7.2 Electric Forces: Coulomb's Law

All the matter around you contains charged particles, and it is the electric forces between these charged particles that determine the strength of the materials and the properties of the substances. But knowing whether the charges attract or repel is not enough; we must also know the factors that determine the magnitude of the electric force between charges. Investigation 7.2.1 in the Lab Activities section at the end of this chapter explores these factors.

Often scientists use well-established theories, patterns, and laws when investigating new phenomena. For example, when scientists began, in the eighteenth century, to study in a systematic way the electric force between charges, they hypothesized that the force would obey an inverse square law, drawing upon their experience with gravitation. In fact, in 1785, when the French physicist Charles Augustin de Coulomb experimentally established the quantitative nature of the electric force between charged particles, it was already widely expected to be an inverse square law.

Coulomb devised a torsion balance similar to that used by Cavendish in his study of gravitational forces but with small charged spheres in place of Cavendish's masses (**Figure 1**).

Coulomb's apparatus consisted of a silver wire attached to the middle of a light horizontal insulating rod. At one end of the rod was a pith ball covered in gold foil. At the other end, to balance the rod, a paper disk was attached. Coulomb brought an identical stationary ball into contact with the suspended ball. He charged both balls equally by touching one of them with a charged object. The two balls then repelled each other, twisting the wire holding the rod until coming to rest some distance away.

Since Coulomb knew how much force was required to twist his wire through any angle, he was able to show that the magnitude of this electric force, F_E, was inversely proportional to the square of the distance, r, between the centres of his charged spheres (**Figure 2**):

$$F_E \propto \frac{1}{r^2}$$

Coulomb also investigated the relationship between the magnitude of the electric force and the charge on the two spheres. By touching either charged sphere with an identical neutral sphere, he was able to divide its charge in half. By repeatedly touching

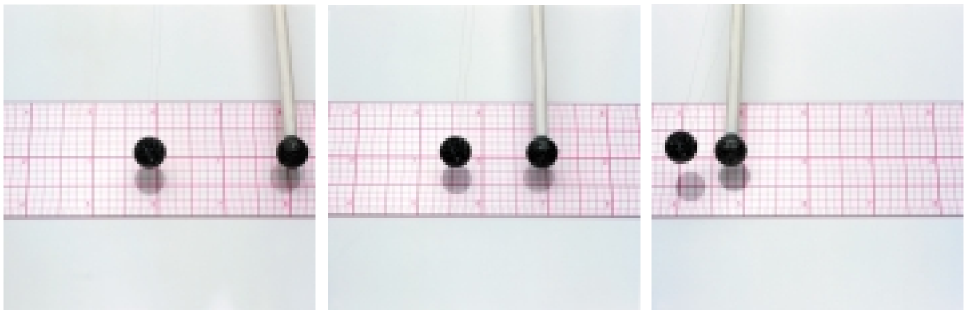
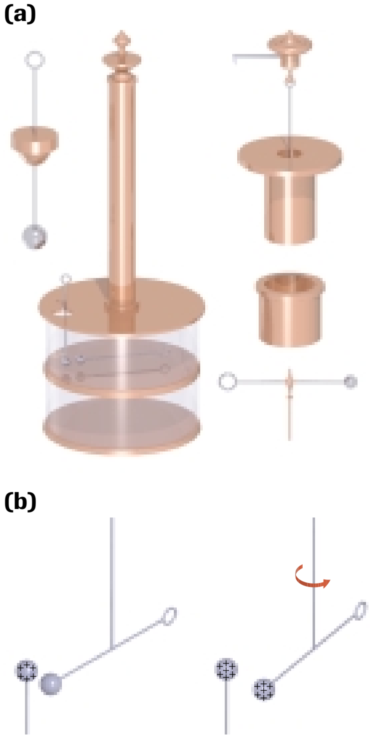


Figure 2
The electrostatic force of repulsion between two identical spheres at different distances

INVESTIGATION 7.2.1

Factors Affecting Electric Force between Charges (p. 372)
How would you show that the force between charged particles obeys an inverse square law? Can you devise two or three different experiments?

