

••10 GO In Fig. 21-25, four particles form a square. The charges are $q_1 = q_4 = Q$ and $q_2 = q_3 = q$. (a) What is Q/q if the net electrostatic force on particles 1 and 4 is zero? (b) Is there any value of q that makes the net electrostatic force on each of the four particles zero? Explain.

••11 ILW In Fig. 21-25, the particles have charges $q_1 = -q_2 = 100 \text{ nC}$ and $q_3 = -q_4 = 200 \text{ nC}$, and distance $a = 5.0 \text{ cm}$. What are the (a) x and (b) y components of the net electrostatic force on particle 3?

••12 Two particles are fixed on an x axis. Particle 1 of charge $40 \mu\text{C}$ is located at $x = -2.0 \text{ cm}$; particle 2 of charge Q is located at $x = 3.0 \text{ cm}$. Particle 3 of charge magnitude $20 \mu\text{C}$ is released from rest on the y axis at $y = 2.0 \text{ cm}$. What is the value of Q if the initial acceleration of particle 3 is in the positive direction of (a) the x axis and (b) the y axis?

••13 GO In Fig. 21-26, particle 1 of charge $+1.0 \mu\text{C}$ and particle 2 of charge $-3.0 \mu\text{C}$ are held at separation $L = 10.0 \text{ cm}$ on an x axis. If particle 3 of unknown charge q_3 is to be located such that the net electrostatic force on it from particles 1 and 2 is zero, what must be the (a) x and (b) y coordinates of particle 3?

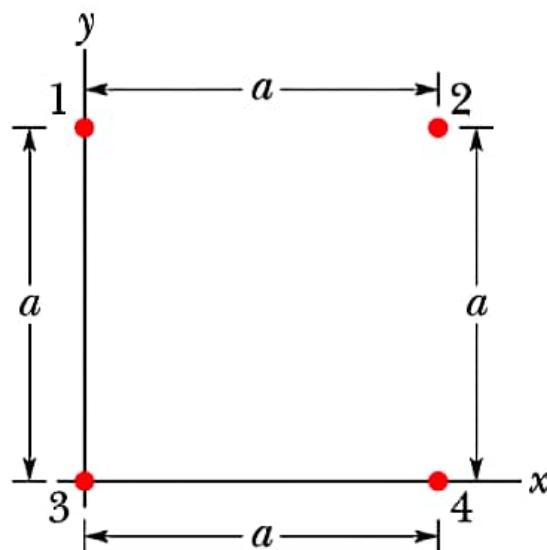


Figure 21-25
Problems 10, 11, and 70.

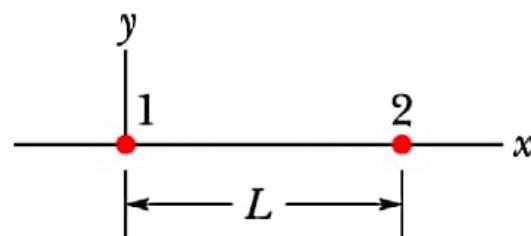


Figure 21-26 Problems 13,
19, 30, 58, and 67.

10. For ease of presentation (of the computations below) we assume $Q > 0$ and $q < 0$ (although the final result does not depend on this particular choice).

(a) The x -component of the force experienced by $q_1 = Q$ is

$$F_{1x} = \frac{1}{4\pi\epsilon_0} \left(-\frac{(Q)(Q)}{(\sqrt{2}a)^2} \cos 45^\circ + \frac{(|q|)(Q)}{a^2} \right) = \frac{Q|q|}{4\pi\epsilon_0 a^2} \left(-\frac{Q/|q|}{2\sqrt{2}} + 1 \right)$$

which (upon requiring $F_{1x} = 0$) leads to $Q/|q| = 2\sqrt{2}$, or $Q/q = -2\sqrt{2} = -2.83$.

(b) The y -component of the net force on $q_2 = q$ is

$$F_{2y} = \frac{1}{4\pi\epsilon_0} \left(\frac{|q|^2}{(\sqrt{2}a)^2} \sin 45^\circ - \frac{(|q|)(Q)}{a^2} \right) = \frac{|q|^2}{4\pi\epsilon_0 a^2} \left(\frac{1}{2\sqrt{2}} - \frac{Q}{|q|} \right)$$

which (if we demand $F_{2y} = 0$) leads to $Q/q = -1/2\sqrt{2}$. The result is inconsistent with that obtained in part (a). Thus, we are unable to construct an equilibrium configuration with this geometry, where the only forces present are given by Eq. 21-1.

11. The force experienced by q_3 is

$$\vec{F}_3 = \vec{F}_{31} + \vec{F}_{32} + \vec{F}_{34} = \frac{1}{4\pi\epsilon_0} \left(-\frac{|q_3||q_1|}{a^2} \hat{j} + \frac{|q_3||q_2|}{(\sqrt{2}a)^2} (\cos 45^\circ \hat{i} + \sin 45^\circ \hat{j}) + \frac{|q_3||q_4|}{a^2} \hat{i} \right)$$

(a) Therefore, the x -component of the resultant force on q_3 is

$$F_{3x} = \frac{|q_3|}{4\pi\epsilon_0 a^2} \left(\frac{|q_2|}{2\sqrt{2}} + |q_4| \right) = (8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2) \frac{2(1.0 \times 10^{-7} \text{ C})^2}{(0.050 \text{ m})^2} \left(\frac{1}{2\sqrt{2}} + 2 \right) = 0.17 \text{ N.}$$

