

AN ELECTRIC FIELD is said to exist at any point in space when a test charge, placed at that point, experiences an electrical force. The direction of the electric field at a point is the same as the direction of the force experienced by a *positive* test charge placed at the point.

Electric field lines can be used to sketch electric fields. The line through a point has the same direction at that point as the electric field. Where the field lines are closest together, the electric field is largest. Field lines come out of positive charges (because a positive charge repels a positive test charge) and come into negative charges (because they attract the positive test charge).

THE STRENGTH OF THE ELECTRIC FIELD (\vec{E}) at a point is equal to the force experienced by a unit positive test charge placed at that point. Because the electric field strength is a force per unit charge, it is a vector quantity. The units of \vec{E} are N/C or (see Chapter 25) V/m.

If a charge q is placed at a point where the electric field due to other charges is \vec{E} , the charge will experience a force \vec{F}_E given by

$$\vec{F}_E = q\vec{E}$$

If q is negative, \vec{F}_E will be opposite in direction to \vec{E} .

ELECTRIC FIELD DUE TO A POINT CHARGE: To find E (the signed magnitude of \vec{E}) due to a point charge q , we make use of Coulomb's Law. If a point charge q' is placed at a distance r from the charge q , it will experience a force

$$F_E = \frac{1}{4\pi\epsilon} \frac{qq'}{r^2} = q' \left(\frac{1}{4\pi\epsilon} \frac{q}{r^2} \right)$$

But if a point charge q' is placed at a position where the electric field is E , then the force on q' is

$$F_E = q'E$$

Comparing these two expressions for F_E , we see that

$$E = \frac{1}{4\pi\epsilon} \frac{q}{r^2}$$

This is the electric field at a distance r from a point charge q . The same relation applies at points outside a finite spherical charge q . For q positive, E is positive and \vec{E} is directed radially outward from q ; for q negative, E is negative and \vec{E} is directed radially inward.

SUPERPOSITION PRINCIPLE: The force experienced by a charge due to other charges is the vector sum of the Coulomb forces acting on it due to these other charges. Similarly, the electric intensity \vec{E} at a point due to several charges is the vector sum of the intensities due to the individual charges.

Solved Problems

- 24.1** Two coins lie 1.5 m apart on a table. They carry identical charges. Approximately how large is the charge on each if a coin experiences a force of 2 N?

The diameter of a coin is small compared to the 1.5 m separation. We may therefore approximate the coins as point charges. Coulomb's Law, $F_E = (k/K)q_1q_2/r^2$, gives (with K approximated as 1.00)

$$q_1 q_2 = q^2 = \frac{F_E r^2}{k} = \frac{(2 \text{ N})(1.5 \text{ m})^2}{9 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2} = 5 \times 10^{-10} \text{ C}^2$$

from which $q = 2 \times 10^{-5} \text{ C}$.

- 24.2** Repeat Problem 24.1 if the coins are separated by a distance of 1.5 m in a large vat of water. The dielectric constant of water is about 80.

From Coulomb's Law,

$$F_E = \frac{k}{K} \frac{q^2}{r^2}$$

where K , the dielectric constant, is now 80. Then

$$q = \sqrt{\frac{F_E r^2 K}{k}} = \sqrt{\frac{(2 \text{ N})(1.5 \text{ m})^2 (80)}{9 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2}} = 2 \times 10^{-4} \text{ C}$$

- 24.3** A helium nucleus has charge $+2e$, and a neon nucleus $+10e$, where e is the quantum of charge, $1.60 \times 10^{-19} \text{ C}$. Find the repulsive force exerted on one by the other when they are 3.0 nanometers ($1 \text{ nm} = 10^{-9} \text{ m}$) apart. Assume the system to be in vacuum.

