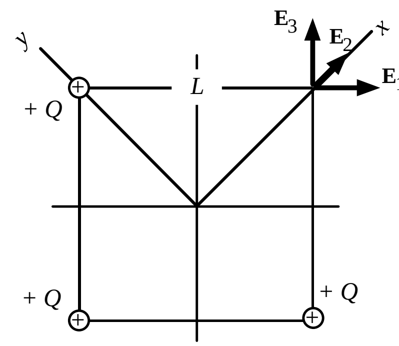
$E_2 = E_3 = E_4 = kQ_2/(L/\text{Ã}2)^2 = 2kQ_2/L^2$
$= 2(9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(31.0 \times 10^{-6}\ \text{C})/(0.60\ \text{m})^2$
$= 1.55 \times 10^6\ \text{N/C}.$

From the symmetry, we see that the resultant field will be along the diagonal shown as the x-axis. For the net field, we have

$E = E_1 + E_3 = 2.25 \times 10^6\ \text{N/C} + 1.55 \times 10^6\ \text{N/C} = 3.80 \times 10^6\ \text{N/C}.$

Thus the field at the center is 3.80×10^6 N/C away from the positive charge.

32. The directions of the individual fields are shown in the figure. We find the magnitudes of the individual fields:



$E_1 = E_3 = kQ/L^2$
$= (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(2.80 \times 10^{-6}\ \text{C})/(1.00\ \text{m})^2$
$= 2.52 \times 10^4\ \text{N/C}.$

$E_2 = kQ/(L\text{Ã}2)^2 = !kQ_2/L^2$
$= !(9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(2.80 \times 10^{-6}\ \text{C})/(1.00\ \text{m})^2$
$= 1.26 \times 10^4\ \text{N/C}.$

From the symmetry, we see that the resultant field will be along the diagonal shown as the x-axis. For the net field, we have

$E = 2E_1 \cos 45° + E_2$
$= 2(2.52 \times 10^4\ \text{N/C}) \cos 45° + 1.26 \times 10^4\ \text{N/C}$
$= 4.82 \times 10^4\ \text{N/C}.$

Thus the field at the unoccupied corner is
4.82×10^4 N/C away from the opposite corner.

33. (*a*) The directions of the individual fields are shown in the figure.

We find the magnitudes of the individual fields:

$E_1 = E_2 = kQ/L^2$.

For the components of the resultant field we have

$E_x = -E_2 \sin 60° = -0.866kQ/L^2$;

$E_y = -E_1 - E_2 \cos 60° = -kQ/L^2 - 0.500kQ/L^2 = -1.50kQ/L^2$.

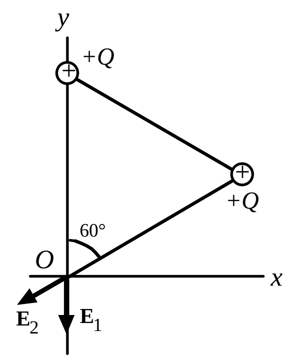
We find the direction from

$\tan \theta = E_y/E_x = (-1.50kQ/L^2)/(-0.866kQ/L^2) = 1.73$, or $\theta = 60°$.

We find the magnitude from

$E = E_x/\cos \theta = (0.866kQ/L^2)/\cos 60° = 1.73kQ/L^2$.

Thus the field is $1.73kQ/L^2$ 60° below the – x-axis.



(*b*) The directions of the individual fields are shown in the figure.

The magnitudes of the individual fields will be the same:

$E_1 = E_2 = kQ/L^2$.

For the components of the resultant field we have

$E_x = +E_2 \sin 60° = +0.866kQ/L^2$;

$E_y = -E_1 + E_2 \cos 60° = -kQ/L^2 + 0.500kQ/L^2 = -0.500kQ/L^2$.