(b) Similarly, the y -component of the net force on q_3 is

$$\begin{aligned} F_{3y} &= \frac{|q_3|}{4\pi\epsilon_0 a^2} \left(-|q_1| + \frac{|q_2|}{2\sqrt{2}} \right) = (8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2) \frac{2(1.0 \times 10^{-7} \text{ C})^2}{(0.050 \text{ m})^2} \left(-1 + \frac{1}{2\sqrt{2}} \right) \\ &= -0.046 \text{ N.} \end{aligned}$$

12. (a) For the net force to be in the $+x$ direction, the y components of the individual forces must cancel. The angle of the force exerted by the $q_1 = 40 \mu\text{C}$ charge on $q_3 = 20 \mu\text{C}$ is 45° , and the angle of force exerted on q_3 by Q is at $-\theta$ where

$$\theta = \tan^{-1} \left(\frac{2.0 \text{ cm}}{3.0 \text{ cm}} \right) = 33.7^\circ.$$

Therefore, cancellation of y components requires

$$k \frac{q_1 q_3}{(0.02\sqrt{2} \text{ m})^2} \sin 45^\circ = k \frac{|Q| q_3}{\left(\sqrt{(0.030 \text{ m})^2 + (0.020 \text{ m})^2} \right)^2} \sin \theta$$

from which we obtain $|Q| = 83 \mu\text{C}$. Charge Q is “pulling” on q_3 , so (since $q_3 > 0$) we conclude $Q = -83 \mu\text{C}$.

- (b) Now, we require that the x components cancel, and we note that in this case, the angle of force on q_3 exerted by Q is $+\theta$ (it is repulsive, and Q is positive-valued). Therefore,

$$k \frac{q_1 q_3}{(0.02\sqrt{2} \text{ m})^2} \cos 45^\circ = k \frac{Q q_3}{\left(\sqrt{(0.030 \text{ m})^2 + (0.020 \text{ m})^2} \right)^2} \cos \theta$$

from which we obtain $Q = 55.2 \mu\text{C} \approx 55 \mu\text{C}$.

13. (a) There is no equilibrium position for q_3 between the two fixed charges, because it is being pulled by one and pushed by the other (since q_1 and q_2 have different signs); in this region this means the two force arrows on q_3 are in the same direction and cannot cancel. It should also be clear that off-axis (with the axis defined as that which passes through the two fixed charges) there are no equilibrium positions. On the semi-infinite region of the axis that is nearest q_2 and furthest from q_1 an equilibrium position for q_3 cannot be found because $|q_1| < |q_2|$ and the magnitude of force exerted by q_2 is everywhere (in that region) stronger than that exerted by q_1 on q_3 . Thus, we must look in the semi-infinite region of the axis which is nearest q_1 and furthest from q_2 , where the net force on q_3 has magnitude

$$\left| k \frac{|q_1 q_3|}{L_0^2} - k \frac{|q_2 q_3|}{(L + L_0)^2} \right|$$

with $L = 10$ cm and L_0 is assumed to be *positive*. We set this equal to zero, as required by the problem, and cancel k and q_3 . Thus, we obtain

$$\frac{|q_1|}{L_0^2} - \frac{|q_2|}{(L + L_0)^2} = 0 \Rightarrow \left(\frac{L + L_0}{L_0} \right)^2 = \left| \frac{q_2}{q_1} \right| = \left| \frac{-3.0 \mu\text{C}}{+1.0 \mu\text{C}} \right| = 3.0$$

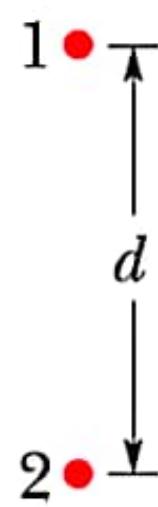
which yields (after taking the square root)

$$\frac{L + L_0}{L_0} = \sqrt{3} \Rightarrow L_0 = \frac{L}{\sqrt{3} - 1} = \frac{10 \text{ cm}}{\sqrt{3} - 1} \approx 14 \text{ cm}$$

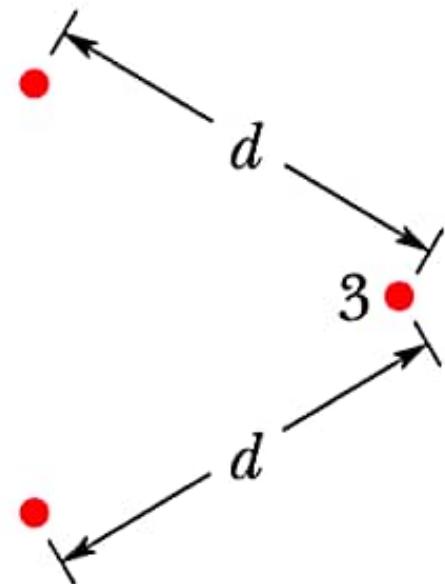
for the distance between q_3 and q_1 . That is, q_3 should be placed at $x = -14$ cm along the x -axis.

(b) As stated above, $y = 0$.

- 17** In Fig. 21-28a, particles 1 and 2 have charge $20.0 \mu\text{C}$ each and are held at separation distance $d = 1.50 \text{ m}$. (a) What is the magnitude of the electrostatic force on particle 1 due to particle 2? In Fig. 21-28b, particle 3 of charge $20.0 \mu\text{C}$ is positioned so as to complete an equilateral triangle. (b) What is the magnitude of the net electrostatic force on particle 1 due to particles 2 and 3?