(a)



(b)

Figure 1
(a) Part of Coulomb's device
(b) The two similarly charged spheres repel each other, twisting the wire until the restoring force from the wire, which resists the twist, balances the electrostatic force.

a charged sphere with an identical neutral sphere, he was able to reduce the charge to a quarter, an eighth, a sixteenth, ... of its original value. Such manipulations revealed that, for example, halving the charge on one sphere decreased the force of electrostatic repulsion to half its original value, whereas halving both charges reduced the force to a quarter of its initial value. Coulomb concluded that the magnitude of the electric force is directly proportional to the product of the magnitudes of the charges on each sphere:

$$F_E \propto q_1 q_2$$

where q_1 and q_2 are the respective magnitudes of the charges on the two spheres.

Combining these two results, we have what has become known as Coulomb's law of electric forces:

$$F_E \propto \frac{q_1 q_2}{r^2}$$

and $$F_E = \frac{k q_1 q_2}{r^2}$$

where k is a proportionality constant, known as Coulomb's constant.

Coulomb's law applies when the charges on the two spheres are very small, and the two spheres are small compared to the distance between them. In this case, the charge distribution on the surface of the spheres will be fairly uniform. If the charge on a sphere is uniformly distributed, then the force measured between the two spheres is the same as if all the charge on each sphere is concentrated at the centre. (This is why we measure r from the centre of each sphere.) It can be assumed that Coulomb's law is extremely accurate when using point charges and reasonably accurate when the spheres are small.

The difference in accuracy is due to the presence of the second charged sphere that causes the charge on the surface of each sphere to redistribute so r can no longer be measured from the centre of the spheres. When the spheres are small, the charge distribution stays nearly uniform due to the strong repulsive forces between the charges on each sphere. This is only true if the distance between the spheres is large compared to the size of the spheres.

Now *Coulomb's law* may be defined in words:

Coulomb's Law

The force between two point charges is inversely proportional to the square of the distance between the charges and directly proportional to the product of the charges.

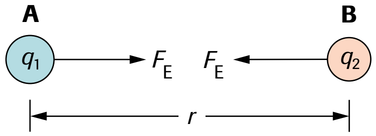


Figure 3
By Newton's third law, the electric force exerted on body A by body B is equal in magnitude and opposite in direction to the force exerted on B by A.

The forces act along the line connecting the two point charges. The charges will repel if the forces are alike and attract if unlike. In all cases, Coulomb's law is consistent with Newton's third law, so when using the equation to find the magnitude of one of the forces, the magnitude of the force on the other sphere is also known to be equal in magnitude but opposite in direction (**Figure 3**). However, to calculate the magnitude of an electric force quantitatively, in newtons, using Coulomb's law, it is necessary to measure the magnitude of each electric charge, q_1 and q_2, as well as establish a numerical value for the Coulomb proportionality constant, k.

coulomb (C) the SI unit of electric charge

Electric charge is measured in units called **coulombs** (SI unit, C). The exact definition of a coulomb of charge depends on the force acting between conductors through which charged particles are moving. This will be explained fully in Chapter 8, when we learn about these forces. How large, in practical terms, is the coulomb? A coulomb is approximately the amount of electric charge that passes through a standard 60-W light bulb (if connected to direct current) in 2 s. In comparison, an electrostatic shock that you might receive from touching a metallic doorknob after walking across a woollen rug, involves the transfer of much less than a microcoulomb. Charging by friction typically builds up around 10 nC (10^{-8} C) for every square centimetre of surface area. The attempt to add more charge typically results in a discharge into the air. Therefore, storing even 1 C of charge is difficult. Because Earth is so large, it actually stores a huge charge, roughly 400 000 C, and releases approximately 1500 C of charge every second in storm-free areas to the atmosphere. The balance of charge is maintained on Earth by other objects dumping excess charge through grounding and when lightning strikes Earth. A bolt may transfer up to 20 C (**Figure 4**).

Figure 4
The charge transfer that occurs between Earth and the clouds maintains the balance of charge.