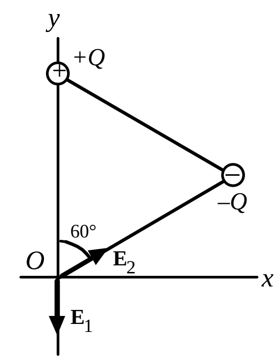
We find the direction from

$\tan \theta = E_y/E_x = (-0.500kQ/L^2)/(+0.866kQ/L^2) = -0.577$, or $\theta = -30°$.

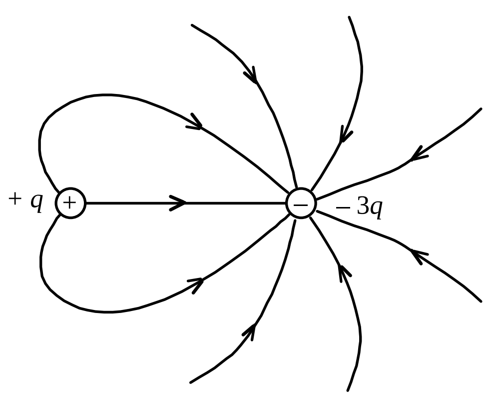
We find the magnitude from

$E = E_x/\cos \theta = (0.866kQ/L^2)/\cos 30° = kQ/L^2$.

Thus the field is kQ/L^2 30° below the + x-axis.



34.



35. The acceleration is produced by the force from the electric field:

$F = qE = ma$;

$(1.60 \times 10^{-19}\ \text{C})E = (1.67 \times 10^{-27}\ \text{kg})(1 \times 10^6)(9.80\ \text{m/s}^2)$, which gives $E =$ 0.10 N/C.

36. If we let x be the distance from the center of the Earth, we have

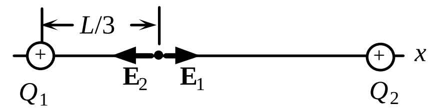
$GM_{\text{Moon}}/(D - x)^2 = GM_{\text{Earth}}/x^2 = 81GM_{\text{Moon}}/x^2$, or $81(D - x)^2 = x^2$.

When we take the square root of both sides, we get

$x = 9D/10 = 9(3.80 \times 10^5\ \text{km})/10 =$ 3.42×10^5 km from the center of the Earth.

Note that taking a negative square root gives $x = 9D/8$, the point on the other side of the Moon where the magnitudes are equal, but the fields have the same direction.

37. For the electric field to be zero, the individual fields must have opposite directions, so the two charges must have the same sign. For the net field to be zero, the magnitudes of the individual fields must be equal:



$E = kQ_1/r_1^2 = kQ_2/r_2^2$, or $Q_1/(@L)^2 = Q_2/(\%L)^2$,

which gives $Q_2 = 4Q_1$.

38. (*a*) We find the acceleration produced by the electric field:

$F = qE = ma$;

$(1.60 \times 10^{-19}\ \text{C})(1.85 \times 10^4\ \text{N/C}) = (9.11 \times 10^{-31}\ \text{kg})a$, which gives $a = 3.24 \times 10^{15}\ \text{m/s}^2$.

Because the field is constant, the acceleration is constant, so we find the speed from

$v^2 = v_0^2 + 2ax = 0 + 2(3.24 \times 10^{15}\ \text{m/s}^2)(0.0120\ \text{m})$, which gives $v = 8.83 \times 10^6\ \text{m/s}$.

(*b*) For the ratio of the two forces, we have

$mg/qE = (9.11 \times 10^{-31}\ \text{kg})(9.80\ \text{m/s}^2)/(1.60 \times 10^{-19}\ \text{C})(1.85 \times 10^4\ \text{N/C}) = 3.0 \times 10^{-15}$.

Thus $mg \ll qE$.

39. (*a*) The acceleration of the electron, and thus the force produced by the electric field, must be opposite its velocity. Because the electron has a negative charge, the direction of the electric field will be opposite that of the force, so the direction of the electric field is

in the direction of the velocity, to the right.