(a)



(b)

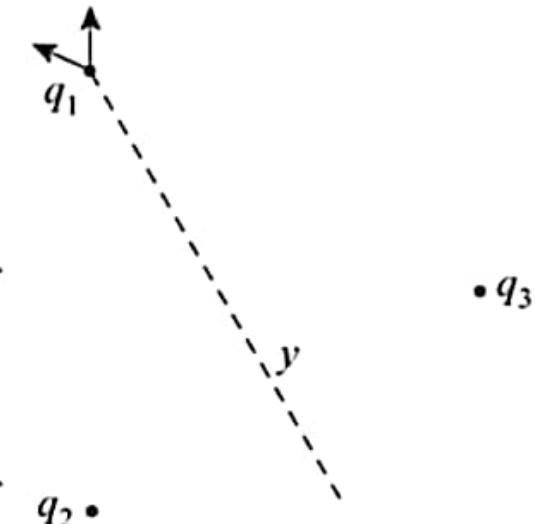
Figure 21-28 Problem 17.

17. (a) Equation 21-1 gives

$$F_{12} = k \frac{q_1 q_2}{d^2} = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(20.0 \times 10^{-6} \text{ C})^2}{(1.50 \text{ m})^2} = 1.60 \text{ N.}$$

(b) On the right, a force diagram is shown as well as our choice of y axis (the dashed line).

The y axis is meant to bisect the line between q_2 and q_3 in order to make use of the symmetry in the problem (equilateral triangle of side length d , equal-magnitude charges $q_1 = q_2 = q_3 = q$). We see



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that the resultant force is along this symmetry axis, and we obtain

$$|F_y| = 2 \left(k \frac{q^2}{d^2} \right) \cos 30^\circ = 2 (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(20.0 \times 10^{-6} \text{ C})^2}{(1.50 \text{ m})^2} \cos 30^\circ = 2.77 \text{ N.}$$

•••22  Figure 21-31 shows an arrangement of four charged particles, with angle $\theta = 30.0^\circ$ and distance $d = 2.00 \text{ cm}$. Particle 2 has charge $q_2 = +8.00 \times 10^{-19} \text{ C}$; particles 3 and 4 have charges $q_3 = q_4 = -1.60 \times 10^{-19} \text{ C}$. (a) What is distance D between the origin and particle 2 if the net electrostatic force on particle 1 due to the other particles is zero? (b) If particles 3 and 4 were moved closer to the x axis but maintained their symmetry about that axis, would the required value of D be greater than, less than, or the same as in part (a)?

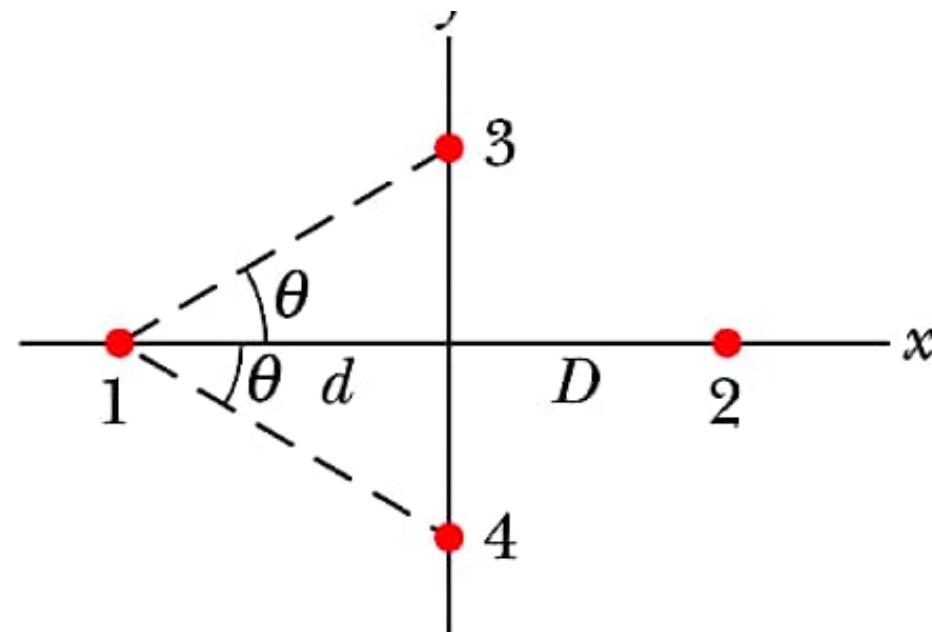


Figure 21-31 Problem 22.

22. (a) We note that $\cos(30^\circ) = \frac{1}{2}\sqrt{3}$, so that the dashed line distance in the figure is $r = 2d/\sqrt{3}$. The net force on q_1 due to the two charges q_3 and q_4 (with $|q_3| = |q_4| = 1.60 \times 10^{-19}$ C) on the y axis has magnitude

$$2 \frac{|q_1 q_3|}{4\pi\epsilon_0 r^2} \cos(30^\circ) = \frac{3\sqrt{3}|q_1 q_3|}{16\pi\epsilon_0 d^2}.$$

This must be set equal to the magnitude of the force exerted on q_1 by $q_2 = 8.00 \times 10^{-19}$ C = $5.00 |q_3|$ in order that its net force be zero:

$$\frac{3\sqrt{3}|q_1 q_3|}{16\pi\epsilon_0 d^2} = \frac{|q_1 q_2|}{4\pi\epsilon_0 (D+d)^2} \Rightarrow D = d \left(2\sqrt{\frac{5}{3\sqrt{3}}} - 1 \right) = 0.9245 d.$$

Given $d = 2.00$ cm, this then leads to $D = 1.92$ cm.

