7.3 Electric Fields

If you have typed a letter on a computer, heard musical tones from a cellphone, or even just pressed a floor button in an elevator, then you have applied an electric force. In fact, almost everywhere you go you will find a device that, in one way or another, uses electric fields. An electric field is what causes the electric force. At the dentist's office, the X-ray machine uses an electric field to accelerate electrons as part of the process for producing X-rays. At coal-burning power plants, electric fields in smokestack scrubbers remove soot and other pollutants before gases are released into the air. Even when you are speaking into a telephone or listening to the other person on the line, electric fields help convert sound to electricity and back to sound again.

The liquid crystal display (LCD) is a device that uses electric fields. Nearly all computer monitors, digital cameras, and smart phones use LCDs for their visual components (**Figure 1**). LCDs consist of a liquid crystal between two transparent sheets of glass or plastic, with a thin conducting material on the outside of the sheets. An electric field across the crystal causes its molecular arrangement to change, so that light passing through it is made either lighter or darker, depending on the design of the device. In this way, small changes in the electric field can make nearly any pattern appear on the LCD.

Figure 1 LCDs use changing electric fields to alter the crystal's optical properties, creating images.

Properties of Electric Fields

electric field ($\vec{\varepsilon}$) the region in which a force is exerted on an electric charge; the electric force per unit positive charge; unit is N/C

We can describe the electric force between a pair of charges using Coulomb's law, but there is another way to describe electric forces. Suppose there is a single isolated point charge that is far from any other charges. This charge produces an **electric field**, a region in which a force is exerted on an electric charge. The electric field is similar to the gravitational field near an isolated mass, as discussed in Chapter 6. Were another charge to enter this field, the electric field would exert a force on it, much as a gravitational field exerts a force on a mass. The electric field has both magnitude and direction, so electric field is a vector denoted by $\vec{\varepsilon}$.

Consider a particular point in space where there is a uniform electric field $\vec{\varepsilon}$ (**Figure 2**). A point charge or an arrangement of several charges may have produced this field. A charge q at this location in the field will be affected by the electric field and experience an electric force given by

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

The electric force, $\vec{F}_E$, is thus parallel to $\vec{\varepsilon}$, with direction depending on whether the charge is positive or negative.

The charge q_1, or the charge affected by the field, in Figure 2 is called a test charge. As a convention, physicists use a positive test charge to determine direction. By measuring the force on a positive test charge, you can determine the magnitude and direction of the electric field at the location of the test charge. Since we are working with a positive test charge, q_1, the electric field points in the same direction as the force that the test charge experiences. If q_1 happens to be a negative charge, then the direction of the electric field is in the opposite direction of the force that the negative charge experiences. The units for the electric field can be determined from the equation relating electric force to electric field. Force is measured in newtons (N), and charge is measured in coulombs (C), so the electric field is expressed in newtons per coulomb (N/C).

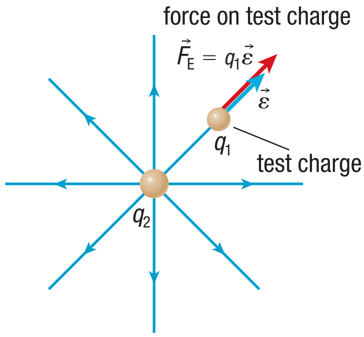

Figure 2 The electric field at a particular point in space is related to the electric force on a test charge q_1 at that location.

The electric field $\vec{\varepsilon}$ also relates to Coulomb's law for electric force. Coulomb's law for electric force allows you to calculate the electric field using the amount of charge that produces the field, q_2, and the distance of the field from the charge. As an example, calculate the magnitude of the electric field at a distance r from a charge q_2. The test charge is, once again, q_1. According to Coulomb's law, the electric force exerted on q_1 has a magnitude of

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

$$F_E = q_1\frac{kq_2}{r^2}$$

Inserting this expression into the equation relating electric force to the electric field gives the result

$$q\varepsilon = F_E$$

$$q\varepsilon = q_1\frac{kq_2}{r^2}$$

In this equation $q = q_1$, so we get

$$\boxed{\varepsilon = \frac{kq_2}{r^2}}$$

This is the magnitude of the electric field at a distance r from a point charge q_2. The direction of $\vec{\varepsilon}$ lies along the line that connects the charge producing the field, q_2, to the point where the field is measured. The direction of the electric field is determined by a positive test charge. If q_2 is positive, then a positive test charge will be repelled away from it, and thus the electric field points in a direction away from a positive charge. If q_2 is negative, then a positive test charge will be attracted toward it and thus the electric field points in a direction toward a negative charge. As a result of the direction of the electric field depending on the type of charge and the location in relation to the charge, we do not include the signs of charges in the equations to avoid implying a direction.

In Tutorial 1, you will solve problems related to the electric field in both one and two dimensions. When using the equation for electric field, the symbol q really means the absolute value of q, just like it does for Coulomb's law.