(*b*) Because the field is constant, the acceleration is constant, so we find the required acceleration from

$v^2 = v_0^2 + 2ax$;

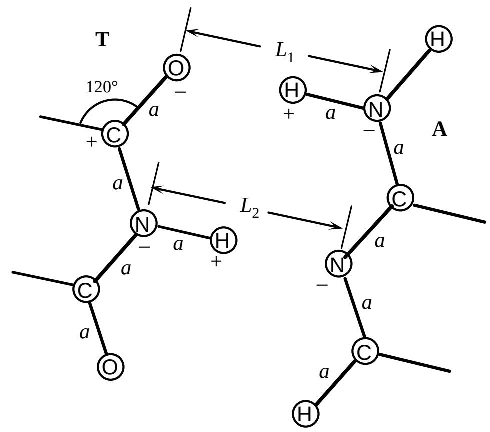
$0 = [0.01(3.0 \times 10^8\ \text{m/s})]^2 + 2a(0.050\ \text{m})$, which gives $a = -9.00 \times 10^{13}\ \text{m/s}^2$.

We find the electric field from

$F = qE = ma$;

$(1.60 \times 10^{-19}\ \text{C})E = (9.11 \times 10^{-31}\ \text{kg})(9.00 \times 10^{13}\ \text{m/s}^2)$, which gives $E = 5.1 \times 10^2\ \text{N/C}$.

40. (*a*) To estimate the force between a thymine and an adenine, we assume that only the atoms with an indicated charge make a contribution. Because all charges are fractions of the electronic charge, we let



$Q_H = Q_N = f_1 e$, and $Q_O = Q_C = f_2 e$.

A convenient numerical factor will be

$ke^2/(10^{-10}\text{ m/Å})^2$

$= (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(1.60 \times 10^{-19}\text{ C})^2/(10^{-10}\text{ m/Å})^2$

$= 2.30 \times 10^{-8}\text{ N}\cdot\text{Å}^2.$

For the first contribution we find the force for the bond of the oxygen on the thymine with the H-N pair on the adenine. From Newton's third law, we know that the force on one must equal the force on the other. We find the attractive force on the oxygen:

$F_O = kQ_O\{[Q_H/(L_1 - a)^2] - (Q_N/L_1^2)\}$

$= ke^2 f_2 f_1\{[1/(L_1 - a)^2] - (1/L_1^2)\}$

$= (2.30 \times 10^{-8}\text{ N}\cdot\text{Å}^2)(0.4)(0.2)\{[1/(2.80\text{ Å} - 1.00\text{ Å})^2] - [1/(2.80\text{ Å})^2]\} = 3.33 \times 10^{-10}\text{ N}.$

For the force for the lower bond of the H-N pair on the thymine with the nitrogen on the adenine, we find the attractive force on the nitrogen:

$F_N = kQ_N\{[Q_H/(L_2 - a)^2] - (Q_N/L_2^2)\} = ke^2 f_1 f_1\{[1/(L_2 - a)^2] - (1/L_2^2)\}$

$= (2.30 \times 10^{-8}\text{ N}\cdot\text{Å}^2)(0.2)(0.2)\{[1/(3.00\text{ Å} - 1.00\text{ Å})^2] - [1/(3.00\text{ Å})^2]\} = 1.28 \times 10^{-10}\text{ N}.$

There will be a repulsive force between the oxygen of the first bond and the nitrogen of the second bond. To find the separation of the two, we note that the distance between the two nitrogens of the adenine, which is approximately perpendicular to L_1, is $2a\cos 30° = 1.73a$. We find the magnitude of this force from

$F_{O\text{-}N} = kQ_O\{Q_N/[L_1^2 + (1.73a)^2]\} = ke^2 f_2 f_1\{1/[L_1^2 + (1.73a)^2]\}$

$= (2.30 \times 10^{-8}\text{ N}\cdot\text{Å}^2)(0.4)(0.2)\{1/[(2.80\text{ Å})^2 + (1.73\text{ Å})^2]\} = 1.7 \times 10^{-10}\text{ N}.$

We find the angle that this force makes with the line of the other bonds from

$\tan\theta = 1.73a/L_1 = 1.73\text{ Å}/2.89\text{ Å} = 0.62$, or $\theta = 32°$.