The value of the proportionality constant k may be determined using a torsional balance similar to that used by Cavendish. By placing charges of known magnitude a given distance apart and measuring the resulting angle of twist in the suspending wire, we can find a value for the electric force causing the twist. Then, using Coulomb's law in the form

$$k = \frac{F_E r^2}{q_1 q_2}$$

a rough value for k can be determined. Over the years, a great deal of effort has gone into the design of intricate equipment for measuring k accurately. To two significant digits, the accepted value for this constant is

$$k = 9.0 \times 10^9 \text{ N·m}^2/\text{C}^2$$

SAMPLE problem 1

The magnitude of the electrostatic force between two small, essentially pointlike, charged objects is 5.0×10^{-5} N. Calculate the force for each of the following situations:

(a) The distance between the charges is doubled, while the size of the charges stays the same.

(b) The charge on one object is tripled, while the charge on the other is halved.

(c) Both of the changes in (a) and (b) occur simultaneously.

Solution

$F_1 = 5.0 \times 10^{-5}$ N

$F_2 = ?$

(a) Since $F_E \propto \frac{1}{r^2}$,

$$\frac{F_2}{F_1} = \left(\frac{r_1}{r_2}\right)^2$$

$$F_2 = F_1\left(\frac{r_1}{r_2}\right)^2$$

$$= (5.0 \times 10^{-5}\text{ N})\left(\frac{1}{2}\right)^2$$

$$F_2 = 1.2 \times 10^{-5}\text{ N}$$

When the distance between the charges is doubled, the magnitude of the force decreases to 1.2×10^{-5} N.

(b) Since $F_E \propto q_A q_B$,

$$\frac{F_2}{F_1} = \frac{q_{A_2} q_{B_2}}{}$$

$$F_2 = F_1\left(\frac{q_{A_2}}{q_{A_1}}\right)\left(\frac{q_{B_2}}{q_{B_1}}\right)$$

$$= (5.0 \times 10^{-5}\ \text{N})\left(\frac{1}{2}\right)\left(\frac{3}{1}\right)$$

$$F_2 = 7.5 \times 10^{-5}\ \text{N}$$

When the charge on one object is tripled, and the charge on the other object is halved, the magnitude of the force increases to 7.5×10^{-5} N.

(c) Since $F_E \propto \frac{q_A q_B}{r^2}$,

$$\frac{F_2}{F_1} = \left(\frac{q_{A_2} q_{B_2}}{}\right)\left(\frac{r_1}{r_2}\right)^2$$

$$F_2 = F_1\left(\frac{q_{A_2}}{q_{A_1}}\right)\left(\frac{q_{B_2}}{q_{B_1}}\right)\left(\frac{r_1}{r_2}\right)^2$$

$$= (5.0 \times 10^{-5}\ \text{N})\left(\frac{1}{2}\right)\left(\frac{3}{1}\right)\left(\frac{1}{2}\right)^2$$

$$F_2 = 1.9 \times 10^{-5}\ \text{N}$$

When the charges and the separation from (a) and (b) change simultaneously, the magnitude of the force decreases to 1.9×10^{-5} N.

SAMPLE problem 2

What is the magnitude of the force of repulsion between two small spheres 1.0 m apart, if each has a charge of 1.0×10^{-12} C?

Solution

$q_1 = q_2 = 1.0 \times 10^{-12}$ C

$r = 1.0$ m

$F_E = ?$

$$F_E = \frac{kq_1q_2}{r^2}$$

$$= \frac{(9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.0 \times 10^{-12}\ \text{C})^2}{(1.0\ \text{m})^2}$$

$$F_E = 9.0 \times 10^{-15}\ \text{N}$$

The magnitude of the force of repulsion is 9.0×10^{-15} N, a very small force.