Tutorial 1 / Determining Electric Fields

This Tutorial shows how to determine the electric field due to charge distribution at a point some distance from the charge.

Sample Problem 1: Electric Field Due to Two Point Charges in One Dimension

Two point charges are 45 cm apart (**Figure 3**). The charge on q_1 is 3.3×10^{-9} C, and the charge on q_2 is -1.00×10^{-8} C.

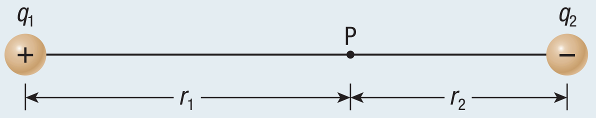

Figure 3

(a) Calculate the net electric field at point P, 27 cm from the positive charge, on the line connecting the charges.

(b) A new charge of $+2.0 \times 10^{-12}$ C is placed at P. Determine the electric force on this new charge.

Solution

(a) **Given:** $r_{12} = 45$ cm; $r_1 = 27$ cm; $q_1 = 3.3 \times 10^{-9}$ C; $q_2 = -1.00 \times 10^{-8}$ C; $k = 8.99 \times 10^9\ \text{N·m}^2/\text{C}^2$

Required: net electric field $\vec{\varepsilon}_{net}$ at point P

Analysis: The net electric field at point P equals the vector sum of the electric fields from the charges producing the fields. Use the equation $\varepsilon = \dfrac{kq}{r^2}$ to calculate ε for each of the charges q_1 and q_2 at point P. Then determine the direction of each field based on the signs of the charges. Combine the two vector quantities to calculate $\vec{\varepsilon}_{net}$.

$r_2 = r_{12} - r_1 = 45\text{ cm} - 27\text{ cm} = 18\text{ cm} = 0.18\text{ m}$

Solution: Calculate the magnitude of the electric field at a distance r_1 from charge q_1 and determine the field's direction.

$$\varepsilon_1 = \frac{kq_1}{r_1^2}$$

$$= \frac{\left(8.99 \times 10^9 \dfrac{\text{N·}\cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)(3.3 \times 10^{-9}\,\cancel{\text{C}})}{(0.27\,\cancel{\text{m}})^2}$$

$\varepsilon_1 = 4.070 \times 10^2$ N/C (two extra digits carried)

Since q_1 is a positive charge, the electric field on a positive test charge at P will be directed away from q_1.

$\vec{\varepsilon}_1 = 4.070 \times 10^2\text{ N/C [right]}$

Calculate the magnitude of the electric field at a distance r_2 from charge q_2 and determine the field's direction.

$$\varepsilon_2 = \frac{kq_2}{r_2^2}$$

$$= \frac{\left(8.99 \times 10^9 \dfrac{\text{N·}\cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)(1.00 \times 10^{-8}\,\cancel{\text{C}})}{(0.18\,\cancel{\text{m}})^2}$$

$\varepsilon_2 = 2.775 \times 10^3$ N/C (two extra digits carried)

Since q_2 is a negative charge, the electric field on a positive test charge at P will be directed toward q_2.

$\vec{\varepsilon}_2 = 2.775 \times 10^3\text{ N/C [right]}$

Now determine the vector sum of the two electric fields. Choose right as positive, so left is negative.

$$\begin{aligned}\vec{\varepsilon}_{net} &= \vec{\varepsilon}_1 + \vec{\varepsilon}_2 \\ &= +4.070 \times 10^2\text{ N/C} + 2.775 \times 10^3\text{ N/C} \\ &= +3.182 \times 10^3\text{ N/C (two extra digits carried)}\end{aligned}$$

$\vec{\varepsilon}_{net} = 3.2 \times 10^3\text{ N/C [right]}$

Statement: The net electric field is 3.2×10^3 N/C to the right of point P.

(b) **Given:** $\vec{\varepsilon}_{net} = 3.182 \times 10^3$ N/C, directed to the right of point P; $q = +2.0 \times 10^{-12}$ C

Required: net electric force $\vec{F}_{E_{net}}$

Analysis: Use the equation $\vec{F}_E = q\vec{\varepsilon}$ to calculate the net electric force for the test charge q at point P.

Solution: Use the sign of the charge to determine the direction of the electric field. Since the charge is positive, the electric force is directed to the right. Choose right as positive, so left is negative.

$$\begin{aligned}\vec{F}_{E_{net}} &= q\vec{\varepsilon}_{net} \\ &= (+2.0 \times 10^{-12}\text{ C})(+3.182 \times 10^3\text{ N/C}) \\ &= +6.4 \times 10^{-9}\text{ N}\end{aligned}$$

$\vec{F}_{E_{net}} = 6.4 \times 10^{-9}\text{ N [right]}$

Statement: The electric force acting on the new charge at point P is 6.4×10^{-9} N to the right of point P.

