Electric Potential 7.4

You might be surprised to learn that the way your own body functions and how it senses and reacts to the environment around it have a lot to do with the principles studied in this section. Medical researchers must have a fundamental understanding of the principles of electric potential. Some of these researchers describe the body as a complex biological electric circuit.

Understanding lightning also requires an understanding of these principles. Once considered a mystical force of nature, we now know that the principles behind lightning are firmly tied to the physics of this section (and the entire unit). Lightning can cause property damage, personal injury, and even death; it can also start forest fires. Researchers are currently studying lightning in the hope that the more we understand it, the more we can protect ourselves and our property.

DID YOU KNOW?

Lightning

On average, at any time of the day, there are approximately 2000 thunderstorms, producing 30 to 100 cloud-to-ground lightning strikes each second for a total of about 5 million a day.

To understand these and other applications, we must first learn more about the interactions between charges. We have often compared interactions between charges to interactions between masses. Keep in mind that any similarities between the two must be carefully considered because the two forces are not identical, as you have learned. The main difference between the two is that gravity is always attractive while the electric force can either attract or repel.

We know that the magnitude of the force of gravity between any two masses is given by

$$F_g = \frac{Gm_1m_2}{r^2}$$

The corresponding gravitational potential energy between two masses is given by

$$E_g = -\frac{Gm_1m_2}{r}$$

provided the zero value of gravitational potential energy is chosen as the value when the two masses are an infinite distance apart. The negative sign associated with this expression for gravitational potential energy reflects the fact that the force between the two masses is attractive, in other words, that potential energy increases (becoming less and less negative) as we force our two gravitating masses farther and farther apart.

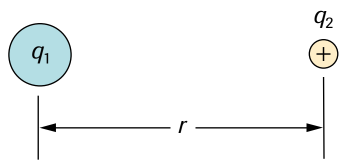

Figure 1
Electric potential energy is stored by two separated charges just as gravitational potential energy is stored by two separated masses.

Consider now a small test charge q_2, a distance r from a point charge q_1, as in **Figure 1**. From Coulomb's law, the magnitude of the force of attraction or repulsion between these two charges is

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

Therefore, it seems reasonable that an approach similar to that used in Section 6.3 for the gravitational potential energy in a system of two masses would yield a corresponding result for **electric potential energy** stored in the system of two charges q_1 and q_2:

$$E_E = \frac{kq_1q_2}{r}$$

electric potential energy (E_E) the energy stored in a system of two charges a distance r apart; $E_E = \frac{kq_1,q_2}{r}$

Notice that the sign for electric potential energy, E_E, could be positive or negative depending on the sign of the charges. If q_1 and q_2 are opposite charges, they attract, and our expression performs correctly, giving the electrical potential a negative value, as in the gravitational case. If q_1 and q_2 are similar charges they repel. We now expect the electric potential energy to be positive; that is, energy is stored by moving them closer

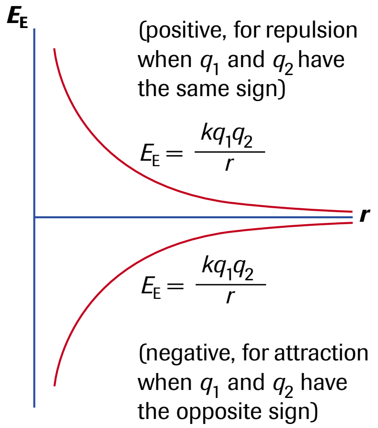

Figure 2
A graph of E_E versus r has two curves: one for forces of attraction between opposite charges (negative curve) and one for forces of repulsion between similar charges (positive curve). Also, as in the gravitational analogy, the zero level of electric potential energy in a sytem of two charged spheres is chosen when they are at an infinite separation distance.

together. In either case, substituting the sign of the charge (+ or −) for q_1 and q_2 will yield the appropriate results for the sign of E_E. Also, in both cases, the zero level of electric potential energy is approached as the separation of the charges q_1 and q_2 approaches infinity (**Figure 2**).