Practice

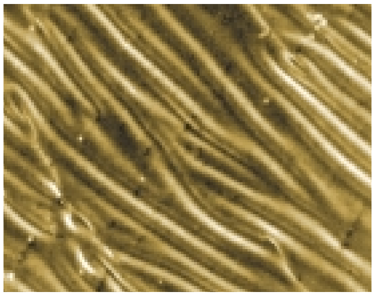
Understanding Concepts

1. Two charged spheres, 10.0 cm apart, attract each other with a force of magnitude 3.0×10^{-6} N. What force results from each of the following changes, considered separately?

(a) Both charges are doubled, while the distance remains the same.

DID YOU KNOW?

Adhesive Tape



The electrostatic force contributes to the stickiness of adhesive tape. When adhesive tape is attached to another material, the distance between the charges in the two materials is very small. The electrons can pass over the small distance, causing the two objects to have opposite charges and contributing to the adhesive bond. The small pits are there because, when pulling adhesive tape off a surface, parts of the adhesive stay stuck on the material.

Answer

1. (a) 1.2×10^{-5} N

(b) An uncharged, identical sphere is touched to one of the spheres and is then taken far away.
(c) The separation is increased to 30.0 cm.

2. The magnitude of the force of electrostatic repulsion between two small positively charged objects, A and B, is 3.6×10^{-5} N when $r = 0.12$ m. Find the force of repulsion if r is increased to (a) 0.24 m, (b) 0.30 m, and (c) 0.36 m.

3. Calculate the force between charges of 5.0×10^{-8} C and 1.0×10^{-7} C if they are 5.0 cm apart.

4. Calculate the magnitude of the force a 1.5×10^{-6} C charge exerts on a 3.2×10^{-4} C charge located 1.5 m away.

5. Two oppositely charged spheres, with a centre-to-centre separation of 4.0 cm, attract each other with a force of magnitude 1.2×10^{-9} N. The magnitude of the charge on one sphere is twice the magnitude of the charge on the other. Determine the magnitude of the charge on each.

6. Two equal uniform spherical charges, each of magnitude 1.1×10^{-7} C, experience an electrostatic force of magnitude 4.2×10^{-4} N. How far apart are the centres of the two charges?

7. Two identical small spheres of mass 2.0 g are fastened to the ends of an insulating thread of length 0.60 m. The spheres are suspended by a hook in the ceiling from the centre of the thread. The spheres are given identical electric charges and hang in static equilibrium, with an angle of 30.0° between the string halves, as shown in **Figure 5**. Calculate the magnitude of the charge on each sphere.

Answers

1. (b) 1.5×10^{-6} N
   (c) 3.3×10^{-7} N
2. (a) 9.0×10^{-6} N
   (b) 5.8×10^{-6} N
   (c) 4.0×10^{-6} N
3. 1.8×10^{-2} N
4. 1.9 N
5. 1.0×10^{-11} C; 2.0×10^{-11} C
6. 0.51 m
7. 1.2×10^{-7} C

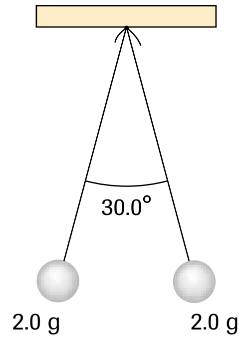


Figure 5
For question 7

Coulomb's Law versus the Law of Universal Gravitation

There are many similarities between Coulomb's law $\left(F_E = \frac{kq_1q_2}{r^2}\right)$ and Newton's law of universal gravitation $\left(F_g = \frac{Gm_1m_2}{r^2}\right)$:

- Both are inverse square laws that are also proportional to the product of another quantity; for gravity it is the product of two masses, and for the electric force it is the product of the two charges.
- The forces act along the line joining the centres of the masses or charges.
- The magnitude of the force is the same as the force that would be measured if all the mass or charge is concentrated at a point at the centre of the sphere. Therefore, distance in both cases is measured from the centres of the spheres. In both cases we are assuming that r is longer than the radius of the object.

These parallels cannot be viewed as a concidence. Their existence implies that there may be other parallels between electric and gravitational forces.