Sample Problem 2: Electric Field Due to Two Point Charges in Two Dimensions

Two point charges are arranged as shown in **Figure 4**. $q_1 = 4.0 \times 10^{-6}$ C, $q_2 = -2.0 \times 10^{-6}$ C, and $r = 3.0$ cm. Calculate the magnitude of the electric field at the origin.

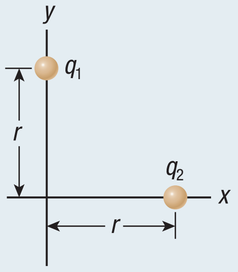

Figure 4

Given: $r = 3.0 \text{ cm} = 0.030 \text{ m}$; $q_1 = 4.0 \times 10^{-6}$ C; $q_2 = -2.0 \times 10^{-6}$ C; $k = 8.99 \times 10^9 \text{ N·m}^2/\text{C}^2$

Required: magnitude of net electric field at the origin, ε_{net}

Analysis: The electric field at the origin results from the electric fields of charges q_1 and q_2. Use the equation $\varepsilon = \frac{kq}{r^2}$ for a point charge q to calculate the magnitudes of the net electric fields at the origin along the horizontal and vertical directions due to the charges q_1 and q_2. Then use the equation $\varepsilon_{\text{net}} = \sqrt{\varepsilon_{x_{\text{net}}}^2 + \varepsilon_{y_{\text{net}}}^2}$ to calculate the magnitude of the net electric field at the origin.

Solution: First, calculate the magnitudes of the electric fields along the horizontal and vertical directions. The electric field of q_2 has only an x-component.

$$\begin{aligned}\varepsilon_x &= \varepsilon_x \\ &= \frac{kq_2}{r^2} \\ &= \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(2.0 \times 10^{-6}\ \cancel{\text{C}})}{(0.030\ \cancel{\text{m}})^2}\end{aligned}$$

$$\varepsilon_x = 1.998 \times 10^7 \text{ N/C (two extra digits carried)}$$

The electric field of q_1 has only a y-component.

$$\begin{aligned}\varepsilon_{y_{\text{net}}} &= \varepsilon_y \\ &= \frac{kq_1}{r^2} \\ &= \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(4.0 \times 10^{-6}\ \cancel{\text{C}})}{(0.030\ \cancel{\text{m}})^2}\end{aligned}$$

$$\varepsilon_{y_{\text{net}}} = 3.996 \times 10^7 \text{ N/C (two extra digits carried)}$$

Then calculate the magnitude of the net electric field at the origin.

$$\begin{aligned}\varepsilon_{\text{net}} &= \sqrt{\varepsilon_{x_{\text{net}}}^2 + \varepsilon_{y_{\text{net}}}^2} \\ &= \sqrt{(1.998 \times 10^7 \text{ N/C})^2 + (3.996 \times 10^7 \text{ N/C})^2}\end{aligned}$$

$$\varepsilon_{\text{net}} = 4.5 \times 10^7 \text{ N/C}$$

Statement: The magnitude of the net electric field at the origin is 4.5×10^7 N/C.

Practice

1. An electric force with a magnitude of 2.5 N, directed to the left, acts on a negative charge of -5.0 C. T/I
   (a) Determine the electric field in which the charge is located. [ans: 0.50 N/C [toward the right]]
   (b) Calculate the electric field when the force is the same but the charge is -0.75 C. [ans: 3.3 N/C [toward the right]]
2. Calculate the magnitude and direction of the electric field at a point 2.50 m to the right of a positive point charge $q = 6.25 \times 10^{-6}$ C. T/I [ans: 8.99×10^3 N/C [toward the right]]
3. Calculate the electric field at point Z in **Figure 5**, due to the point charges $q_1 = 5.56 \times 10^{-9}$ C at point X and $q_2 = -1.23 \times 10^{-9}$ C at point Y. T/I [ans: -50.3 N/C, or 50.3 N/C [toward the left]]

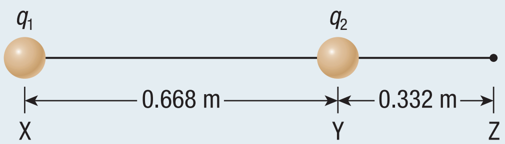

Figure 5

Electric Field Lines

electric field lines the continuous lines of force around charges that show the direction of the electric force at all points in the electric field

An electric field exists in a region around a charge. The field and its properties can be represented with **electric field lines**. These electric field lines can help us determine the direction of the force on a nearby test charge.

As was stated earlier, electric fields point away from positive charges and toward negative charges. This convention is based on using a positive test charge to determine direction. To show what the electric field would look like around a positive point charge, we draw electric field lines that extend radially outward from the charge, as shown in **Figure 6(a)**. For a negative charge, the field lines are directed inward, toward the charge (**Figure 6(b)**). As you may expect, the electric field lines are parallel to $\vec{\varepsilon}$, and the density of the field lines is proportional to the magnitude of $\vec{\varepsilon}$. In both parts of Figure 6, the field lines are densest near the charges. In both cases, the magnitude of $\vec{\varepsilon}$ increases as the distance to the charge decreases.