(b) As the angle decreases, its cosine increases, resulting in a larger contribution from the charges on the y axis. To offset this, the force exerted by q_2 must be made stronger, so that it must be brought closer to q_1 (keep in mind that Coulomb's law is *inversely proportional to distance-squared*). Thus, D must be decreased.

- 38**  Figure 21-37 shows four identical conducting spheres that are actually well separated from one another. Sphere W (with an initial charge of zero) is touched to sphere A and then they are separated. Next, sphere W is touched to sphere B (with an initial charge of $-32e$) and then they are separated. Finally, sphere W is touched to sphere C (with an initial charge of $+48e$), and then they are separated. The final charge on sphere W is $+18e$. What was the initial charge on sphere A ?

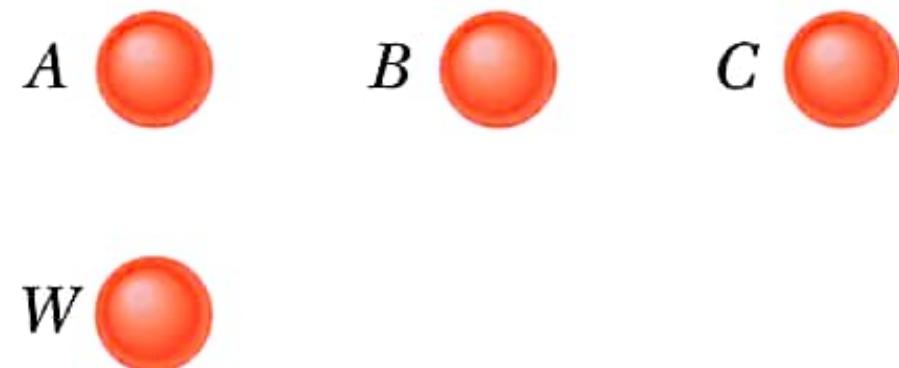


Figure 21-37 Problem 38.

38. As a result of the first action, both sphere W and sphere A possess charge $\frac{1}{2}q_A$, where q_A is the initial charge of sphere A . As a result of the second action, sphere W has charge

$$\frac{1}{2}\left(\frac{q_A}{2}-32e\right).$$

As a result of the final action, sphere W now has charge equal to



$$\frac{1}{2}\left[\frac{1}{2}\left(\frac{q_A}{2}-32e\right)+48e\right].$$

Setting this final expression equal to $+18e$ as required by the problem leads (after a couple of algebra steps) to the answer: $q_A = +16e$.

39 SSM In Fig. 21-38, particle 1 of charge $+4e$ is above a floor by distance $d_1 = 2.00 \text{ mm}$ and particle 2 of charge $+6e$ is on the floor, at distance $d_2 = 6.00 \text{ mm}$ horizontally from particle 1. What is the x component of the electrostatic force on particle 2 due to particle 1?

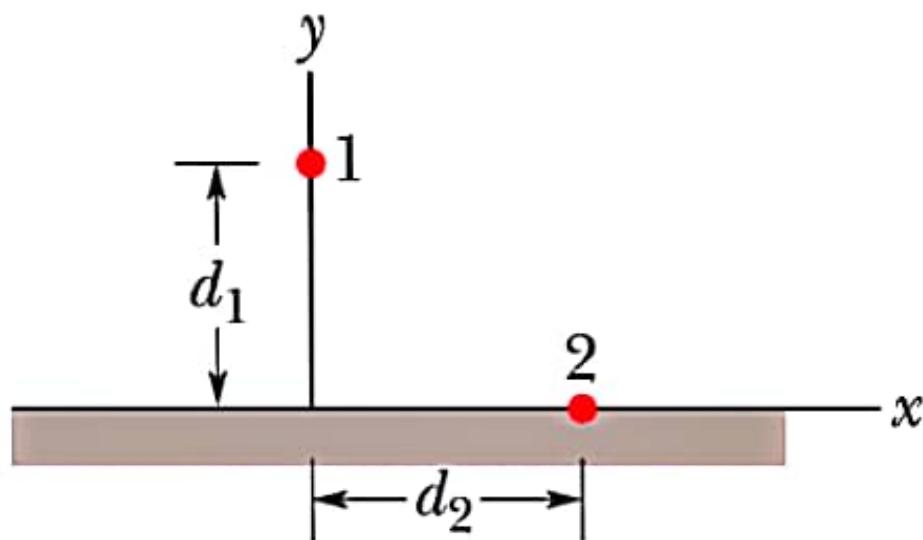


Figure 21-38 Problem 39.

39. THINK We have two discrete charges in the xy -plane. The electrostatic force on particle 2 due to particle 1 has both x and y components.