However, the two forces also differ in some important ways:

- The electric force can attract or repel, depending on the charges involved, whereas the gravitational force can only attract.
- The universal gravitational constant, $G = 6.67 \times 10^{-11}$ N·m^2/kg^2, is very small, meaning that in many cases the gravitational force can be ignored unless at least one of the masses is very large. In contrast, Coulomb's constant, $k = 9.0 \times 10^9$ N·m^2/C^2, is a very large number (over one hundred billion billion times bigger than G), implying that even small charges can result in noticeable forces.

Just as a mass can be attracted gravitationally by more than one body at once, so a charge can experience electric forces from more than one body at once. Experiments have shown that the force between two charges can be determined using Coulomb's law independently of the other charges present, and that the net force on a single charge is the vector sum of all these independently calculated electric forces acting on it. If all the charges lie on a straight line, we can treat electric forces like scalars, using plus and minus signs to keep track of directions. If the charges do not lie on a straight line, trigonometry and symmetries are used.

SAMPLE problem 3

Charged spheres A and B are fixed in position (**Figure 6**) and have charges $+4.0 \times 10^{-6}$ C and -2.5×10^{-7} C, respectively. Calculate the net force on sphere C, whose charge is $+6.4 \times 10^{-6}$ C.

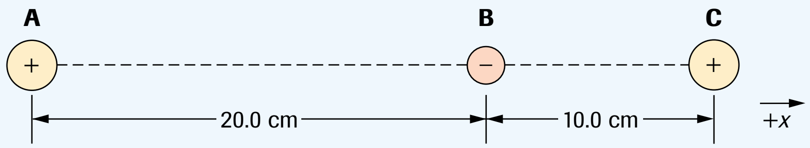


Figure 6

Solution

$q_A = +4.0 \times 10^{-6}$ C $\quad r_{AB} = 20.0$ cm

$q_B = -2.5 \times 10^{-7}$ C $\quad r_{BC} = 10.0$ cm

$q_C = +6.4 \times 10^{-6}$ C $\quad \sum \vec{F}_{net} = ?$

Since all three charges are in a straight line, we can take the vector nature of force into account by assigning forces to the right as positive. Sphere C has forces acting on it from spheres A and B. We first determine the magnitude of the force exerted on C by A:

$$F_{CA} = \frac{kq_A q_C}{r_{CA}^2}$$

$$= \frac{(9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(4.0 \times 10^{-6} \text{ C})(6.4 \times 10^{-6} \text{ C})}{(0.30 \text{ m})^2}$$

$$F_{CA} = 2.6 \text{ N}$$

Therefore, $\vec{F}_{CA} = 2.6$ N [right].

Next, we determine the magnitude of the force exerted on C by B:

$$F_{CB} = \frac{kq_B q_C}{r_{CB}^2}$$

$$= \frac{(9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(2.5 \times 10^{-7} \text{ C})(6.4 \times 10^{-6} \text{ C})}{(0.10 \text{ m})^2}$$

$$F_{CB} = 1.4 \text{ N}$$

Our formulation of Coulomb's law gives only the magnitude of the force. But since B and C are dissimilar charges, we know that B attracts C leftward, so the direction of the force exerted on C by B is

$$\vec{F}_{BC} = 1.4 \text{ N [left]}$$

The net force acting on sphere C is the sum of $\vec{F}_{CA}$ and $\vec{F}_{CB}$:

$$\begin{aligned}\sum\vec{F} &= \vec{F}_{CA} + \vec{F}_{CB}\\ &= 2.6\ \text{N [right]} + 1.4\ \text{N [left]}\\ \sum\vec{F} &= 1.2\ \text{N [right]}\end{aligned}$$

The net force acting on sphere C is 1.2 N [right].

SAMPLE problem 4

Identical spheres A, B, C, and D, each with a charge of magnitude 5.0×10^{-6} C, are situated at the corners of a square whose sides are 25 cm long. Two diagonally opposite charges are positive, the other two negative, as shown in **Figure 7**. Calculate the net force acting on each of the four spheres.