To look at the concept of electric potential energy in a systematic way, we consider the electric potential energy not just of any charge q_2 but of a unit positive test charge when in the field of any other charge q_1. We call this value of potential energy per unit positive charge the **electric potential**, V. It is a property of the electric field of the charge q_1 and represents the amount of work necessary to move a unit positive test charge from rest at infinity to rest at any specific point in the field of q_1.

Thus, at a distance r from a spherical point charge q_1, the electric potential is given by

$$V = \frac{E_E}{q} = \frac{\frac{kq_1q}{r}}{q}$$

$$V = \frac{kq_1}{r}$$

The units of electric potential are joules per coulomb, or volts, and

> 1 V is the electric potential at a point in an electric field if 1 J of work is required to move 1 C of charge from infinity to that point; 1 V = 1 J/C.

electric potential (V) the value, in volts, of potential energy per unit positive charge; 1 V = 1 J/C

There are two ways of considering what V represents: the absolute potential considering that $V = 0$ at $r = \infty$, and as a potential difference measured from infinity to r. The electric potential changes with the inverse of the first power of the distance from the charge rather than with the inverse square of the distance, as the electric field does. For a positive charge, the electric potential is large near the charge and decreases, approaching zero, as r increases. For a negative charge, the electric potential is a large negative value near the charge and increases, approaching zero, as r increases (**Figure 3**).

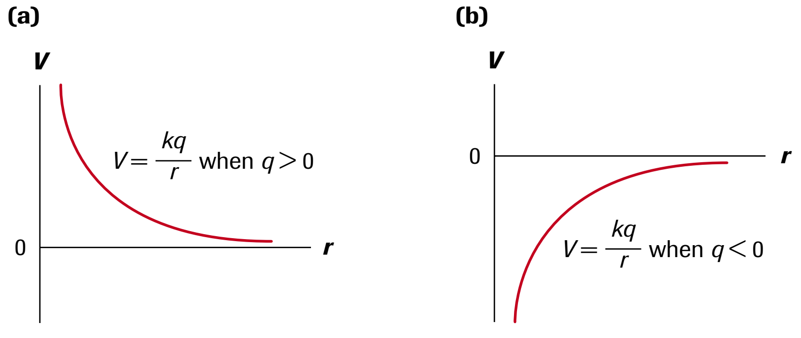

Figure 3
The electric potential V of a single point charge q as a function of r
(a) V for a positive charge
(b) V for a negative charge

We must always be very careful to distinguish between E_E, the electric potential energy of a charge at a point, and V, the electric potential at the point. They are related by the equation $E_E = qV$.

This concept of electric potential can be extended to include the electric fields that result from any distribution of electric charge, rather than just a single point charge. The definition of electric potential in these cases is the same: it is the work done per unit positive test charge to move the charge from infinity to any given point. It is more common, however, not to think of the work necessary to move a unit test charge from infinity to a particular point in a field, but rather from one point to another in the field. In this case, we are dealing with the difference in electric potential between these two points, commonly called the **electric potential difference**.

electric potential difference the amount of work required per unit charge to move a positive charge from one point to another in the presence of an electric field

Often Earth is treated as $V = 0$ for convenience, especially when dealing with just electric potential differences rather than individual electric potentials. This method is similar to that used in situations involving gravity where $h = 0$ is set at any convenient height according to what is needed for the problem. Whereas the choice of zero level for potential is arbitrary, differences in potential are physically real. In particular, it is a fundamental physical fact that two conducting objects connected by a conducting wire are at the same potential. If they were not at the same potential, then the electric potential difference would cause a current redistributing the charge until the electric potential difference reached zero. Then the two conductors would be at the same potential as we stated. This process is used in grounding, placing the object at the same electric potential as Earth.

We now examine the change in the electric potential energy of a positive charge q that is moved from point A to point B in an electric field (**Figure 4**).

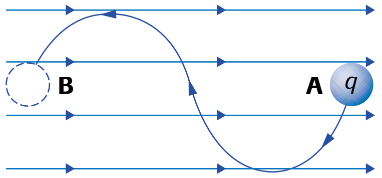

Figure 4
The change in the electric potential energy in moving a charge from A to B in an electric field is independent of the path taken.