EXPRESS Using Coulomb's law, the magnitude of the force of particle 1 on particle 2 is $F_{21} = k \frac{q_1 q_2}{r^2}$, where $r = \sqrt{d_1^2 + d_2^2}$ and $k = 1/4\pi\epsilon_0 = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$. Since both q_1 and q_2 are positively charged, particle 2 is repelled by particle 1, so the direction of \vec{F}_{21} is away from particle 1 and toward 2. In unit-vector notation, $\vec{F}_{21} = F_{21} \hat{\mathbf{r}}$, where

$$\hat{\mathbf{r}} = \frac{\vec{r}}{r} = \frac{d_2 \hat{\mathbf{i}} - d_1 \hat{\mathbf{j}}}{\sqrt{d_1^2 + d_2^2}}.$$

The x component of \vec{F}_{21} is $F_{21,x} = F_{21} d_2 / \sqrt{d_1^2 + d_2^2}$.

ANALYZE Combining the expressions above, we obtain

$$\begin{aligned} F_{21,x} &= k \frac{q_1 q_2 d_2}{r^3} = k \frac{q_1 q_2 d_2}{(d_1^2 + d_2^2)^{3/2}} \\ &= \frac{(8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(4 \cdot 1.60 \times 10^{-19} \text{ C})(6 \cdot 1.60 \times 10^{-19} \text{ C})(6.00 \times 10^{-3} \text{ m})}{[(2.00 \times 10^{-3} \text{ m})^2 + (6.00 \times 10^{-3} \text{ m})^2]^{3/2}} \\ &= 1.31 \times 10^{-22} \text{ N} \end{aligned}$$

LEARN In a similar manner, we find the y component of \vec{F}_{21} to be

$$\begin{aligned} F_{21,y} &= -k \frac{q_1 q_2 d_1}{r^3} = -k \frac{q_1 q_2 d_1}{(d_1^2 + d_2^2)^{3/2}} \\ &= -\frac{(8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(4 \cdot 1.60 \times 10^{-19} \text{ C})(6 \cdot 1.60 \times 10^{-19} \text{ C})(2.00 \times 10^{-3} \text{ m})}{[(2.00 \times 10^{-3} \text{ m})^2 + (6.00 \times 10^{-3} \text{ m})^2]^{3/2}} \\ &= -0.437 \times 10^{-22} \text{ N}. \end{aligned}$$

Thus, $\vec{F}_{21} = (1.31 \times 10^{-22} \text{ N})\hat{\mathbf{i}} - (0.437 \times 10^{-22} \text{ N})\hat{\mathbf{j}}$.

42 In Fig. 21-39, two tiny conducting balls of identical mass m and identical charge q hang from nonconducting threads of length L . Assume that θ is so small that $\tan \theta$ can be replaced by its approximate equal, $\sin \theta$. (a) Show that

$$x = \left(\frac{q^2 L}{2\pi\epsilon_0 mg} \right)^{1/3}$$

gives the equilibrium separation x of the balls. (b) If $L = 120$ cm, $m = 10$ g, and $x = 5.0$ cm, what is $|q|$?

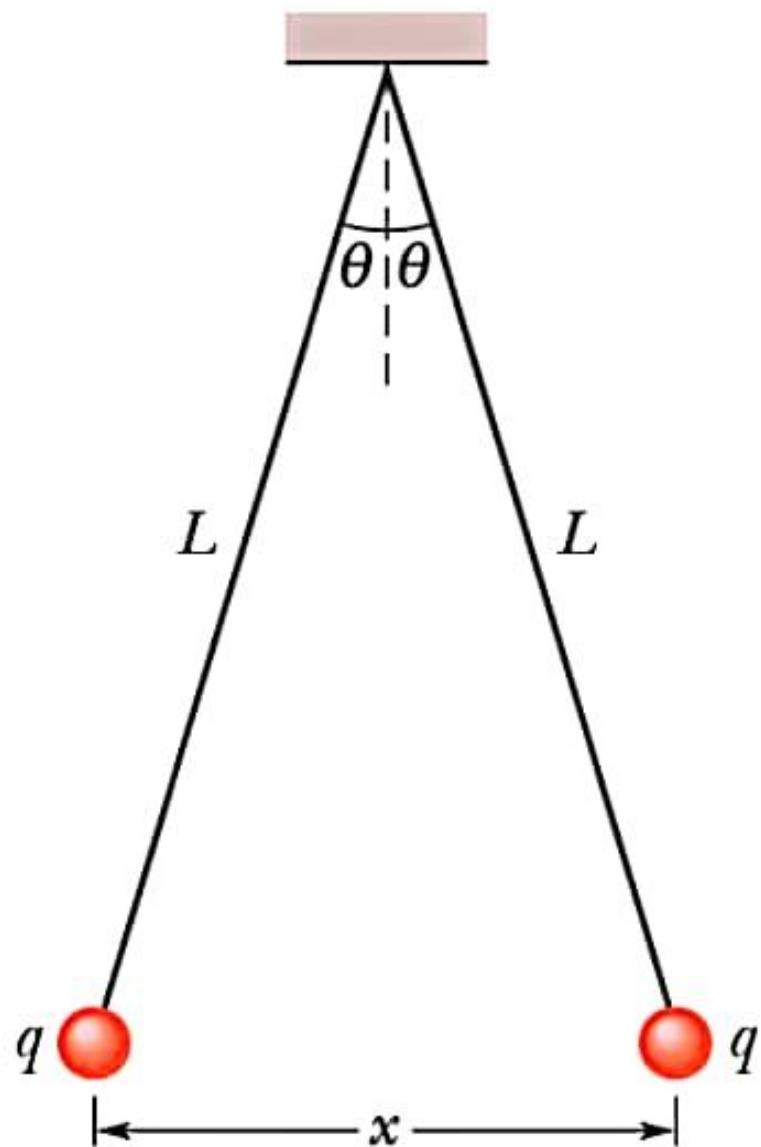
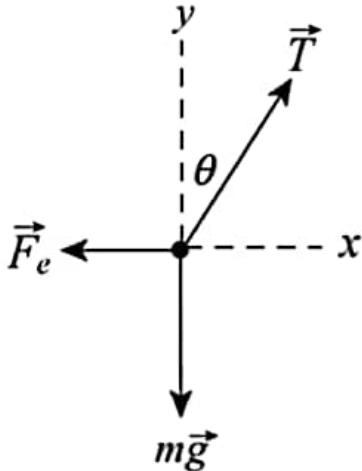


Figure 21-39
Problems 42 and 43.