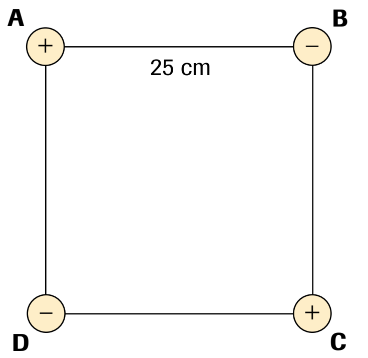


Figure 7
For Sample Problem 4

Solution

$q_A = q_B = q_C = q_D = 5.0 \times 10^{-6}$ C

$s = 25$ cm $= 0.25$ m

$r = 35$ cm $= 0.35$ m

$\sum\vec{F} = ?$

Each sphere experiences three electric forces, one from each of the two adjacent charges (acting along the sides of the square) and one from the more distant charge (acting along the diagonal). While some of the 12 forces acting will be attractions and some will be repulsions, each of the 12 forces has one of just two possible magnitudes: one magnitude in the case of equal charges 25 cm apart, the other in the case of equal charges separated by the length of the diagonal, 35.4 cm. We begin by determining these two magnitudes:

$$\begin{aligned}F_{side} &= \frac{kq_1q_2}{s^2}\\ &= \frac{(9.0 \times 10^9\ \text{N·m}^2/\text{C}^2)(5.0 \times 10^{-6}\ \text{C})^2}{(0.25\ \text{m})^2}\\ F_{side} &= 3.6\ \text{N}\end{aligned}$$

$$\begin{aligned}F_{diag} &= \frac{kq_1q_2}{r^2}\\ &= \frac{(9.0 \times 10^9\ \text{N·m}^2/\text{C}^2)(5.0 \times 10^{-6}\ \text{C})^2}{(0.35\ \text{m})^2}\\ F_{diag} &= 1.8\ \text{N}\end{aligned}$$

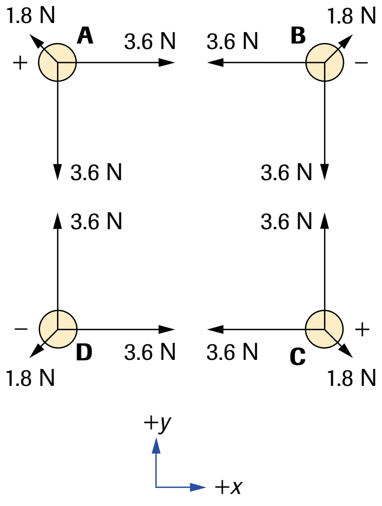


Figure 8
For the solution to Sample Problem 4

Then draw a vector diagram showing each of these forces with its vector in the appropriate direction, whether an attraction or repulsion. The required diagram is shown in **Figure 8**. We find that the forces acting on each sphere are similar, comprising in each case an attraction of 3.6 N along two sides of the square and a repulsion of 1.8 N along the diagonal. The net force on each sphere is the vector sum of these three forces. As an example, we find the three-vector sum for sphere A. Using the rules for vector addition, and drawing the vectors tip-to-tail, we obtain the diagram in **Figure 9**.

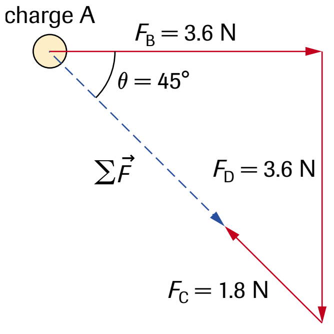


Figure 9
The net force on charge A

The desired sum (the dashed vector) has a magnitude equal to the length of the hypotenuse in the vector triangle minus 1.8 N. The magnitude of the hypotenuse is

$$\sqrt{(3.6\ \text{N})^2 + (3.6\ \text{N})^2} = 5.1\ \text{N}$$

Therefore,

$$\left|\sum\vec{F}\right| = 5.1\text{ N} - 1.8\text{ N}$$
$$\left|\sum\vec{F}\right| = 3.3\text{ N}$$

We can now find the direction of the vector sum from the diagram:

$$\sum\vec{F} = 3.3\text{ N [45° down from right]}$$

The same calculation at each of the other three corners produces the same result: a net force of 3.3 N directed inward along the corresponding diagonal.