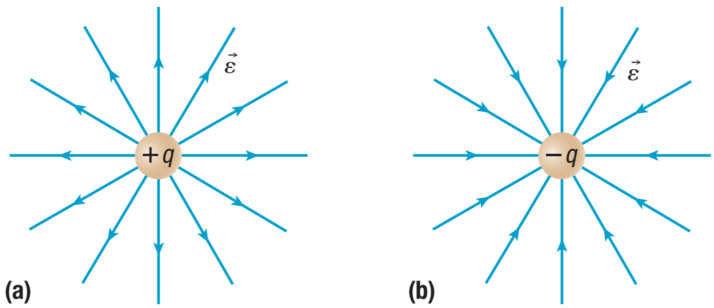

Figure 6 Electric field lines near a point charge placed at the origin. (a) If the charge is positive, the electric field lines are directed outward, away from the charge. (b) If the charge is negative, the electric field lines are directed inward, toward the charge.

According to Coulomb's law, the force between two point charges varies as $\frac{1}{r^2}$, where r is the separation between the two charges. In a similar way, the electric field produced by a point charge also varies as $\frac{1}{r^2}$. The electric field thus obeys an inverse-square law, just as the gravitational force does (**Figure 7(a)**).

The magnitude of the electric force is proportional to the density of field lines—that is, the number of field lines per unit area of space—at some distance r from the charge or charges producing the field. For a point charge q (**Figure 7(b)**), the density of field lines decreases farther away from the charge. The field lines from q spread out through a surface area. Therefore, the number of field lines per unit area (A), and thus the respective strengths of the electric field and electric force, decreases as r^2 increases.

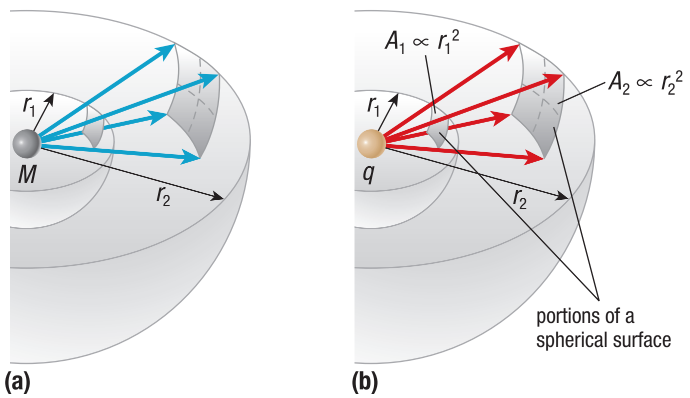

Figure 7 (a) The gravitational force lines from a mass M spread out as r increases in all directions. (b) The electric field lines from a charge q also spread out in all directions. Both types of field lines pass through larger spherical surface areas at greater distances. The surface areas (A) over which the fields act increase as r^2 increases, so the fields themselves exert inverse-square forces.

Another interesting aspect of the electric force relates to the question of action at a distance. How do two point charges that interact through Coulomb's law "know" about each other? In other words, how does one charge transmit electric force to another charge? In terms of the electric field lines, every charge generates (or carries with it) an electric field, through which the electric force is transmitted.

Electric Dipoles

Consider the two point particles with equal but opposite charge in **Figure 8**. Charges $-q$ and $+q$, where q is the positive magnitude of the charge, are separated by a small distance r. This charge configuration is called an **electric dipole**.

electric dipole a pair of equal and opposite electric charges with centres separated by a small distance

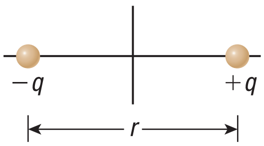

Figure 8 Two opposite charges separated by a distance *r* form an electric dipole.

The two charges in an electric dipole give rise to a more complicated electric field than the one associated with a single electric charge. This is because the electric fields around the individual charges interact most strongly with each other at close distances, such as those that are similar in size to the dipole separation. Initially, the fields at the negative charge radiate inward toward the charge, and the fields at the positive charge radiate outward from the charge (**Figure 9(a)**). As the fields extend into the space around the other charge, they interact with each other, producing field lines that bend toward the other charge (**Figure 9(b)**).