Thus the component that contributes to the bond is $(1.7 \times 10^{-10}\text{ N})\cos 32° = 1.4 \times 10^{-10}\text{ N}$.

The other contribution will be from the carbon atom on the thymine. Because the distance is slightly greater and there will be attraction to the nitrogens and repulsion from the hydrogen, we neglect this contribution.

Thus the estimated net bond is $3.33 \times 10^{-10}\text{ N} + 1.28 \times 10^{-10}\text{ N} - 1.4 \times 10^{-10}\text{ N} \approx 3 \times 10^{-10}\text{ N}.$

(*b*) To estimate the net force between a cytosine and a guanine, we note that there are two oxygen bonds, one nitrogen bond, and one repulsive O-N force. We neglect the other forces because they involve cancellation from the involvement of both hydrogen and nitrogen. If we ignore the small change in distances, we have

$2(3.33 \times 10^{-10}\text{ N}) + 1.28 \times 10^{-10}\text{ N} - 1.4 \times 10^{-10}\text{ N} \approx 7 \times 10^{-10}\text{ N}.$

(*c*) The total force for the DNA molecule is

$(3 \times 10^{-10}\text{ N} + 7 \times 10^{-10}\text{ N})(10^5\text{ pairs}) \approx 10^{-4}\text{ N}.$

41. When we equate the two forces, we have

$mg = ke^2/r^2;$

$(9.11 \times 10^{-31}\text{ kg})(9.80\text{ m/s}^2) = (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(1.60 \times 10^{-19}\text{ C})^2/r^2$, which gives $r = 5.08\text{ m}$.

42. Because a copper atom has 29 electrons, we find the number of electrons in the penny from

$N = [(3.0\text{ g})/(63.5\text{ g/mol})](6.02 \times 10^{23}\text{ atoms/mol})(29\text{ electrons/atom}) = 8.24 \times 10^{23}\text{ electrons}.$

We find the fractional loss from

$Æq/q$ = $(42 \times 10^{-6}$ C$)/(8.24 \times 10^{23}$ electrons$)(1.6 \times 10^{-19}$ C/electron$)$ = 3.2×10^{-10}.

43. The weight must be balanced by the force from the electric field:

$mg = qE$;

$(1.67 \times 10^{-27}\ \text{kg})(9.80\ \text{m/s}^2) = (1.60 \times 10^{-19}\ \text{C})E$, which gives $E =$ 1.02×10^{-7} N/C (up).

44. Because we can treat the charge on the Earth as a point charge at the center, we have

$E = kQ/r^2$;

$150\ \text{N/C} = (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)Q/(6.38 \times 10^6\ \text{m})^2$, which gives $Q =$ 6.8×10^5 C.

Because the field points toward the center, the charge must be negative.

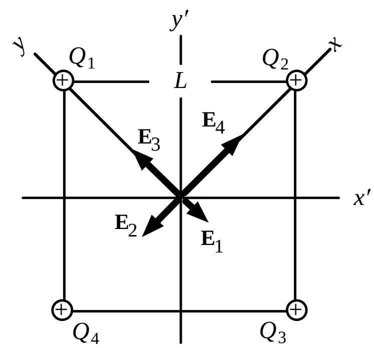
45. The weight must be balanced by the force from the electric field:

$mg = \rho 9^1 r^3 g = NeE$;

$(1000\ \text{kg/m}^3)9^1(1.8 \times 10^{-5}\ \text{m})^3(9.80\ \text{m/s}^2) = N(1.60 \times 10^{-19}\ \text{C})(150\ \text{N/C})$,

which gives $N =$ 1.0×10^7 electrons.