The same problem may be readily solved using components of the forces, in the *x* and *y* directions, acting on each sphere.

For the force on sphere A:

$$\sum\vec{F} = \vec{F}_B + \vec{F}_C + \vec{F}_D$$

Components in the x direction:

$$F_{Ax} = F_{Bx} + F_{Cx} + F_{Dx} = 3.6\text{ N} + (-1.8\text{ N}\cos 45°) + 0 = 2.3\text{ N}$$

Components in the y direction:

$$F_{Ay} = F_{By} + F_{Cy} + F_{Dy} = 0 + (+1.8\text{ N}\cos 45°) + (-3.6\text{ N}) = -2.3\text{ N}$$

Therefore,

$$\sum F = \sqrt{(F_{Ax})^2 + (F_{Ay})^2}$$
$$= \sqrt{(2.3\text{ N}) + (-2.3\text{ N})^2}$$
$$\sum F = 3.3\text{ N}$$

$$\theta = \tan^{-1}\frac{|F_{Ay}|}{|F_{Ax}|}$$
$$= \tan^{-1}1$$
$$\theta = 45°$$

$$\sum\vec{F} = 3.3\text{ N [45° down from right]}$$

The net force acting on each charge is 3.3 N toward the centre of the square.

Practice

Understanding Concepts

8. Three objects, carrying charges of -4.0×10^{-6} C, -6.0×10^{-6} C, and $+9.0 \times 10^{-6}$ C, are placed in a line, equally spaced from left to right by a distance of 0.50 m. Calculate the magnitude and direction of the net force acting on each.

9. Three spheres, each with a negative charge of 4.0×10^{-6} C, are fixed at the vertices of an equilateral triangle whose sides are 0.20 m long. Calculate the magnitude and direction of the net electric force on each sphere.

Answers

8. 0.54 N [left]; 2.8 N [right]; 2.3 N [left]
9. 6.2 N [outward, 150° away from each side]

SUMMARY Electric Forces: Coulomb's Law

- Coulomb's law states that the force between two point charges is inversely proportional to the square of the distance between the charges and directly proportional to the product of the charges: $F_E = \frac{kq_1q_2}{r^2}$, where $k = 9.0 \times 10^9 \text{ N·m}^2/\text{C}^2$.
- Coulomb's law applies when the charges on the two spheres are very small, and the two spheres are small compared to the distance between them.
- There are similarities and differences between Coulomb's law and Newton's law of universal gravitation: Both are inverse square laws that are also proportional to the product of quantities that characterize the bodies involved; the forces act along the line joining the two centres of the masses or charges; and the magnitude of the force is accurately given by the force that would be measured if all the mass or charge is concentrated at a point at the centre of the sphere. However, the gravitational force can only attract while the electric force can attract or repel. The universal gravitational constant is very small, while Coulomb's constant is very large.

Section 7.2 Questions

Understanding Concepts

1. (a) Describe the electric force between two small charges and compare this force to the gravitational force between two small masses. How are the two forces different?
   (b) State Coulomb's law and Newton's law of universal gravitation. In which respect are these two laws similar? How are they different? Organize your answer by copying and completing **Figure 10**.