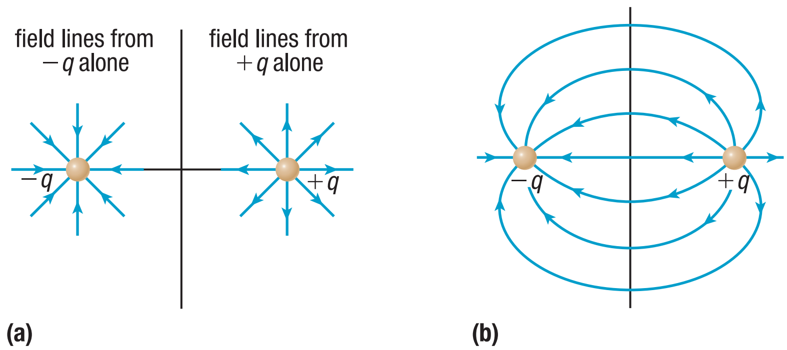

Figure 9 The electric field lines around each individual charge of an electric dipole (a) are affected by the field lines from the other charge, causing them to bend (b). It is important to note that the field lines extend in three dimensions around the charges, and that the view depicted here is of the field lines in a plane perpendicular to the line of sight.

Notice that, along the vertical axis midway between the two charges, the electric field is parallel to the line connecting the two charges. This remains true along the vertical axis at all distances from the dipole, although the magnitude of the electric field decreases at distances that are farther from the dipole. The direction of this electric field always points from the positive charge to the negative charge.

Although the field lines of a dipole merge at the midpoint, field lines do not cross. Instead, the cumulative effect, or the vector sum, of the electric fields from both charges produces a net electric field. That net electric field is represented by the electric field line.

Now consider an arrangement of charges slightly different from an electric dipole. In this case, a positive charge, $+q$, replaces the negative charge, $-q$, so that the two charges are equal and alike. Now the electric field lines extend outward from both charges. Instead of the field lines from a positive charge merging with the lines from a negative charge, the lines from similar charges do not connect at any point. This arrangement produces a disk-shaped region of zero electric field everywhere around the midpoint between the two charges (**Figure 10**).

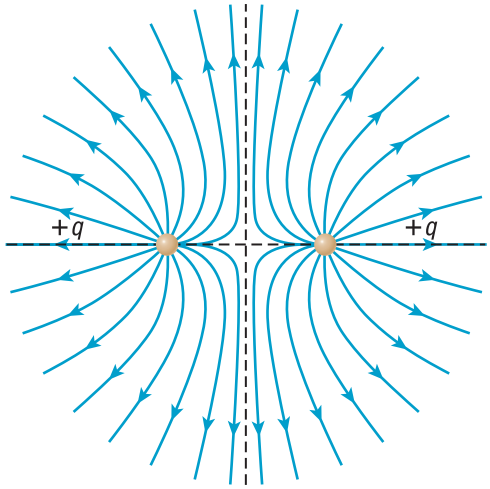

Figure 10 Two identical charges separated by a small distance produce this electric field pattern. Again, the field lines occupy all the space around the charges. This illustration shows how they appear in a plane. Note that the electric field is zero along the line that bisects the line connecting the charges.

Notice that, farther away from the charges, the field behaviour starts to resemble that of a single charge. That is, the field lines appear to be radiating from a single point charge. This makes sense because, at a large distance from the two charges, the separation between them is not noticeable, and both charges have the same sign. Midway between the two charges, there is a gap where there are no field lines. This is expected because the vector sum of the two electric fields from both charges is zero at the midpoint.

Note that this electric field pattern would be the same if the two charges were both negative. The difference would be in the direction in which the field lines were pointing but not the shape of the combined fields.

Finally, consider a dipole-like arrangement of two charges that have different magnitudes and signs. If the positive charge $+q$ is replaced with a charge $+2q$, the symmetry of the dipole field is altered (**Figure 11** on the next page). This is because the number of field lines for each charge is proportional to the magnitude of that charge. The number of field lines leaving the positive charge is therefore twice the number of field lines meeting at the negative charge. Half of these lines converge on the negative charge, while the other half emanate outward, as if there were only one charge ($+2q$). At large distances, where r is much greater than the charge separation, the electric field radiates outward as it would for a charge of $+2q$.

The field-line pattern for unequal and opposite charges includes regions near the charges where the density of field lines becomes very high. Note that this does not mean that the electric field is stronger in these regions. The electric field is still strongest along the line connecting the charges. Electric field patterns can become very complex, but many simulations exist to show what the electric field would look like in a multi-charge system. WEB LINK

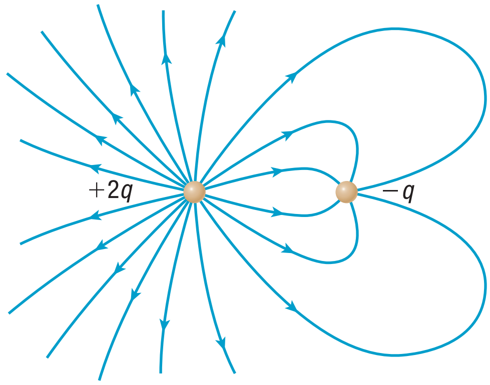

Figure 11 The electric field lines around a dipole consisting of charges $-q$ and $+2q$. The number of lines from the larger charge is twice the number of lines from the smaller charge. Half of these lines extend from the positive charge to the negative charge. The other half extend outward, as if there were only one charge, $+2q$.

