

$$= (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \times \frac{(1.60 \times 10^{-19} \text{ C})(1.60 \times 10^{-19} \text{ C})}{(0.530 \times 10^{-10} \text{ m})^2}$$
18.6

Thus the Coulomb force is

$$F = 8.19 \times 10^{-8} \text{ N}.$$
18.7

The charges are opposite in sign, so this is an attractive force. This is a very large force for an electron—it would cause an acceleration of  $8.99 \times 10^{22} \text{ m/s}^2$  (verification is left as an end-of-section problem). The gravitational force is given by Newton's law of gravitation as:

$$F_G = G \frac{mM}{r^2},$$
18.8

where  $G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$ . Here  $m$  and  $M$  represent the electron and proton masses, which can be found in the appendices. Entering values for the knowns yields

$$F_G = (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2) \times \frac{(9.11 \times 10^{-31} \text{ kg})(1.67 \times 10^{-27} \text{ kg})}{(0.530 \times 10^{-10} \text{ m})^2} = 3.61 \times 10^{-47} \text{ N}$$
18.9

This is also an attractive force, although it is traditionally shown as positive since gravitational force is always attractive. The ratio of the magnitude of the electrostatic force to gravitational force in this case is, thus,

$$\frac{F}{F_G} = 2.27 \times 10^{39}.$$
18.10

### Discussion

This is a remarkably large ratio! Note that this will be the ratio of electrostatic force to gravitational force for an electron and a proton at any distance (taking the ratio before entering numerical values shows that the distance cancels). This ratio gives some indication of just how much larger the Coulomb force is than the gravitational force between two of the most common particles in nature.

As the example implies, gravitational force is completely negligible on a small scale, where the interactions of individual charged particles are important. On a large scale, such as between the Earth and a person, the reverse is true. Most objects are nearly electrically neutral, and so attractive and repulsive **Coulomb forces** nearly cancel. Gravitational force on a large scale dominates interactions between large objects because it is always attractive, while Coulomb forces tend to cancel.

## 18.4 Electric Field: Concept of a Field Revisited

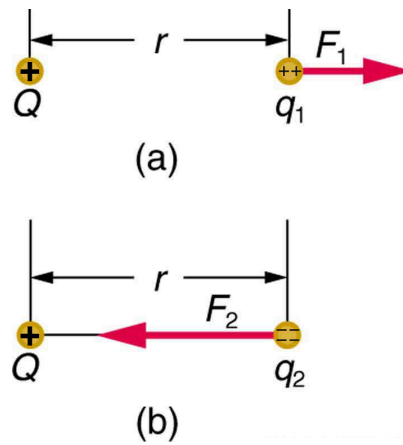
Contact forces, such as between a baseball and a bat, are explained on the small scale by the interaction of the charges in atoms and molecules in close proximity. They interact through forces that include the **Coulomb force**. Action at a distance is a force between objects that are not close enough for their atoms to “touch.” That is, they are separated by more than a few atomic diameters.

For example, a charged rubber comb attracts neutral bits of paper from a distance via the Coulomb force. It is very useful to think of an object being surrounded in space by a **force field**. The force field carries the force to another object (called a test object) some distance away.

### Concept of a Field

A field is a way of conceptualizing and mapping the force that surrounds any object and acts on another object at a distance without apparent physical connection. For example, the gravitational field surrounding the earth (and all other masses) represents the gravitational force that would be experienced if another mass were placed at a given point within the field.

In the same way, the Coulomb force field surrounding any charge extends throughout space. Using Coulomb's law,  $F = k|q_1 q_2|/r^2$ , its magnitude is given by the equation  $F = k|qQ|/r^2$ , for a **point charge** (a particle having a charge  $Q$ ) acting on a **test charge**  $q$  at a distance  $r$  (see [Figure 18.20](#)). Both the magnitude and direction of the Coulomb force field depend on  $Q$  and the test charge  $q$ .



**Figure 18.20** The Coulomb force field due to a positive charge  $Q$  is shown acting on two different charges. Both charges are the same distance from  $Q$ . (a) Since  $q_1$  is positive, the force  $F_1$  acting on it is repulsive. (b) The charge  $q_2$  is negative and greater in magnitude than  $q_1$ , and so the force  $F_2$  acting on it is attractive and stronger than  $F_1$ . The Coulomb force field is thus not unique at any point in space, because it depends on the test charges  $q_1$  and  $q_2$  as well as the charge  $Q$ .