Venn Diagram

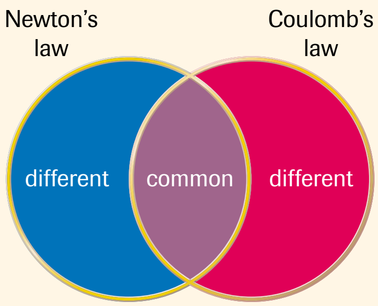


Figure 10

2. Two identical metal spheres, each with positive charge q, are separated by a centre-to-centre distance r. What effect will each of the following changes have on the magnitude of the electric force F_E exerted on each sphere by the other?
   (a) The distance between the two spheres is tripled.
   (b) The distance between the two spheres is halved.
   (c) Both charges are doubled.
   (d) One of the charges becomes negative.
   (e) One sphere is touched by an identical neutral sphere, which is then taken far away and the distance is decreased to $\frac{2}{3}r$.
3. Two small spheres of charge $+5.0\ \mu\text{C}$ and $-4.0\ \mu\text{C}$ are separated by a distance of 2.0 m. Determine the magnitude of the force that each sphere exerts on the other.
4. Two 10.0-kg masses, each with a charge of $+1.0$ C, are separated by a distance of 0.500 km in interstellar space, far from other masses and charges.
   (a) Calculate the force of gravity between the two objects.
   (b) Calculate the electric force between the two objects.
   (c) Draw FBDs showing all the forces acting on the objects.
   (d) Calculate the net force on each object, and use it to find the initial acceleration of each object.
   (e) Repeat (c) ignoring the gravitational force. What have you found?

5. Two identically charged small spheres, of negligible mass, are separated by a centre-to-centre distance of 2.0 m. The force between them is 36 N. Calculate the charge on each sphere.
6. Neutral metal sphere A, of mass 0.10 kg, hangs from an insulating wire 2.0 m long. An identical metal sphere B, with charge $-q$, is brought into contact with sphere A. The spheres repel and settle as shown in **Figure 11**. Calculate the initial charge on B.

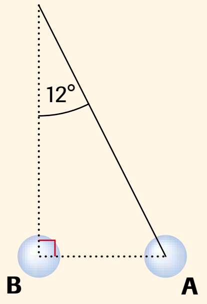


Figure 11

7. Three objects with charges $+5.0\ \mu C$, $-6.0\ \mu C$, and $+7.0\ \mu C$ are placed in a line, as in **Figure 12**. Determine the magnitude and direction of the net electric force on each charge.

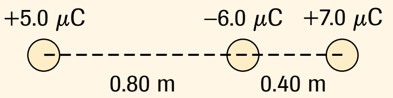


Figure 12

8. Four objects, each with a positive charge of 1.0×10^{-5} C, are placed at the corners of a 45° rhombus with sides of length 1.0 m, as in **Figure 13**. Calculate the magnitude of the net force on each charge.

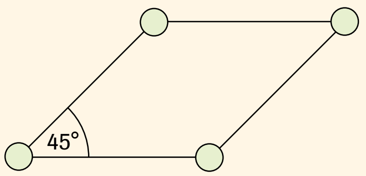


Figure 13

9. Two small spheres, with charges 1.6×10^{-5} C and 6.4×10^{-5} C, are 2.0 m apart. The charges have the same sign. Where, relative to these two spheres, should a third sphere, of opposite charge 3.0×10^{-6} C, be placed if the third sphere is to experience no net electrical force? Do we really need to know the charge or sign of the third object?
10. Two spheres are attached to two identical springs and separated by 8.0 cm, as in **Figure 14**. When a charge of 2.5×10^{-6} C is placed on each sphere, the distance between the spheres doubles. Calculate the force constant k of the springs.

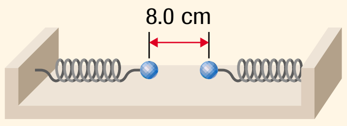


Figure 14

Applying Inquiry Skills

11. A charged sphere is attached to an insulating spring on a horizontal surface. Assume no charge is lost to the surroundings. An identical sphere is attached to an insulating rod. Using only this equipment, design an experiment to verify Coulomb's law. How will the compression of the spring be related to the product of the charges and the distance between the charges?

Making Connections

12. Under normal circumstances, we are not aware of the electric or gravitational forces between two objects.
    (a) Explain why this is so for each force.
    (b) Describe an example for each in which we are aware of the force. Explain why.
13. Assume the electric force, instead of gravity, holds the Moon in its orbit around Earth. Assume the charge on Earth is $-q$ and the charge on the Moon is $+q$.
    (a) Find q, the magnitude of the charge required on each to hold the Moon in orbit. (See Appendix C for data.)
    (b) How stable do you think this orbit would be over long periods of time? (Will the charges stay constant?) Explain what might happen to the Moon.