Uniform Electric Fields

So far, you have learned about electric fields that vary with distance from a charge. In the case of a dipole, for instance, the strength of the electric field varies with the number of charges, their placement, and the distance from the charges.

A different electric field arises from a different type of dipole. Instead of point charges, suppose you have two parallel planes of charge. As with the dipole, one plane has a positive charge and the other plane has a negative charge. In both cases, the charge spreads uniformly along each plane.

Just as the electric field along the line connecting two unlike charges extends straight from the positive to the negative charge, the electric field between the planes of charge extends from the positive plane of charge to the negative plane and is uniform. These field lines are straight, parallel to each other, and perpendicular to the planes of charge. At any location between the planes, the electric field has the same magnitude and direction. Outside the planes, the vector sum of the electric fields from all the individual charges in the two parallel planes yields a value of zero.

This description of planes of charges involves "infinite" parallel planes carrying "infinite" amounts of charge and thus does not exist in real-world scenarios. However, you can create a close approximation by using two large conducting plates charged by dry cells. These plates are parallel and carry equal and opposite charges. As long as the separation between the plates is much smaller than their surface area, the electric field between the plates remains uniform (**Figure 12**). In fact, except near the edges of the plates, the magnitude of the electric field depends only on the amount of charge, the area of the plates, and the material between the plates.

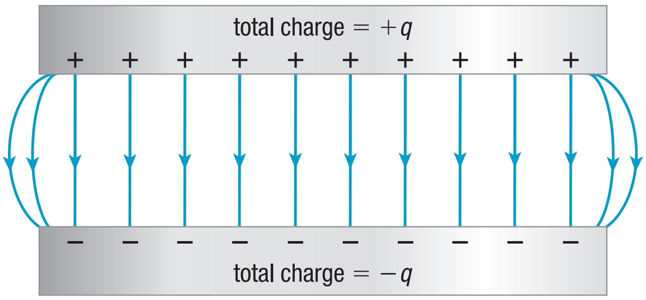

Figure 12 The electric field between two parallel conducting plates is uniform in direction and magnitude.

Earth's Electric Field

Energy from the Sun bombards Earth's upper atmosphere. Some of this energy strips electrons from atoms, leaving a region of positively charged ions and free electrons. Some of the electrons recombine with the ions, but others travel into space and other regions of the atmosphere. This region, appropriately called the ionosphere, therefore has a positive charge and is able to conduct electricity.

In contrast to the ionosphere, Earth's surface is more negatively charged. Both areas tend to stay charged, so that a permanent electric field exists throughout the atmosphere. Near Earth's surface, when the sky is clear of storms, the electric field has an average magnitude of about 120 N/C.

This electric field varies seasonally, but the greatest and most sudden change occurs during thunderstorms, when the atmospheric electric field can reverse direction. Cloud-to-ground lightning, which often accompanies these storms, is both very common and potentially very destructive, so it is essential that scientists understand how Earth's electric field changes during storms, and what field conditions are likely to result in a lightning strike.

One device, called an electric field mill, or just field mill, is widely used to measure Earth's electric field. A field mill makes use of the uniform electric field between two parallel conducting plates and detects changes in the field strength at a given location.

The design of a field mill incorporates two circular conducting plates (**Figure 13**). The conducting plate at the front of the mill is the sensor plate. This part of the mill is exposed to the atmospheric electric field. A set of motor-driven, rotating shutter blades (the mill) exposes the sensor plate for a short time and then blocks the plate from the electric field for an identical length of time. During exposure, the plate becomes charged. During non-exposure, an analyzer circuit measures the electric field between the charged sensor plate and the uncharged detector plate. This process repeats continuously, providing information about variations in the field strength of Earth's electric field over a given time interval and in a particular region of the atmosphere. CAREER LINK

Field mills have fairly simple designs and generally perform reliably. Although often set up in permanent positions on the ground, field mills located in balloons and aircraft measure field changes at different elevations. Field mills are used in cases where lightning could do extreme damage, such as to spacecraft before launch.

UNIT TASK BOOKMARK

You can apply what you have learned about electric fields to the Unit Task on page 422.

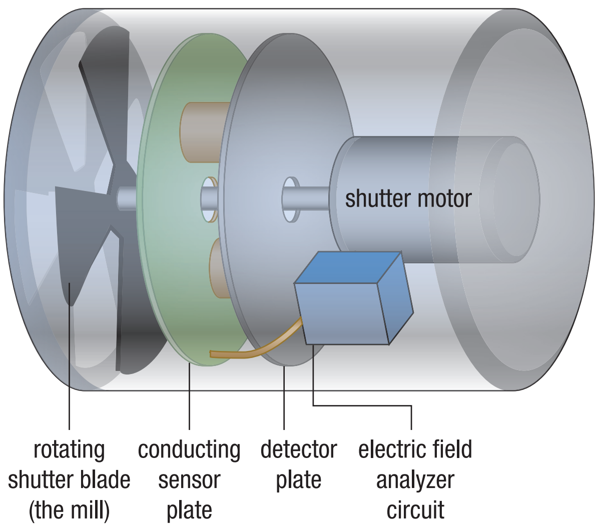

Figure 13 A field mill measures the electric field between two parallel conducting plates to determine the changes in Earth's electric field.