Nuclei have radii of order 10^{-15} m . We can assume them to be point charges in this case. Then

$$F_E = k \frac{qq'}{r^2} = (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2) \frac{(2)(10)(1.6 \times 10^{-19} \text{ C})^2}{(3.0 \times 10^{-9} \text{ m})^2} = 5.1 \times 10^{-10} \text{ N} = 0.51 \text{ nN}$$

- 24.4** In the Bohr model of the hydrogen atom, an electron ($q = -e$) circles a proton ($q' = e$) in an orbit of radius $5.3 \times 10^{-11} \text{ m}$. The attraction of the proton for the electron furnishes the centripetal force needed to hold the electron in orbit. Find (a) the force of electrical attraction between the particles and (b) the electron's speed. The electron mass is $9.1 \times 10^{-31} \text{ kg}$.

$$(a) \quad F_E = k \frac{qq'}{r^2} = (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2) \frac{(1.6 \times 10^{-19} \text{ C})^2}{(5.3 \times 10^{-11} \text{ m})^2} = 8.2 \times 10^{-8} \text{ N} = 82 \text{ nN}$$

- (b) The force found in (a) is the centripetal force, mv^2/r . Therefore,

$$8.2 \times 10^{-8} \text{ N} = \frac{mv^2}{r}$$

from which

$$v = \sqrt{\frac{(8.2 \times 10^{-8} \text{ N})(r)}{m}} = \sqrt{\frac{(8.2 \times 10^{-8} \text{ N})(5.3 \times 10^{-11} \text{ m})}{9.1 \times 10^{-31} \text{ kg}}} = 2.2 \times 10^6 \text{ m/s}$$

- 24.5** Three point charges are placed on the x -axis as shown in Fig. 24-1. Find the net force on the $-5 \mu\text{C}$ charge due to the two other charges.

Because unlike charges attract, the forces on the $-5 \mu\text{C}$ charge are as shown. The *magnitudes* of \vec{F}_{E3} and \vec{F}_{E8} are given by Coulomb's Law:

$$F_{E3} = (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2) \frac{(3.0 \times 10^{-6} \text{ C})(5.0 \times 10^{-6} \text{ C})}{(0.20 \text{ m})^2} = 3.4 \text{ N}$$

$$F_{E8} = (9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2) \frac{(8.0 \times 10^{-6} \text{ C})(5.0 \times 10^{-6} \text{ C})}{(0.30 \text{ m})^2} = 4.0 \text{ N}$$

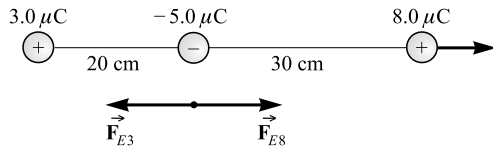


Fig. 24-1

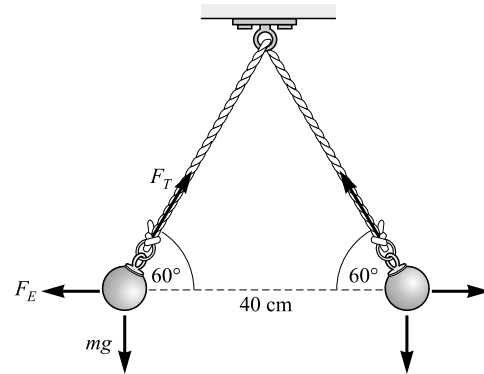


Fig. 24-2

Notice two things about the computation: (1) Proper units (coulombs and meters) must be used. (2) Because we want only the magnitudes of the forces, *we do not carry along the signs of the charges*. (That is, we use their absolute values.) The direction of each force is given by the diagram, which we drew from inspection of the situation.

From the diagram, the resultant force on the center charge is

$$F_E = F_{E8} - F_{E3} = 4.0 \text{ N} - 3.4 \text{ N} = 0.6 \text{ N}$$

and it is in the $+x$ -direction.

- 24.6** Find the ratio of the Coulomb electric force F_E to the gravitational force F_G between two electrons in vacuum.

From Coulomb's Law and Newton's Law of gravitation,

$$F_E = k \frac{q^2}{r^2} \quad \text{and} \quad F_G = G \frac{m^2}{r^2}$$

Therefore

$$\begin{aligned} \frac{F_E}{F_G} &= \frac{kq^2/r^2}{Gm^2/r^2} = \frac{kq^2}{Gm^2} \\ &= \frac{(9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(1.6 \times 10^{-19} \text{ C})^2}{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(9.1 \times 10^{-31} \text{ kg})^2} = 4.2 \times 10^{42} \end{aligned}$$

As you can see, the electric force is much stronger than the gravitational force.