42. (a) A force diagram for one of the balls is shown below. The force of gravity $m\vec{g}$ acts downward, the electrical force \vec{F}_e of the other ball acts to the left, and the tension in the thread acts along the thread, at the angle θ to the vertical. The ball is in equilibrium, so its acceleration is zero. The y component of Newton's second law yields $T \cos\theta - mg = 0$ and the x component yields $T \sin\theta - F_e = 0$. We solve the first equation for T and obtain $T = mg/\cos\theta$. We substitute the result into the second to obtain $mg \tan\theta - F_e = 0$.



Examination of the geometry of the figure shown leads to $\tan\theta = \frac{x/2}{\sqrt{L^2 - (x/2)^2}}$.

If L is much larger than x (which is the case if θ is very small), we may neglect $x/2$ in the denominator and write $\tan\theta \approx x/2L$. This is equivalent to approximating $\tan\theta$ by $\sin\theta$. The magnitude of the electrical force of one ball on the other is

$$F_e = \frac{q^2}{4\pi\epsilon_0 x^2}$$

by Eq. 21-4. When these two expressions are used in the equation $mg \tan\theta = F_e$, we obtain

$$\frac{mgx}{2L} \approx \frac{1}{4\pi\epsilon_0} \frac{q^2}{x^2} \Rightarrow x \approx \left(\frac{q^2 L}{2\pi\epsilon_0 mg} \right)^{1/3}.$$

(b) We solve $x^3 = 2kq^2L/mg$ for the charge (using Eq. 21-5):

$$q = \sqrt[3]{\frac{mgx^3}{2kL}} = \sqrt[3]{\frac{(0.010 \text{ kg})(9.8 \text{ m/s}^2)(0.050 \text{ m})^3}{2(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(1.20 \text{ m})}} = \pm 2.4 \times 10^{-8} \text{ C.}$$

Thus, the magnitude is $|q| = 2.4 \times 10^{-8} \text{ C}$.

- 46** In Fig. 21-40, four particles are fixed along an x axis, separated by distances $d = 2.00 \text{ cm}$. The charges are $q_1 = +2e$, $q_2 = -e$, $q_3 = +e$, and $q_4 = +4e$, with $e = 1.60 \times 10^{-19} \text{ C}$. In unit-vector notation, what is the net electrostatic force on (a) particle 1 and (b) particle 2 due to the other particles?

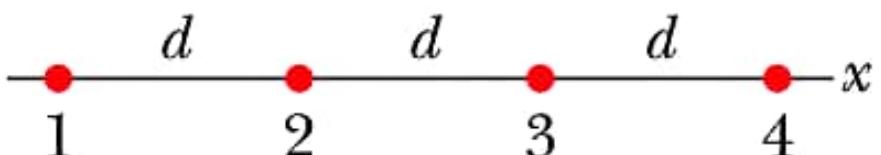


Figure 21-40 Problem 46.

46. Let \vec{F}_{12} denotes the force on q_1 exerted by q_2 and F_{12} be its magnitude.

(a) We consider the net force on q_1 . \vec{F}_{12} points in the $+x$ direction since q_1 is attracted to q_2 . \vec{F}_{13} and \vec{F}_{14} both point in the $-x$ direction since q_1 is repelled by q_3 and q_4 . Thus, using $d = 0.0200 \text{ m}$, the net force is

$$\begin{aligned} F_1 &= F_{12} - F_{13} - F_{14} = \frac{2e|-e|}{4\pi\epsilon_0 d^2} - \frac{(2e)(e)}{4\pi\epsilon_0 (2d)^2} - \frac{(2e)(4e)}{4\pi\epsilon_0 (3d)^2} = \frac{11}{18} \frac{e^2}{4\pi\epsilon_0 d^2} \\ &= \frac{11}{18} \frac{(8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(1.60 \times 10^{-19} \text{ C})^2}{(2.00 \times 10^{-2} \text{ m})^2} = 3.52 \times 10^{-25} \text{ N} \end{aligned}$$

or $\vec{F}_1 = (3.52 \times 10^{-25} \text{ N})\hat{i}$.

(b) We now consider the net force on q_2 . We note that $\vec{F}_{21} = -\vec{F}_{12}$ points in the $-x$ direction, and \vec{F}_{23} and \vec{F}_{24} both point in the $+x$ direction. The net force is

$$F_{23} + F_{24} - F_{21} = \frac{4e|-e|}{4\pi\epsilon_0 (2d)^2} + \frac{e|-e|}{4\pi\epsilon_0 d^2} - \frac{2e|-e|}{4\pi\epsilon_0 d^2} = 0.$$

54 A charge of $6.0 \mu\text{C}$ is to be split into two parts that are then separated by 3.0 mm. What is the maximum possible magnitude of the electrostatic force between those two parts?