Regardless of the actual path taken by the charge q, in moving from A to B,

$$\left\{\begin{array}{l}\text{the difference between}\\ \text{the electric potential}\\ \text{at B and the electric}\\ \text{potential at A}\end{array}\right\} = \left\{\begin{array}{l}\text{the work-per-unit-charge that}\\ \text{we would perform in moving our}\\ \text{hypothetical positive test charge}\\ \text{from A to B in the electric field}\end{array}\right\}$$

$$\begin{aligned}\Delta E_E &= qV_B - qV_A\\ &= q(V_B - V_A)\\ \Delta E_E &= q\Delta V\end{aligned}$$

ΔV, often written V_{BA}, is the potential difference between points B and A in the field. The potential decreases in the direction of the electric field (and therefore increases in the opposite direction).

For a point charge q, the electric potential difference between two points A and B can be found by subtracting the electric potentials due to the charge at each position:

$$\Delta V = V_B - V_A = \frac{kq}{r_B} - \frac{kq}{r_A} = kq\left(\frac{1}{-} - \frac{1}{r_A}\right)$$

Multiplying by the charge that is moved from A to B gives the change in electric potential energy, ΔE. The sign on the electric potential difference depends on both the magnitudes of the distances from the charge and the sign of the charge itself, as summarized in **Figure 5**.

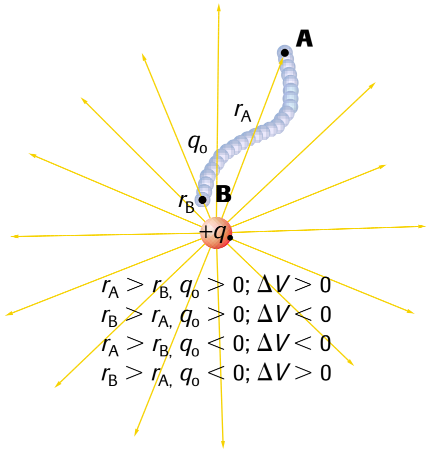

Figure 5
The sign of the electric potential difference depends on the change in the distance and the sign of the charge.

For a second example of a potential difference calculation, consider the electric field between two large, oppositely charged parallel plates whose area is large in comparison with their separation r (**Figure 6**).

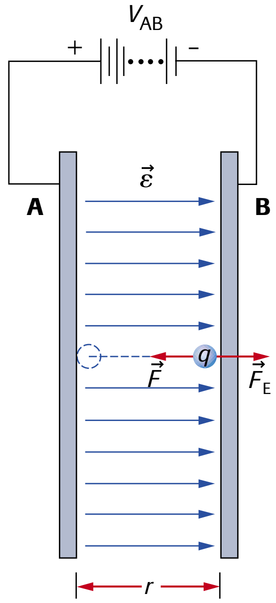

Figure 6
Since the electric field between the two parallel plates is uniform, the force on the charge is constant.

Recall that the electric field is, in the case of parallel plates, constant in magnitude and direction at essentially all points and is defined as the force per unit positive charge:

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

The increase in electric potential energy of the charge q, in moving from plate B to plate A, is equal to the work done in moving it from B to A. To do so, a force $\vec{F}$, equal in magnitude but opposite in direction to $\vec{F}_E$, must be applied over a distance r. The magnitude of the work done is given by

$W = Fr$ since F and r are in the same direction

$W = q\varepsilon r$ since $F = F_E = q\varepsilon$

Therefore, since $W = \Delta E_E = q\Delta V$

$$q\Delta V = q\varepsilon r$$

or $$\varepsilon = \frac{\Delta V}{r}$$

This is an expression for the magnitude of the electric field at any point in the space between two large parallel plates, a distance r apart, with a potential difference $\Delta V = V_{BA}$. Remember: the electric field direction is from the + plate to the − plate, in the direction of decreasing potential.

For a constant electric field, between parallel plates for example, the electric potential difference is directly proportional to the distance r:

$$\Delta V = \varepsilon r$$

Therefore, $\Delta V \propto r$ since ε is constant.

This means that if the electric potential difference between two plates is ΔV and a charge moves one-third of the distance between the plates, the charge will experience a potential difference of $\frac{\Delta V}{3}$.