- 24.7** As shown in Fig. 24-2, two identical balls, each of mass 0.10 g, carry identical charges and are suspended by two threads of equal length. At equilibrium they position themselves as shown. Find the charge on either ball.

Consider the ball on the left. It is in equilibrium under three forces: (1) the tension F_T in the thread; (2) the force of gravity,

$$mg = (1.0 \times 10^{-4} \text{ kg})(9.81 \text{ m/s}^2) = 9.8 \times 10^{-4} \text{ N}$$

and (3) the Coulomb repulsion F_E .

Writing $\sum F_x = 0$ and $\sum F_y = 0$ for the ball on the left, we obtain

$$F_T \cos 60^\circ - F_E = 0 \quad \text{and} \quad F_T \sin 60^\circ - mg = 0$$

From the second equation,

$$F_T = \frac{mg}{\sin 60^\circ} = \frac{9.8 \times 10^{-4} \text{ N}}{0.866} = 1.13 \times 10^{-3} \text{ N}$$

Substituting in the first equation gives

$$F_E = F_T \cos 60^\circ = (1.13 \times 10^{-3} \text{ N})(0.50) = 5.7 \times 10^{-4} \text{ N}$$

But this is the Coulomb force, kqq'/r^2 . Therefore,

$$qq' = q^2 = \frac{F_E r^2}{k} = \frac{(5.7 \times 10^{-4} \text{ N})(0.40 \text{ m})^2}{9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}$$

from which $q = 0.10 \mu\text{C}$.

- 24.8** The charges shown in Fig. 24-3 are stationary. Find the force on the $4.0 \mu\text{C}$ charge due to the other two.

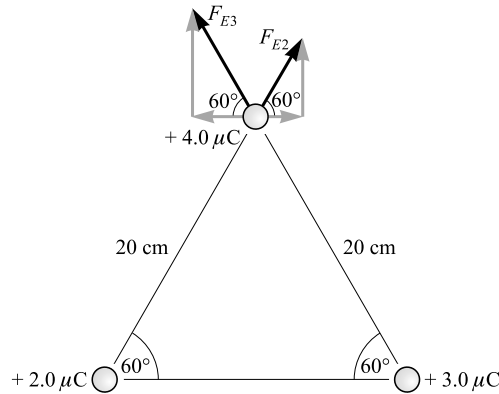


Fig. 24-3

From Coulomb's Law we have

$$F_{E2} = k \frac{qq'}{r^2} = (9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(2.0 \times 10^{-6} \text{ C})(4.0 \times 10^{-6} \text{ C})}{(0.20 \text{ m})^2} = 1.8 \text{ N}$$

$$F_{E3} = k \frac{qq'}{r^2} = (9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(3.0 \times 10^{-6} \text{ C})(4.0 \times 10^{-6} \text{ C})}{(0.20 \text{ m})^2} = 2.7 \text{ N}$$

The resultant force on the $4 \mu\text{C}$ charge has components

$$F_{Ex} = F_{E2} \cos 60^\circ - F_{E3} \cos 60^\circ = (1.8 - 2.7)(0.50) \text{ N} = -0.45 \text{ N}$$

$$F_{Ey} = F_{E2} \sin 60^\circ + F_{E3} \sin 60^\circ = (1.8 + 2.7)(0.866) \text{ N} = 3.9 \text{ N}$$

so

$$F_E = \sqrt{F_{Ex}^2 + F_{Ey}^2} = \sqrt{(0.45)^2 + (3.9)^2} \text{ N} = 3.9 \text{ N}$$

The resultant makes an angle of $\tan^{-1}(0.45/3.9) = 7^\circ$ with the positive y -axis, that is, $\theta = 97^\circ$.

- 24.9** Two charges are placed on the x -axis: $+3.0\ \mu\text{C}$ at $x = 0$ and $-5.0\ \mu\text{C}$ at $x = 40\ \text{cm}$. Where must a third charge q be placed if the force it experiences is to be zero?