54. Let q_1 be the charge of one part and q_2 that of the other part; thus, $q_1 + q_2 = Q = 6.0 \mu\text{C}$. The repulsive force between them is given by Coulomb's law:

$$F = \frac{q_1 q_2}{4\pi\epsilon_0 r^2} = \frac{q_1(Q - q_1)}{4\pi\epsilon_0 r^2}.$$

If we maximize this expression by taking the derivative with respect to q_1 and setting equal to zero, we find $q_1 = Q/2$, which might have been anticipated (based on symmetry arguments). This implies $q_2 = Q/2$ also. With $r = 0.0030 \text{ m}$ and $Q = 6.0 \times 10^{-6} \text{ C}$, we find

$$F = \frac{(Q/2)(Q/2)}{4\pi\epsilon_0 r^2} = \frac{1}{4} \frac{Q^2}{4\pi\epsilon_0 r^2} = \frac{1}{4} \frac{(8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(6.0 \times 10^{-6} \text{ C})^2}{(3.00 \times 10^{-3} \text{ m})^2} \approx 9.0 \times 10^3 \text{ N}.$$

- 60**  In Fig. 21-43, six charged particles surround particle 7 at radial distances of either $d = 1.0\text{ cm}$ or $2d$, as drawn. The charges are $q_1 = +2e, q_2 = +4e, q_3 = +e, q_4 = +4e, q_5 = +2e, q_6 = +8e, q_7 = +6e$, with $e = 1.60 \times 10^{-19}\text{ C}$. What is the magnitude of the net electrostatic force on particle 7?

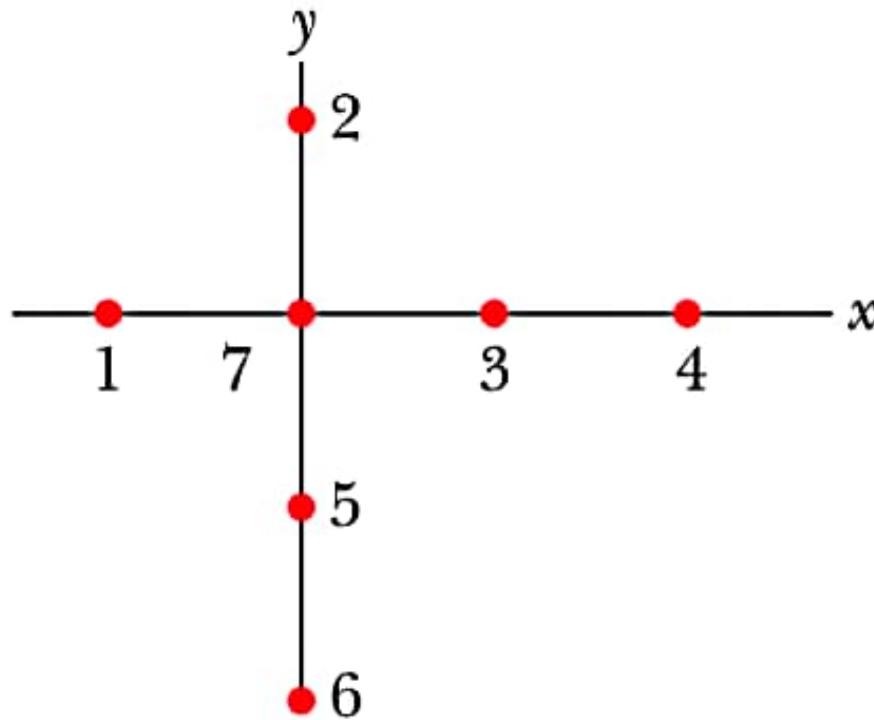


Figure 21-43 Problem 60.

60. We note that, as result of the fact that the Coulomb force is inversely proportional to r^2 , a particle of charge Q that is distance d from the origin will exert a force on some charge q_0 at the origin of equal strength as a particle of charge $4Q$ at distance $2d$ would exert on q_0 . Therefore, $q_6 = +8e$ on the $-y$ axis could be replaced with a $+2e$ closer to the origin (at half the distance); this would add to the $q_5 = +2e$ already there and produce $+4e$ below the origin, which exactly cancels the force due to $q_2 = +4e$ above the origin.

Similarly, $q_4 = +4e$ to the far right could be replaced by a $+e$ at half the distance, which would add to $q_3 = +e$ already there to produce a $+2e$ at distance d to the right of the central charge q_7 . The horizontal force due to this $+2e$ is cancelled exactly by that of $q_1 = +2e$ on the $-x$ axis, so that the net force on q_7 is zero.

62 ssm In Fig. 21-44, what are the (a) magnitude and (b) direction of the net electrostatic force on particle 4 due to the other three particles? All four particles are fixed in the xy plane, and $q_1 = -3.20 \times 10^{-19} \text{ C}$, $q_2 = +3.20 \times 10^{-19} \text{ C}$, $q_3 = +6.40 \times 10^{-19} \text{ C}$, $q_4 = +3.20 \times 10^{-19} \text{ C}$, $\theta_1 = 35.0^\circ$, $d_1 = 3.00 \text{ cm}$, and $d_2 = d_3 = 2.00 \text{ cm}$.