46. The directions of the individual fields will be along the diagonals of the square, as shown. All distances are the same. We find the magnitudes of the individual fields:



$E_1 = kQ_1/(L/\text{Ã}2)^2 = 2kQ_1/L^2$

$= 2(9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.0 \times 10^{-6}\ \text{C})/(0.25\ \text{m})^2$

$= 2.88 \times 10^5\ \text{N/C}$.

$E_2 = kQ_2/(L/\text{Ã}2)^2 = 2E_1 = 2(2.88 \times 10^5\ \text{N/C}) = 5.76 \times 10^5\ \text{N/C}$.

$E_3 = kQ_3/(L/\text{Ã}2)^2 = 3E_1 = 3(2.88 \times 10^5\ \text{N/C}) = 8.64 \times 10^5\ \text{N/C}$.

$E_4 = kQ_4/(L/\text{Ã}2)^2 = 4E_1 = 4(2.88 \times 10^5\ \text{N/C}) = 11.52 \times 10^5\ \text{N/C}$.

We simplify the vector addition by using the xy-coordinate system shown. For the components of the resultant field we have

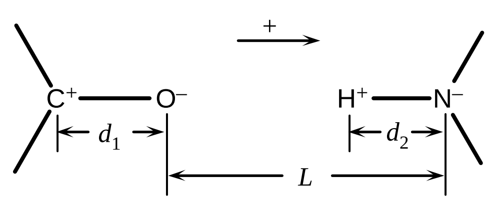
$E_x = E_4 - E_2 = 11.52 \times 10^5\ \text{N/C} - 5.76 \times 10^5\ \text{N/C} = 5.76 \times 10^5\ \text{N/C}$;

$E_y = E_3 - E_1 = 8.64 \times 10^5\ \text{N/C} - 2.88 \times 10^5\ \text{N/C} = 5.76 \times 10^5\ \text{N/C}$.

Thus we see that the resultant will be in the y'-direction:

$E = 2E_x \cos 45° = 2(5.76 \times 10^5\ \text{N/C}) \cos 45° =$ 8.1×10^5 N/C up.

47. We find the force between the groups by finding the force on the CO group from the HN group. A convenient numerical factor will be



$ke^2/(10^{-9}\ \text{m/nm})^2$

$= (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.60 \times 10^{-19}\ \text{C})^2/(10^{-9}\ \text{m/nm})^2$

$= 2.30 \times 10^{-10}\ \text{N}\cdot\text{nm}^2$.

For the forces on the atoms, we have

$F_O = kQ_O\{[Q_H/(L - d_2)^2] - (Q_N/L^2)\} = ke^2 f_O f_H\{[1/(L - d_2)^2] - (1/L^2)\}$

$= (2.30 \times 10^{-10}\ \text{N}\cdot\text{nm}^2)(0.4)(0.2)\{[1/(0.28\ \text{nm} - 0.10\ \text{nm})^2] - [1/(0.28\ \text{nm})^2]\} = 3.33 \times 10^{-10}\ \text{N}$.

$F_C = kQ_C\{[Q_N/(L + d_1)^2] - Q_H/(L + d_1 - d_2)^2]\} = ke^2 f_C f_N\{[1/(L + d_1)^2] - [1/(L + d_1 - d_2)^2]\}$

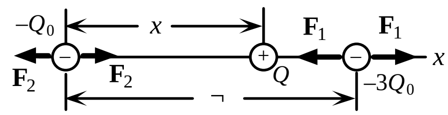
$= (2.30 \times 10^{-10}\ \text{N}\cdot\text{nm}^2)(0.4)(0.2)\{[1/(0.28\ \text{nm} + 0.12\ \text{nm})^2] - [1/(0.28\ \text{nm} + 0.12\ \text{nm} - 0.10\ \text{nm})^2]\}$

$= - 8.94 \times 10^{-11}\ \text{N}$.

Thus the net force is

$F = F_O + F_C = 3.33 \times 10^{-10}\ \text{N} - 8.94 \times 10^{-11}\ \text{N} =$ 2.4×10^{-10} N (attraction).

