1. Point charge $q_1 = 3.0$ nC is located at the origin and point charge $q_2 = -4.0$ nC is located at (2.0 m, 0). (a) Determine the force on q_1. (b) Determine the force on q_2.

2. Point charge $q_1 = 3.00$ nC is located at the origin and point charge $q_2 = 2.00$ nC is located at (0.100 m, 0). (a) Determine the net electrostatic force on $q_3 = 4.00$ nC located at (3.00 m, 0). (b) Repeat, taking charges 1 and 2 to be a single charge.

3. Point charge $q_1 = 5.0$ nC is located at the origin and point charge $q_2 = -5.0$ nC is located at (0, 3.0 m). Determine the net force on a third point charge $q_3 = 2.0$ nC if it is located at: (a) (0, 2.0 m), (b) (2.0 m, 0), or (c) (2.0 m, 1.5 m).

4. A charged pith ball of mass 0.15 g dangles from a string and is attracted to a sphere with charge −2.0 μC. It "floats" in equilibrium with the string tilted 20.0° from vertical when located 0.40 m from the center of the sphere. (a) Find the charge on the pith ball. (b) Find the number of excess or deficit electrons on the pith ball.

5. Two protons are separated by 3.2 fm. Which is greater – gravitational attraction or electrical repulsion?

6. A neutral pith ball with diameter 1.0 cm is located 0.30 m from the center of a sphere with charge −2.5 μC. Because of induction, the pith ball experiences a net attraction of 0.10 mN. Estimate the amount of charge induced "on each side" of the pith ball's metallic coating.

7. Two oppositely charged point objects, $-q$ and nq are separated by distance a. Determine an expression for the position at which a third point charge could be placed and experience a net electrostatic force of zero.

8. Three point charges are situated in the form of an equilateral triangle with sides of length a. (a) If all three charges are equal to q, determine the net force on any one of the three. (b) If one of the charges is $-q$ and the others are each q, determine the net force on each.

9. A thin rod of length L has a uniform charge Q. Determine the force on a point charge q located a distance d from one end of the rod (along the axis of the rod).

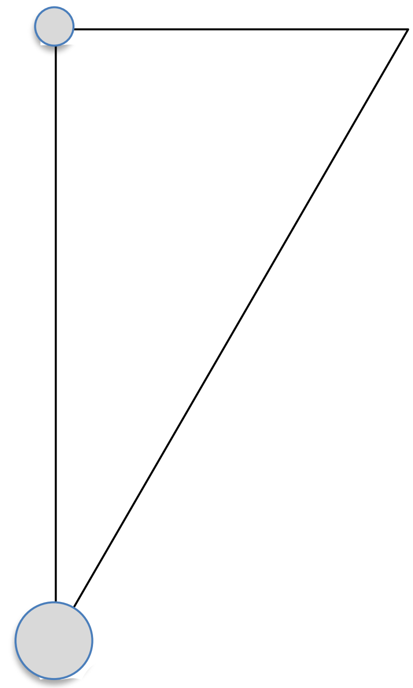
10. An “electron gun” produces an electric field of 90.0 kN/C in a region between two parallel metal plates separated by 0.50 cm. (a) Determine the amount of force acting on the electron ($q = 1.602 \times 10^{-19}$ C, $m = 9.11 \times 10^{-31}$ kg). (b) Determine its acceleration. (c) Determine the speed acquired by the electron assuming it starts from rest at one plate. (d) Repeat for a proton ($m = 1.67 \times 10^{-27}$ kg) from the same “gun”.

11. A uniform electric field of 150 N/C downward exists near the surface of the Earth. Suppose an electron is “launched” from the end of a TV picture tube with a horizontal speed 2.0×10^{7} m/s and travels a horizontal distance of 20.0 cm before impacting the screen. (a) Determine the acceleration of the electron. (b) Determine the vertical deflection that occurs before the electron hits the screen.

12. An oil drop in Millikan's experiment is observed to fall with a terminal velocity of 0.250 mm/s in the presence of air resistance of $\mathbf{F} = -k\mathbf{v}$, where $k = 1.60 \times 10^{-10}$ kg/s. This drop is then subjected to a downward electric field of 1.00×10^{5} N/C and observed to rise with a terminal velocity of 0.0500 mm/s. Determine the oil drop's: (a) mass, (b) charge, (c) number of excess/deficit electrons.