The situation is shown in Fig. 24-4. We know that q must be placed somewhere on the x -axis. (Why?) Suppose that q is positive. When it is placed in interval BC , the two forces on it are in the same direction and cannot cancel. When it is placed to the right of C , the attractive force from the $-5\ \mu\text{C}$ charge is always larger than the repulsion of the $+3.0\ \mu\text{C}$ charge. Therefore, the force on q cannot be zero in this region. Only in the region to the left of B can cancellation occur. (Can you show that this is also true if q is negative?)

For q placed as shown, when the net force on it is zero, we have $F_3 = F_5$ and so, for distances in meters,

$$k \frac{q(3.0 \times 10^{-6}\ \text{C})}{d^2} = k \frac{q(5.0 \times 10^{-6}\ \text{C})}{(0.40\ \text{m} + d)^2}$$

After canceling q , k , and $10^{-6}\ \text{C}$ from each side, we cross-multiply to obtain

$$5d^2 = 3.0(0.40 + d)^2 \quad \text{or} \quad d^2 - 1.2d - 0.24 = 0$$

Using the quadratic formula, we find

$$d = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{1.2 \pm \sqrt{1.44 + 0.96}}{2} = 0.60 \pm 0.775\ \text{m}$$

Two values, $1.4\ \text{m}$ and $-0.18\ \text{m}$, are therefore found for d . The first is the correct one; the second gives the point in BC where the two forces have the same magnitude but do not cancel.

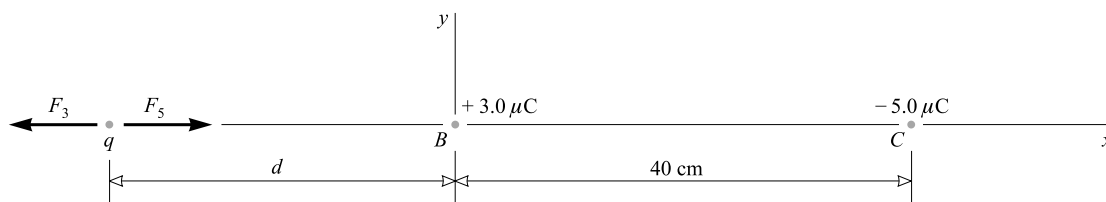


Fig. 24-4

- 24.10** Compute (a) the electric field E in air at a distance of $30\ \text{cm}$ from a point charge $q_1 = 5.0 \times 10^{-9}\ \text{C}$, (b) the force on a charge $q_2 = 4.0 \times 10^{-10}\ \text{C}$ placed $30\ \text{cm}$ from q_1 , and (c) the force on a charge $q_3 = -4.0 \times 10^{-10}\ \text{C}$ placed $30\ \text{cm}$ from q_1 (in the absence of q_2).

$$(a) \quad E = k \frac{q_1}{r^2} = (9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2) \frac{5.0 \times 10^{-9}\ \text{C}}{(0.30\ \text{m})^2} = 0.50\ \text{kN/C}$$

directed away from q_1 .

$$(b) \quad F_E = Eq_2 = (500\ \text{N/C})(4.0 \times 10^{-10}\ \text{C}) = 2.0 \times 10^{-7}\ \text{N} = 0.20\ \mu\text{N}$$

directed away from q_1 .

$$(c) \quad F_E = Eq_3 = (500\ \text{N/C})(-4.0 \times 10^{-10}\ \text{C}) = -0.20\ \mu\text{N}$$

This force is directed toward q_1 .

- 24.11** For the situation shown in Fig. 24-5, find (a) the electric field E at point P , (b) the force on a -4.0×10^{-8} C charge placed at P , and (c) where in the region the electric field would be zero (in the absence of the -4.0×10^{-8} C charge).