48. Because the charges have the same sign, they repel each other. The force from the third charge must balance the repulsive force for each charge, so the third charge must be positive and between the two negative charges. For each of the negative charges, we have



Q_0: $kQ_0Q/x^2 = kQ_0(3Q_0)/¬^2$, or $¬^2Q = 3x^2Q_0$;

$3Q_0$: $k3Q_0Q/(¬ - x)^2 = kQ_0(3Q_0)/¬^2$, or $¬^2Q = (¬ - x)^2Q_0$.

Thus we have

$3x^2 = (¬ - x)^2$, which gives $x = -1.37¬, + 0.366¬$.

Because the positive charge must be between the charges, it must be $0.366¬$ from Q_0. When we use this value in one of the force equations, we get

$Q = 3(0.366¬)^2Q_0/¬^2 = 0.402Q_0$.

Thus we place a charge of $0.402Q_0$ $0.366¬$ from Q_0.

Note that the force on the middle charge is also zero.

49. Because the charge moves in the direction of the electric field, it must be positive.

We find the angle of the string from the dimensions:

$\cos\theta = (0.49\text{ m})/(0.50\text{ m}) = 0.98$, or $\theta = 11.5°$.

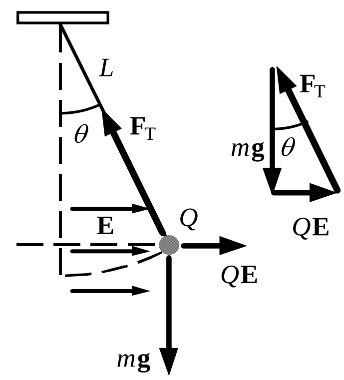
Because the charge is in equilibrium, the resultant force is zero.

We see from the force diagram that

$\tan\theta = QE/mg$;

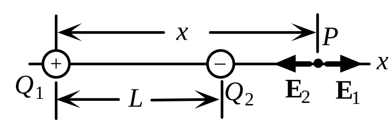
$\tan 11.5° = Q(9200\text{ N/C})/(1.0 \times 10^{-3}\text{ kg})(9.80\text{ m/s}^2)$,

which gives $Q = 2.2 \times 10^{-7}$ C.



50. Because the charges have opposite signs, the location where the electric field is zero must be outside the two charges, as shown.

The fields from the two charges must balance:



$kQ_1/x^2 = kQ_2/(L - x)^2$;

$(2.5 \times 10^{-5}\text{ C})/x^2 = (5.0 \times 10^{-6}\text{ C})/(2.0\text{ m} - x)^2$,

which gives $x = 1.4$ m, 3.6 m.

Because 1.4 m is between the charges, the location is

3.6 m from the positive charge, and 1.6 m from the negative charge.

51. (*a*) The force is opposite to the direction of the electron. We find the acceleration produced by the electric field:

$-qE = ma$;

$-(1.60 \times 10^{-19}\text{ C})(7.7 \times 10^3\text{ N/C}) = (9.11 \times 10^{-31}\text{ kg})a$, which gives $a = -1.35 \times 10^{15}\text{ m/s}^2$.

Because the field is constant, the acceleration is constant, so we find the distance from

$v^2 = v_0^2 + 2ax$;

$0 = (1.5 \times 10^6\text{ m/s})^2 + 2(-1.35 \times 10^{15}\text{ m/s}^2)x$, which gives $x = 8.3 \times 10^{-4}\text{ m} =$ 0.83 mm.

(*b*) We find the time from

$x = v_0t + !at^2$;

$0 = (1.5 \times 10^6\text{ m/s})t + !(-1.35 \times 10^{15}\text{ m/s}^2)t^2$,

which gives $t = 0$ (the starting time), and 2.2×10^{-9} s = 2.2 ns.

52. The angular frequency of the SHM is

$\omega = (k/m)^{1/2} = [(126\text{ N/m})/(0.800\text{ kg})]^{1/2} = 12.5\text{ s}^{-1}$.