Electrostatic Precipitators

During the Industrial Age, heavily polluted air resulted from the smoke pouring out of chimneys and smokestacks. Most of these emissions, called flue gases because they passed through the flues of chimneys, consisted of gases such as nitrogen and carbon dioxide, both of which are clear substances. However, tiny particles of carbon, sulfur compounds, and dust produced by various chemical processes and combustion combined with the gases. These particles gave the air its smoky appearance.

Today, industrial processes continue to pollute our air. Air containing polluting gases leads to many environmental concerns such as climate change and acid precipitation. Acid precipitation is known to harm both plant and aquatic life. The polluting gases also affect the respiratory health of not only the people who live nearby but also those who live where the prevailing winds tend to push the gases.

In recent years, devices called electrostatic precipitators have reduced the numbers of these particles released into the atmosphere. Electrostatic precipitators use electric fields to remove extremely small particles of soot, dust, and ash from flue gases and other emissions produced by combustion, smelting, and refining.

The exact arrangements of different electrostatic precipitators vary, but the basic principle is the same in all of them. In the design shown in **Figure 14**, the flue gas and particles it contains pass between a grid of negatively charged conducting wires and a conducting plate carrying a positive charge. The wires transfer electrons to the various particles that come into contact with the wires, making the particles negatively charged. The electric field between the wires and the plates is about 1×10^6 N/C, so the force drawing these negatively charged particles toward the positively charged plates is very large. Shaking the plates from time to time loosens the particles that accumulate on them. A storage (collection) hopper below the precipitator collects this refuse. Repeating the procedure of passing the flue gas through several series of plates and wires removes about 99 % of the various particles from the gas.

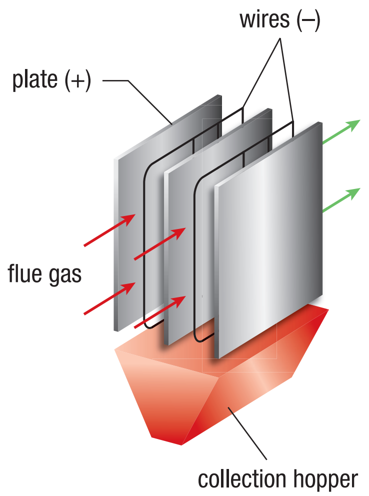

Figure 14 An electrostatic precipitator uses electric fields to remove particles from flue gases.

Some of the devices used for home air purification use the basic principles of electrostatic precipitators. However, the results from these air cleaners have been mixed, partly because of the comparatively low levels of particles in household air, and partly because the electric fields are not as strong as in industrial precipitators.

Electric Fields in Nature

Electric fields are also produced by animals. These fields are often weak and produced by ordinary actions, such as motion in the muscles. Some animals have organs that detect and respond to these weak electric fields. Hammerhead sharks, for instance, detect fields as low as 6 N/C in fish that hide beneath the sand or in tunnelled shelters along shallow ocean bottoms.

The hammerhead shark swims close to the sandy ocean floor (**Figure 15**). It preys on goby, small fish that hide in sand-covered holes. A goby produces electric fields from muscular movements of its fins or gills. Although the shark cannot see the goby, it can detect these electric fields up to 25 cm above the sand. Having detected the goby, the hammerhead shark swims in a figure eight until it pinpoints the location of greatest electric field strength and then catches and consumes the goby.