SAMPLE problem 1

Calculate the electric potential a distance of 0.40 m from a spherical point charge of $+6.4 \times 10^{-6}$ C. (Take $V = 0$ at infinity.)

Solution

$r = 0.40$ m

$q = +6.4 \times 10^{-6}$ C

$V = ?$

$$V = \frac{kq}{r}$$

$$= \frac{(9.0 \times 10^9 \text{ N·m}^2/\text{C}^2)(6.4 \times 10^{-6} \text{ C})}{0.40 \text{ m}}$$

$$V = 1.5 \times 10^5 \text{ V}$$

The electric potential is 1.5×10^5 V.

Note that the value for the potential created by a positive charge has a positive value, characteristic of a system where the force acting on the test charge is repulsion. If the spherical point charge in the above example had been a negative charge, then substituting a negative value for q would have yielded a negative value for V, which is consistent with a system in which the force acting is attractive.

SAMPLE problem 2

How much work must be done to increase the potential of a charge of 3.0×10^{-7} C by 120 V?

Solution

$q = 3.0 \times 10^{-7}$ C

$\Delta V = 120$ V

$W = ?$

$$W = \Delta E_E$$
$$= q\Delta V$$
$$= (3.0 \times 10^{-7}\ \text{C})(120\ \text{V})$$
$$W = 3.6 \times 10^{-5}\ \text{J}$$

The amount of work that must be done is 3.6×10^{-5} J.

SAMPLE problem 3

In a uniform electric field, the potential difference between two points 12.0 cm apart is 1.50×10^2 V. Calculate the magnitude of the electric field strength.

Solution

$r = 12.0$ cm

$\Delta V = 1.50 \times 10^2$ V

$\varepsilon = ?$

$$\varepsilon = \frac{\Delta V}{r}$$
$$= \frac{1.50 \times 10^2\ \text{V}}{1.20 \text{ x } 10^{-1}\ \text{m}}$$
$$\varepsilon = 1.25 \times 10^3\ \text{N/C}$$

The magnitude of the electric field strength is 1.25×10^3 N/C.

SAMPLE problem 4

The magnitude of the electric field strength between two parallel plates is 450 N/C. The plates are connected to a battery with an electric potential difference of 95 V. What is the plate separation?

Solution

$\varepsilon = 450$ N/C

$\Delta V = 95$ V

$r = ?$

For parallel plates, $\varepsilon = \frac{\Delta V}{r}$. Thus,

$$r = \frac{\Delta V}{\varepsilon}$$
$$= \frac{95\ \text{V}}{450\ \text{N/C}}$$
$$r = 0.21\ \text{m}$$

The separation of the plates is 0.21 m.

Answers

1. -1.8×10^{-6} C
2. 3.5×10^{3} V
3. 6.0×10^{4} N/C
4. 1.8×10^{2} V

Practice

Understanding Concepts

1. The electric potential at a distance of 25 cm from a point charge is -6.4×10^4 V. Determine the sign and magnitude of the point charge.
2. It takes 4.2×10^{-3} J of work to move 1.2×10^{-6} C of charge from point X to point Y in an electric field. Calculate the potential difference between X and Y.
3. Calculate the magnitude of the electric field strength in a parallel plate apparatus whose plates are 5.0 mm apart and have a potential difference of 3.0×10^2 V between them.
4. What potential difference would have to be maintained across the plates of a parallel plate apparatus if the plates were 1.2 cm apart, to create an electric field strength of 1.5×10^4 N/C?

Lightning and Lightning Rods

We have all experienced small electric shocks when touching a metal doorknob after walking across a woollen rug on a dry winter day. Lightning discharges are similar but operate on a grand scale, with potential differences between the ground and the air of approximately 10^8 V. A cloud will typically develop a large charge separation before a lightning strike, with about –40 C centred at a region such as N in **Figure 7** and +40 C centred at P. Each lightning flash has a maximum current of 30 000 A, or 30 000 C/s, lasts 30 μs, and delivers about a coulomb of charge.