If we take down as positive, with respect to the equilibrium position, the ball will start at maximum displacement, so the position as a function of time is

$x = A\cos(\omega t) = (0.0500\text{ m})\cos[(12.5\text{ s}^{-1})t]$.

Because the charge is negative, the electric field at the table will be up and the distance from the table is

$r = H - x = 0.150\text{ m} - (0.0500\text{ m})\cos[(12.5\text{ s}^{-1})t]$.

The electric field is

$E = kQ/r^2 = (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(3.00 \times 10^{-6}\text{ C})/\{0.150\text{ m} - (0.0500\text{ m})\cos[(12.5\text{ s}^{-1})t]\}^2$

$= (1.08 \times 10^7\text{ N/C})/\{3 - \cos[(12.5\text{ s}^{-1})t]\}^2$ up.

53. We consider the forces on one ball. (The other will be the same except for the reversal.) The separation of the charges is

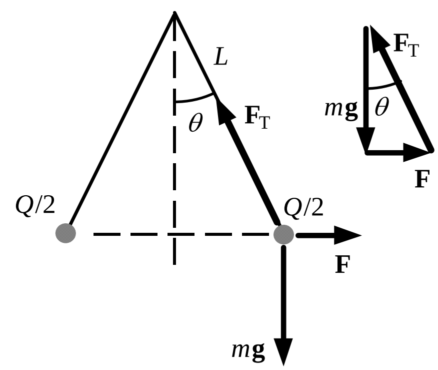
$r = 2L\sin 30° = 2(0.70\text{ m})\sin 30° = 0.70\text{ m}$.

From the equilibrium force diagram, we have

$\tan\theta = F/mg = [k(!Q)(!Q)/r^2]/mg$;

$\tan 30° = ((9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)Q^2/(0.70\text{ m})^2(24 \times 10^{-3}\text{ kg})(9.80\text{ m/s}^2)$,

which gives $Q = 5.4 \times 10^{-6}\text{ C} = 5.4\ \mu\text{C}$.



54. The pea will discharge when the electric field at the surface exceeds the breakdown field. Because we can treat the charge on the pea as a point charge at the center, we have

$E = kQ/r^2$;

$3 \times 10^6\text{ N/C} = (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)Q/(0.375 \times 10^{-2}\text{ m})^2$, which gives $Q = 5 \times 10^{-9}\text{ C}$.

55. We find the electric field at the location of Q_1 due to the plates and Q_2. For the field of Q_2 we have

$E_2 = kQ_2/x^2$

$= (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(1.3 \times 10^{-6}\text{ C})/(0.34\text{ m})^2$

$= 1.01 \times 10^5\text{ N/C}$ (left).

The field from the plates is to the right, so we have

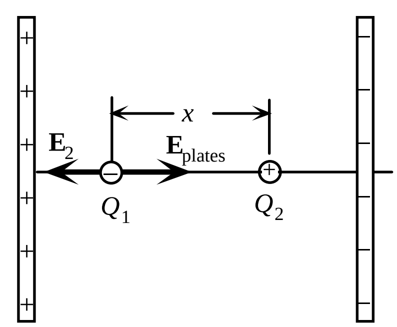
$E_{net} = E_{plates} - E_2$

$= 73{,}000\text{ N/C} - 1.01 \times 10^5\text{ N/C} = -2.8 \times 10^5\text{ N/C}$ (left).

For the force on Q_1, we have

$F_1 = Q_1E_{net} = (-6.7 \times 10^{-6}\text{ C})(-2.8 \times 10^5\text{ N/C})$

$= +0.19\text{ N}$ (right).



56. We take up as the positive direction and assume that E is up. From the equilibrium force diagram, we have

$F_T + QE = mg;$

$5.67 \text{ N} + (0.340 \times 10^{-6} \text{ C})E = (0.210 \text{ kg})(9.80 \text{ m/s}^2),$

which gives $E =$ -1.06×10^7 N/C (down).