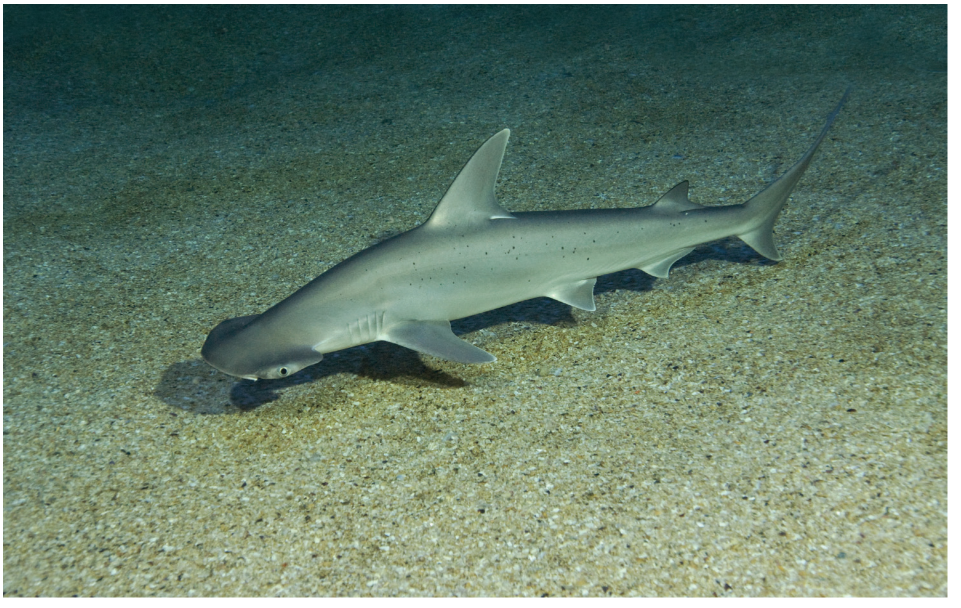

Figure 15 A hammerhead shark can detect the electric fields produced by the movements of its prey.

Research This

Fish and Electric Fields

Skills: Researching, Communicating — SKILLS HANDBOOK A4.1

Many fish use electric fields to detect or stun their prey, or to ward off predators. Some examples are electric eels, electric catfish, elephant fish, Nile knifefish, and torpedo fish.

1. Research one of these fish on the Internet, and determine how it detects or uses electric fields.
2. Compare this fish's abilities with those of the hammerhead shark.
3. Write a brief report of your findings that includes answers to the following questions.

A. What types of behaviours that are related to electric fields are typical for the organism you chose? T/I

B. Why are fish that stun prey with electric fields typically freshwater species? T/I

C. Many fish are able to detect weak electric fields from prey that live in rivers with large amounts of silt and soil suspended in the water. Why would an adaptation such as electric-field detection be beneficial for these fish? T/I

WEB LINK

7.3 Review

Summary

- An electric field exists in a region of space when a test charge placed at any point in the region has a force exerted upon it.
- The electric field is a vector and is denoted by $\vec{\varepsilon}$. A test charge q will experience an electric force given by $\vec{F}_E = q\vec{\varepsilon}$. The directions of the electric force and electric field are determined by a positive test charge.
- For a point charge q_2, the magnitude of the electric field at a distance r from the charge is $\varepsilon = \dfrac{kq_2}{r^2}$.
- Electric field lines are continuous lines of force that show the direction of electric force at all points in the electric field around a charge or charges.
- An electric dipole consists of two equal but opposite charges separated by some small distance.
- The electric field between two parallel plates of charge is uniform and perpendicular to the plates. The electric field outside the parallel plates is zero.
- One application of electric fields is in electrostatic precipitators, which use electric fields to remove extremely small particles of soot, dust, and ash from flue gases.
- Some organisms can detect the weak electric fields produced by the movement of other organisms.

Questions

1. A proton and an electron are placed in a uniform electric field. Comment on the magnitudes of the forces experienced by both. K/U
2. Calculate the magnitude of the electric field at a distance of 1.5 m from a point charge with $q = 3.5$ C. K/U
3. A point particle of charge $q_1 = 4.5 \times 10^{-6}$ C is placed on the x-axis at $x = -10$ cm. A second particle of charge q_2 is placed on the x-axis at $x = +25$ cm. The electric field at the origin is zero. Determine the charge q_2. K/U T/I
4. A ring with a radius of 25 cm and total charge 5.00×10^{-4} C is centred at the origin as shown in **Figure 16**. The charge is distributed uniformly around the ring. Calculate the electric field at the origin. (Hint: Think of applying symmetry.) K/U T/I

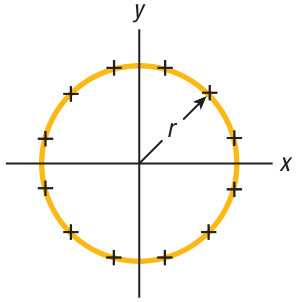

Figure 16

5. When drawing electric field lines, what determines the number of lines originating from a charge? K/U
6. Two point particles with charges q_1 and q_2 are separated by a distance L, as shown in **Figure 17**. The electric field is zero at point A, which is a distance $\frac{L}{4}$ from q_1. Determine the ratio q_1:q_2. K/U T/I

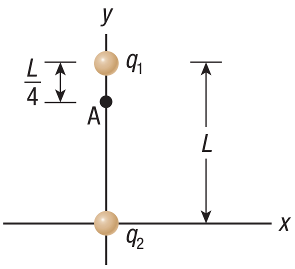

Figure 17

7. Five point charges, all with $q = 7.5$ C, are spaced equally along a semicircle with a radius of 2.3 m, as shown in **Figure 18**. Calculate the electric field at the origin. K/U T/I

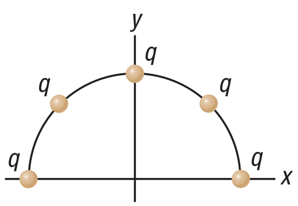

Figure 18

8. Draw the electric field lines between the wires and plates of an electrostatic precipitator. T/I C