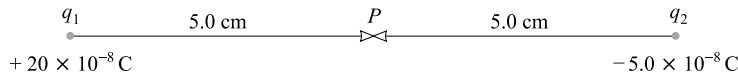


Fig. 24-5

- (a) A positive test charge placed at P will be repelled to the right by the positive charge q_1 and attracted to the right by the negative charge q_2 . Because \vec{E}_1 and \vec{E}_2 have the same direction, we can add their magnitudes to obtain the magnitude of the resultant field:

$$E = E_1 + E_2 = k \frac{|q_1|}{r_1^2} + k \frac{|q_2|}{r_2^2} = \frac{k}{r_1^2} (|q_1| + |q_2|)$$

where $r_1 = r_2 = 0.05$ m, and $|q_1|$ and $|q_2|$ are the absolute values of q_1 and q_2 . Hence,

$$E = \frac{9.0 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2}{(0.050 \text{ m})^2} (25 \times 10^{-8} \text{ C}) = 9.0 \times 10^5 \text{ N/C}$$

directed toward the right.

- (b) A charge q placed at P will experience a force Eq . Therefore,

$$F_E = Eq = (9.0 \times 10^5 \text{ N/C})(-4.0 \times 10^{-8} \text{ C}) = -0.036 \text{ N}$$

The negative sign tells us the force is directed toward the left. This is correct because the electric field represents the force on a positive charge. The force on a negative charge is opposite in direction to the field.

- (c) Reasoning as in Problem 24.9, we conclude that the field will be zero somewhere to the right of the -5.0×10^{-8} C charge. Represent the distance to that point from the -5.0×10^{-8} C charge by d . At that point,

$$E_1 - E_2 = 0$$

because the field due to the positive charge is to the right, while the field due to the negative charge is to the left. Thus

$$k \left(\frac{|q_1|}{r_1^2} - \frac{|q_2|}{r_2^2} \right) = (9.0 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2) \left[\frac{20 \times 10^{-8} \text{ C}}{(d + 0.10 \text{ m})^2} - \frac{5.0 \times 10^{-8} \text{ C}}{d^2} \right] = 0$$

Simplifying, we obtain

$$3d^2 - 0.2d - 0.01 = 0$$

which gives $d = 0.10$ m and -0.03 m. Only the plus sign has meaning here, and therefore $d = 0.10$ m. The point in question is 10 cm to the right of the negative charge.

- 24.12** Three charges are placed on three corners of a square, as shown in Fig. 24-6. Each side of the square is 30.0 cm. Compute \vec{E} at the fourth corner. What would be the force on a $6.00 \mu\text{C}$ charge placed at the vacant corner?

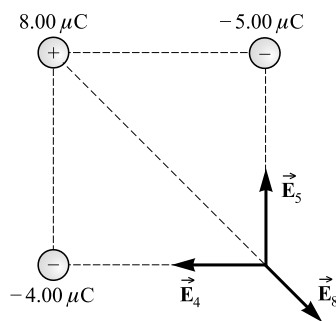


Fig. 24-6

The contributions of the three charges to the field at the vacant corner are as indicated. Notice in particular their directions. Their magnitudes are given by $E = kq/r^2$ to be

$$E_4 = 4.00 \times 10^5 \text{ N/C} \quad E_8 = 4.00 \times 10^5 \text{ N/C} \quad E_5 = 5.00 \times 10^5 \text{ N/C}$$

Because the E_8 vector makes an angle of 45.0° to the horizontal, we have

$$E_x = E_8 \cos 45.0^\circ - E_4 = -1.17 \times 10^5 \text{ N/C}$$

$$E_y = E_5 - E_8 \sin 45.0^\circ = 2.17 \times 10^5 \text{ N/C}$$

Using $E = \sqrt{E_x^2 + E_y^2}$ and $\tan \theta = E_y/E_x$, we find $E = 2.47 \times 10^5 \text{ N}$ at 118° .

The force on a charge placed at the vacant corner would be simply $F_E = Eq$. Since $q = 6.00 \times 10^{-6} \text{ C}$, we have $F_E = 1.48 \text{ N}$ at an angle of 118° .