13. Seventeen equal point charges q are arranged in a circle of radius R. The charges are equally spaced along the circumference. If one of the point charges is removed, what is the electric field at the center of the circle due to the presence of the remaining sixteen charges?

14. Point charges q and $4q$ are separated by distance y and located at vertices of a 30-60-90 triangle as shown. Determine the electric field at the empty vertex and the location at which the electric field is zero.



15. An electric dipole consists of point charges $\pm q$ separated by distance s. The electric dipole moment is defined as a vector with magnitude $p = qs$ pointing from the negative to the positive. (a) Show that for $r >> s$ along the axis: $E = 2kp/r^3$. (b) For a water molecule $p = 6.2 \times 10^{-30}$ Cm. At what distance would its field be 100 kN/C? (c) Use this concept to solve problem 6 above!

16. Consider a line of charge with length L and uniform charge Q. Determine the electric field at a distance y along a perpendicular bisector.

17. Consider a thin ring of radius R and uniform charge Q in the xy plane. Determine the electric field a distance z along the axis of the ring.

18. Consider a thin disk of radius R and uniform charge Q in the xy plane. Determine the electric field a distance z along the axis of the disk.

19. Determine the electric field near an infinite surface of charge with uniform charge per area σ.

20. Determine the electric field between and beyond two parallel infinite surfaces of charge with uniform charge per area σ on each. Repeat with charge per area $+\sigma$ on one and $-\sigma$ on the other.

21. Consider a thin ring of radius R and uniform charge Q in the xy plane centered on the origin. Determine the electric field as a function of x.

Answers

1. a. 2.7×10^{-8} N, 0°
   b. 2.7×10^{-8} N, 180°
2. a. 20.5 nN, 0°
   b. 20.7 nN, 0°
3. a. 1.1×10^{-7} N, 90°
   b. 1.9×10^{-8} N, 17°
   c. 1.7×10^{-8} N, 90°
4. a. 4.8 nC
   b. deficit of 30 billion electrons
5. $F_G = 1.8 \times 10^{-35}$ N, $F_E = 23$ N
6. 6.0 nC
7. $x = \dfrac{a\left(q_2 + \sqrt{q_1 q_2}\right)}{\left(q_1 - q_2\right)}$ on the side of q_2 opposite from the other charge
8. a. on each: $F = \dfrac{\sqrt{3}\,q^2}{4\pi\varepsilon_o a^2}$ away from the center of the triangle

   b. on $-q$: $F = \dfrac{\sqrt{3}\,q^2}{4\pi\varepsilon_o a^2}$ toward the center of the triangle

   on each q: $F = \dfrac{q^2}{4\pi\varepsilon_o a^2}$ parallel to the opposite side
9. $F = \dfrac{qQ}{4\pi\varepsilon_o d\left(d + L\right)}$
10. a. 1.44×10^{-14} N
    b. 1.58×10^{16} m/s^2 opposite field
    c. 13 Mm/s
    d. 1.44×10^{-14} N, 8.63×10^{12} m/s^2 in direction of field, 290 km/s
11. a. 2.6×10^{13} m/s^2
    b. 1.3 mm upward
12. a. 4.08×10^{-15} kg
    b. 4.80×10^{-19} C
    c. 3.0
13. kq/R^2 away from center, toward missing charge
14. $E = 0$ at a point $y/3$ from q and $2y/3$ from $4q$. Field at empty vertex: $\vec{E} = 3\sqrt{3}k\frac{q}{y^2}, 30°$
15. a. can be done algebraically *or* using calculus with similarity to tidal force analysis!
    b. 10 nm
    c. 6.0 nC
16. $E = \dfrac{Q}{4\pi\varepsilon_o r\sqrt{r^2 + \dfrac{L^2}{4}}}$ perpendicular to line of charge
17. $E = \dfrac{Qz}{4\pi\varepsilon_o\left(R^2 + z^2\right)^{\frac{3}{2}}}$ along the axis

18. $E = \dfrac{Qz}{2\pi\varepsilon_o R^2}\left(\dfrac{1}{z} - \dfrac{1}{\sqrt{z^2 + R^2}}\right)$ along the axis

19. $E = \dfrac{Q}{4\pi^2\varepsilon_o}\displaystyle\int_0^{\pi} \dfrac{x - R\cos\theta}{\left(R^2 + x^2 - 2Rx\cos\theta\right)^{\frac{3}{2}}}\,d\theta$ along the x-axis