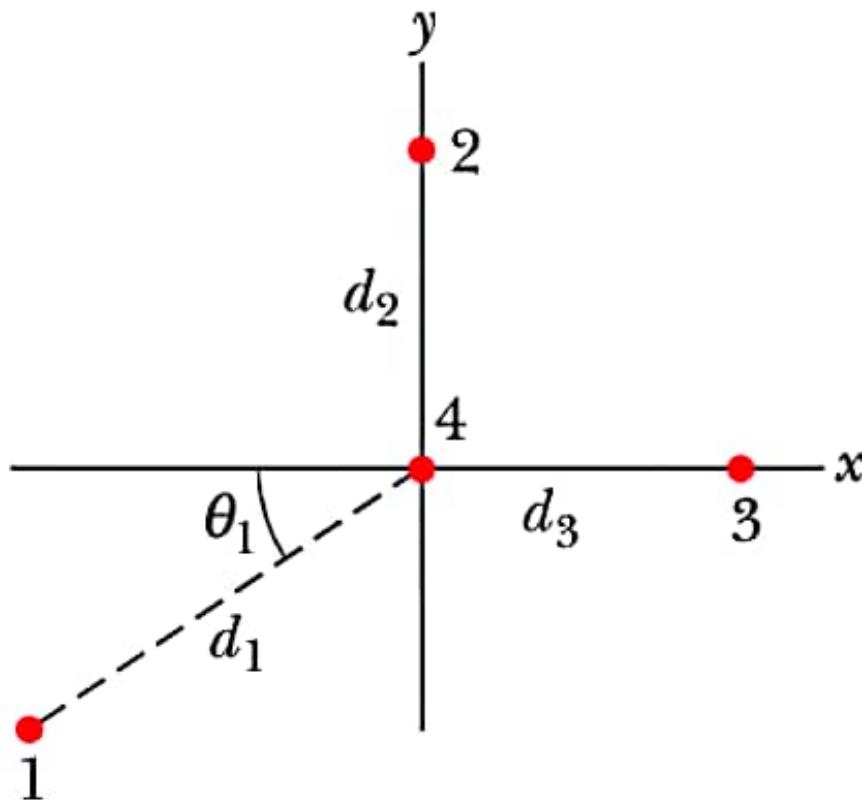


Figure 21-44 Problem 62.

62. **THINK** We have four discrete charges in the xy -plane. We use superposition principle to calculate the net electrostatic force on particle 4 due to the other three particles.

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EXPRESS Using Coulomb's law, the magnitude of the force on particle 4 by particle i is

$$F_{4i} = k \frac{q_4 q_i}{r_{4i}^2}. \text{ For example, the magnitude of } \vec{F}_{41} \text{ is}$$

$$\begin{aligned} F_{41} &= k \frac{|q_4||q_1|}{r_{41}^2} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(3.20 \times 10^{-19} \text{ C})(3.20 \times 10^{-19} \text{ C})}{(0.0300 \text{ m})^2} \\ &= 1.02 \times 10^{-24} \text{ N} \end{aligned}.$$

Since the force is attractive, $\hat{r}_{41} = -\cos \theta_1 \hat{i} - \sin \theta_1 \hat{j} = -\cos 35^\circ \hat{i} - \sin 35^\circ \hat{j} = -0.82 \hat{i} - 0.57 \hat{j}$. In unit-vector notation, we have

$$\vec{F}_{41} = F_{41} \hat{r}_{41} = (1.02 \times 10^{-24} \text{ N})(-0.82 \hat{i} - 0.57 \hat{j}) = -(8.36 \times 10^{-25} \text{ N}) \hat{i} - (5.85 \times 10^{-24} \text{ N}) \hat{j}.$$

Similarly,

$$\begin{aligned} \vec{F}_{42} &= -k \frac{|q_4||q_2|}{r_{42}^2} \hat{j} = -\frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(3.20 \times 10^{-19} \text{ C})(3.20 \times 10^{-19} \text{ C})}{(0.0200 \text{ m})^2} \hat{j} \\ &= -(2.30 \times 10^{-24} \text{ N}) \hat{j} \end{aligned}$$

and

$$\begin{aligned} \vec{F}_{43} &= -k \frac{|q_4||q_3|}{r_{43}^2} \hat{i} = -\frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(6.40 \times 10^{-19} \text{ C})(3.20 \times 10^{-19} \text{ C})}{(0.0200 \text{ m})^2} \hat{i} \\ &= -(4.60 \times 10^{-24} \text{ N}) \hat{i}. \end{aligned}$$

ANALYZE (a) The net force on particle 4 is

$$\vec{F}_{4,\text{net}} = \vec{F}_{41} + \vec{F}_{42} + \vec{F}_{43} = -(5.44 \times 10^{-24} \text{ N}) \hat{i} - (2.89 \times 10^{-24} \text{ N}) \hat{j}.$$

The magnitude of the force is

$$F_{4,\text{net}} = \sqrt{(-5.44 \times 10^{-24} \text{ N})^2 + (-2.89 \times 10^{-24} \text{ N})^2} = 6.16 \times 10^{-24} \text{ N}.$$

(b) The direction of the net force is at an angle of

$$\varphi = \tan^{-1} \left(\frac{F_{4y,\text{net}}}{F_{4x,\text{net}}} \right) = \tan^{-1} \left(\frac{-2.89 \times 10^{-24} \text{ N}}{-5.44 \times 10^{-24} \text{ N}} \right) = 208^\circ,$$

measured counterclockwise from the $+x$ axis.

LEARN A nonzero net force indicates that particle 4 will be accelerated in the direction of the force.