- 24.13** Two charged metal plates in vacuum are 15 cm apart as shown in Fig. 24-7. The electric field between the plates is uniform and has a strength of $E = 3000 \text{ N/C}$. An electron ($q = -e$, $m_e = 9.1 \times 10^{-31} \text{ kg}$) is released from rest at point P just outside the negative plate. (a) How long will it take to reach the other plate? (b) How fast will it be going just before it hits?

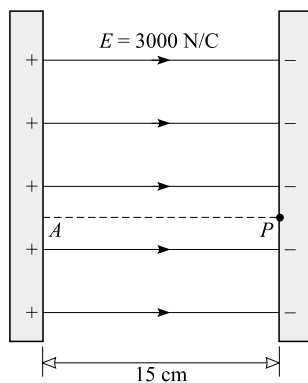


Fig. 24-7

The electric field lines show the force on a positive charge. (A positive charge would be repelled to the right by the positive plate and attracted to the right by the negative plate.) An electron, being negative, will experience a force in the opposite direction, toward the left, of magnitude

$$F_E = |q|E = (1.6 \times 10^{-19} \text{ C})(3000 \text{ N/C}) = 4.8 \times 10^{-16} \text{ N}$$

Because of this force, the electron experiences an acceleration toward the left given by

$$a = \frac{F_E}{m} = \frac{4.8 \times 10^{-16} \text{ N}}{9.1 \times 10^{-31} \text{ kg}} = 5.3 \times 10^{14} \text{ m/s}^2$$

In the motion problem for the electron released at the negative plate and traveling to the positive plate,

$$v_i = 0 \quad x = 0.15 \text{ m} \quad a = 5.3 \times 10^{14} \text{ m/s}^2$$

(a) From $x = v_i t + \frac{1}{2} a t^2$ we have

$$t = \sqrt{\frac{2x}{a}} = \sqrt{\frac{(2)(0.15 \text{ m})}{5.3 \times 10^{14} \text{ m/s}^2}} = 2.4 \times 10^{-8} \text{ s}$$

(b) $v = v_i + at = 0 + (5.3 \times 10^{14} \text{ m/s}^2)(2.4 \times 10^{-8} \text{ s}) = 1.30 \times 10^7 \text{ m/s}$

As you will see in Chapter 41, relativistic effects begin to become important at speeds above this. Therefore, this approach must be modified for very fast particles.

24.14 Suppose in Fig. 24-7 an electron is shot straight upward from point P with a speed of $5.0 \times 10^6 \text{ m/s}$. How far above A will it strike the positive plate?

This is a projectile problem. (Since the gravitational force is so small compared to the electrical force, we ignore gravity.) The only force acting on the electron after its release is the horizontal electric force. We found in Problem 24.13(a) that under the action of this force the electron has a time-of-flight of $2.4 \times 10^{-8} \text{ s}$. The vertical displacement in this time is

$$(5.0 \times 10^6 \text{ m/s})(2.4 \times 10^{-8} \text{ s}) = 0.12 \text{ m}$$

The electron strikes the positive plate 12 cm above point A .

24.15 In Fig. 24-7 a proton ($q = +e$, $m = 1.67 \times 10^{-27} \text{ kg}$) is shot with speed $2.00 \times 10^5 \text{ m/s}$ toward P from A . What will be its speed just before hitting the plate at P ?

$$a = \frac{F_E}{m} = \frac{qE}{m} = \frac{(1.60 \times 10^{-19} \text{ C})(3000 \text{ N/C})}{1.67 \times 10^{-27} \text{ kg}} = 2.88 \times 10^{11} \text{ m/s}^2$$

For the problem involving horizontal motion,

$$v_i = 2.00 \times 10^5 \text{ m/s} \quad x = 0.15 \text{ m} \quad a = 2.88 \times 10^{11} \text{ m/s}^2$$

We use $v_f^2 = v_i^2 + 2ax$ to find

$$v_f = \sqrt{v_i^2 + 2ax} = \sqrt{(2.00 \times 10^5 \text{ m/s})^2 + (2)(2.88 \times 10^{11} \text{ m/s}^2)(0.15 \text{ m})} = 356 \text{ km/s}$$

24.16 Two identical tiny metal balls have charges q_1 and q_2 . The repulsive force one exerts on the other when they are 20 cm apart is $1.35 \times 10^{-4} \text{ N}$. After the balls are touched together and then separated once again to 20 cm, the repulsive force is found to be $1.406 \times 10^{-4} \text{ N}$. Find q_1 and q_2 .