To simplify things, we would prefer to have a field that depends only on  $Q$  and not on the test charge  $q$ . The electric field is defined in such a manner that it represents only the charge creating it and is unique at every point in space. Specifically, the electric field  $E$  is defined to be the ratio of the Coulomb force to the test charge:

$$\mathbf{E} = \frac{\mathbf{F}}{q}, \quad 18.11$$

where  $\mathbf{F}$  is the electrostatic force (or Coulomb force) exerted on a positive test charge  $q$ . It is understood that  $\mathbf{E}$  is in the same direction as  $\mathbf{F}$ . It is also assumed that  $q$  is so small that it does not alter the charge distribution creating the electric field. The units of electric field are newtons per coulomb (N/C). If the electric field is known, then the electrostatic force on any charge  $q$  is simply obtained by multiplying charge times electric field, or  $\mathbf{F} = q\mathbf{E}$ . Consider the electric field due to a point charge  $Q$ . According to Coulomb's law, the force it exerts on a test charge  $q$  is  $F = k|qQ|/r^2$ . Thus the magnitude of the electric field,  $E$ , for a point charge is

$$E = \left| \frac{F}{q} \right| = k \left| \frac{qQ}{qr^2} \right| = k \frac{|Q|}{r^2}. \quad 18.12$$

Since the test charge cancels, we see that

$$E = k \frac{|Q|}{r^2}. \quad 18.13$$

The electric field is thus seen to depend only on the charge  $Q$  and the distance  $r$ ; it is completely independent of the test charge  $q$ .



## EXAMPLE 18.2

### Calculating the Electric Field of a Point Charge

Calculate the strength and direction of the electric field  $E$  due to a point charge of 2.00 nC (nano-Coulombs) at a distance of 5.00 mm from the charge.

#### Strategy

We can find the electric field created by a point charge by using the equation  $E = kQ/r^2$ .

#### Solution

Here  $Q = 2.00 \times 10^{-9}$  C and  $r = 5.00 \times 10^{-3}$  m. Entering those values into the above equation gives

$$\begin{aligned}
 E &= k \frac{Q}{r^2} \\
 &= (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \times \frac{(2.00 \times 10^{-9} \text{ C})}{(5.00 \times 10^{-3} \text{ m})^2} \\
 &= 7.19 \times 10^5 \text{ N/C}.
 \end{aligned}$$

18.14

**Discussion**

This **electric field strength** is the same at any point 5.00 mm away from the charge  $Q$  that creates the field. It is positive, meaning that it has a direction pointing away from the charge  $Q$ .

**EXAMPLE 18.3****Calculating the Force Exerted on a Point Charge by an Electric Field**

What force does the electric field found in the previous example exert on a point charge of  $-0.250 \mu\text{C}$ ?

**Strategy**

Since we know the electric field strength and the charge in the field, the force on that charge can be calculated using the definition of electric field  $\mathbf{E} = \mathbf{F}/q$  rearranged to  $\mathbf{F} = q\mathbf{E}$ .

**Solution**

The magnitude of the force on a charge  $q = -0.250 \mu\text{C}$  exerted by a field of strength  $E = 7.20 \times 10^5 \text{ N/C}$  is thus,

$$\begin{aligned}
 F &= -qE \\
 &= (0.250 \times 10^{-6} \text{ C})(7.20 \times 10^5 \text{ N/C}) \\
 &= 0.180 \text{ N}.
 \end{aligned}$$

18.15

Because  $q$  is negative, the force is directed opposite to the direction of the field.

**Discussion**

The force is attractive, as expected for unlike charges. (The field was created by a positive charge and here acts on a negative charge.) The charges in this example are typical of common static electricity, and the modest attractive force obtained is similar to forces experienced in static cling and similar situations.

**PHET EXPLORATIONS****Electric Field of Dreams**

Play ball! Add charges to the Field of Dreams and see how they react to the electric field. Turn on a background electric field and adjust the direction and magnitude.

[Click to view content \(https://phet.colorado.edu/sims/efield/efield-600.png\)](https://phet.colorado.edu/sims/efield/efield-600.png)

Figure 18.21

[Electric Field of Dreams \(https://phet.colorado.edu/en/simulation/legacy/efield\)](https://phet.colorado.edu/en/simulation/legacy/efield)

**18.5 Electric Field Lines: Multiple Charges**

Drawings using lines to represent **electric fields** around charged objects are very useful in visualizing field strength and direction. Since the electric field has both magnitude and direction, it is a vector. Like all **vectors**, the electric field can be represented by an arrow that has length proportional to its magnitude and that points in the correct direction. (We have used arrows extensively to represent force vectors, for example.)