Because the force is one of repulsion, q_1 and q_2 are of the same sign. After the balls are touched, they share charge equally, so each has a charge $\frac{1}{2}(q_1 + q_2)$. Writing Coulomb's Law for the two situations described, we have

$$0.000\,135\text{ N} = k \frac{q_1 q_2}{0.040\text{ m}^2}$$

$$\text{and} \quad 0.000\,140\,6\text{ N} = k \frac{[\frac{1}{2}(q_1 + q_2)]^2}{0.040\text{ m}^2}$$

After substitution for k , these equations reduce to

$$q_1 q_2 = 6.00 \times 10^{-16}\text{ C}^2 \quad \text{and} \quad q_1 + q_2 = 5.00 \times 10^{-8}\text{ C}$$

Solving these equations simultaneously gives $q_1 = 20\text{ nC}$ and $q_2 = 30\text{ nC}$ (or vice versa). Alternatively, both charges could have been negative.

Supplementary Problems

- 24.17** How many electrons are contained in 1.0 C of charge? What is the mass of the electrons in 1.0 C of charge? *Ans.* 6.2×10^{18} electrons, $5.7 \times 10^{-12}\text{ kg}$
- 24.18** If two equal charges, each of 1 C, were separated in air by a distance of 1 km, what would be the force between them? *Ans.* 9 kN repulsion
- 24.19** Determine the force between two free electrons spaced 1.0 angstrom (10^{-10} m) apart. *Ans.* 23 nN repulsion
- 24.20** What is the force of repulsion between two argon nuclei that are separated by 1.0 nm (10^{-9} m)? The charge on an argon nucleus is $+18e$. *Ans.* 75 nN
- 24.21** Two equally charged balls are 3 cm apart in air and repel each other with a force of $40\text{ }\mu\text{N}$. Compute the charge on each ball. *Ans.* 2 nC
- 24.22** Three point charges are placed at the following points on the x -axis: $+2.0\text{ }\mu\text{C}$ at $x = 0$, $-3.0\text{ }\mu\text{C}$ at $x = 40\text{ cm}$, $-5.0\text{ }\mu\text{C}$ at $x = 120\text{ cm}$. Find the force (a) on the $-3.0\text{ }\mu\text{C}$ charge, (b) on the $-5.0\text{ }\mu\text{C}$ charge. *Ans.* (a) -0.55 N ; (b) 0.15 N
- 24.23** Four equal point charges of $+3.0\text{ }\mu\text{C}$ are placed at the four corners of a square that is 40 cm on a side. Find the force on any one of the charges. *Ans.* 0.97 N outward along the diagonal
- 24.24** Four equal-magnitude point charges ($3.0\text{ }\mu\text{C}$) are placed at the corners of a square that is 40 cm on a side. Two, diagonally opposite each other, are positive, and the other two are negative. Find the force on either negative charge. *Ans.* 0.46 N inward along the diagonal
- 24.25** Charges of $+2.0$, $+3.0$, and $-8.0\text{ }\mu\text{C}$ are placed at the vertices of an equilateral triangle of side 10 cm. Calculate the magnitude of the force acting on the $-8.0\text{ }\mu\text{C}$ charge due to the other two charges. *Ans.* 31 N
- 24.26** One charge of ($+5.0\text{ }\mu\text{C}$) is placed at exactly $x = 0$, and a second charge ($+7.0\text{ }\mu\text{C}$) at $x = 100\text{ cm}$. Where can a third be placed so as to experience zero net force due to the other two? *Ans.* at $x = 46\text{ cm}$
- 24.27** Two identical tiny metal balls carry charges of $+3\text{ nC}$ and -12 nC . They are 3 m apart. (a) Compute the force of attraction. (b) The balls are now touched together and then separated to 3 cm. Describe the forces on them now. *Ans.* (a) $4 \times 10^{-4}\text{ N}$ attraction; (b) $2 \times 10^{-4}\text{ N}$ repulsion
- 24.28** A charge of $+6.0\text{ }\mu\text{C}$ experiences a force of 2.0 mN in the $+x$ -direction at a certain point in space. (a) What was the electric field there before the charge was placed there? (b) Describe the force a $-2.0\text{ }\mu\text{C}$ charge would

experience if it were used in place of the $+6.0\ \mu\text{C}$ charge. *Ans.* (a) $0.33\ \text{kN/C}$ in $+x$ -direction; (b) $0.67\ \text{mN}$ in $-x$ -direction

24.29 A point charge of $-3.0 \times 10^{-5}\ \text{C}$ is placed at the origin of coordinates. Find the electric field at the point $x = 5.0\ \text{m}$ on the x -axis. *Ans.* $11\ \text{kN/C}$ in $-x$ -direction

24.30 Four equal-magnitude ($4.0\ \mu\text{C}$) charges are placed at the four corners of a square that is $20\ \text{cm}$ on each side. Find the electric field at the center of the square (a) if the charges are all positive, (b) if the charges alternate in sign around the perimeter of the square, (c) if the charges have the following sequence around the square: plus, plus, minus, minus. *Ans.* (a) zero; (b) zero; (c) $5.1\ \text{MN/C}$ toward the negative side

24.31 A 0.200-g ball hangs from a thread in a vertical electric field of $3.00\ \text{kN/C}$ directed upward. What is the charge on the ball if the tension in the thread is (a) zero and (b) $4.00\ \text{mN}$? *Ans.* (a) $+653\ \text{nC}$; (b) $-680\ \text{nC}$

24.32 Determine the acceleration of a proton ($q = +e$, $m = 1.67 \times 10^{-27}\ \text{kg}$) in an electric field of strength $0.50\ \text{kN/C}$. How many times is this acceleration greater than that due to gravity? *Ans.* $4.8 \times 10^{10}\ \text{m/s}^2$, 4.9×10^9

24.33 A tiny, 0.60-g ball carries a charge of magnitude $8.0\ \mu\text{C}$. It is suspended by a thread in a downward $300\ \text{N/C}$ electric field. What is the tension in the thread if the charge on the ball is (a) positive, (b) negative? *Ans.* (a) $8.3\ \text{mN}$; (b) $3.5\ \text{mN}$

24.34 The tiny ball at the end of the thread shown in Fig. 24-8 has a mass of $0.60\ \text{g}$ and is in a horizontal electric field of strength $700\ \text{N/C}$. It is in equilibrium in the position shown. What are the magnitude and sign of the charge on the ball? *Ans.* $-3.1\ \mu\text{C}$

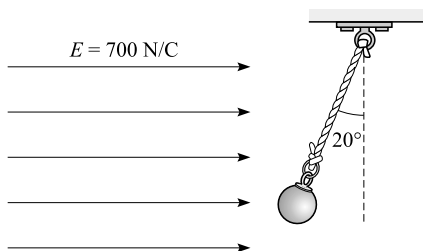


Fig. 24-8

24.35 An electron ($q = -e$, $m_e = 9.1 \times 10^{-31}\ \text{kg}$) is projected out along the $+x$ -axis with an initial speed of $3.0 \times 10^6\ \text{m/s}$. It goes $45\ \text{cm}$ and stops due to a uniform electric field in the region. Find the magnitude and direction of the field. *Ans.* $57\ \text{N/C}$ in $+x$ -direction

24.36 A particle of mass m and charge $-e$ is projected with horizontal speed v into an electric field (E) directed downward. Find (a) the horizontal and vertical components of its acceleration, a_x and a_y ; (b) its horizontal and vertical displacements, x and y , after time t ; (c) the equation of its trajectory. *Ans.* (a) $a_x = 0$, $a_y = Ee/m$; (b) $x = vt$, $y = \frac{1}{2}a_y t^2 = \frac{1}{2}(Ee/m)t^2$; (c) $y = \frac{1}{2}(Ee/mv^2)x^2$ (a parabola)