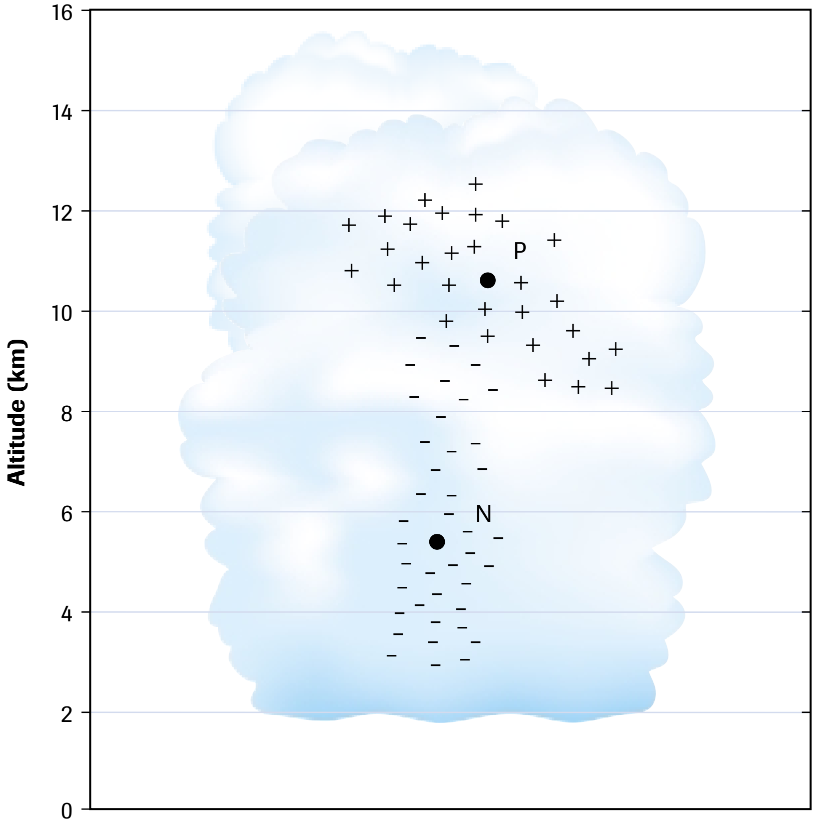

Figure 7
A side view of the separation of charge in a typical thundercloud. The black dots indicate the charge centres for both the positive and negative charge distributions.

According to one current theory (research is ongoing), the separation of charge in a cloud results from the presence of the mixed phases of water typical of large clouds—liquid water, ice crystals, and soft hail. Air resistance and turbulent air flows within the cloud jointly cause the soft hail to fall faster than the smaller ice crystals. As the soft hail collides with the ice crystals, both are charged by friction, the hail negatively and the ice crystals positively. Charge separation occurs because the hail moves down relative to the ice crystals.

Now that the bottom of the cloud is negatively charged, it induces a positive charge on the surface of Earth. The two relatively flat surfaces—the positively charged ground and the negatively charged bottom of the cloud—resemble oppositely charged parallel plates separated by the insulating air. The air stops acting as an insulator and serves as a conductor for the lightning when the charge at the bottom of the cloud becomes large enough to increase the electric field strength to about 3.0×10^6 N/C. When the magnitude of the electric field reaches this critical value, the air ionizes and changes from insulator to conductor.

The lightning strike itself is a sequence of three events. First, the step leader, a package of charge moving erratically along the path of least resistance, moves from the bottom of the cloud toward the ground. On its way down, it often halts temporarily and

Figure 8
Notice the different branches of the lightning caused by the step leader. The ground and bottom of the cloud are modelled after parallel plates.

breaks up into different branches. But whatever its path, it leaves a path of weakly ionized air in its wake. Second, the step leader, now near the ground, induces a strong positive charge, and when it makes contact, a continuous ionized path is opened. Finally, this causes a return stroke from the ground to the cloud producing visible light and increasing the ionization. If the charge on the cloud is large enough, the process continues with a dart leader descending from the cloud, causing another return stroke. Typically, there are three or four return strokes, each lasting 40 to 80 ms (**Figure 8**).

We know what lightning rods are used for, but the physics behind how they protect buildings and people is less well known. Lightning rods are long, thin, pointed metal stakes, usually placed at the highest point on a building and connected to the ground with a conductor (**Figure 9**). The key to influencing the course of a lightning bolt is the ionized path. The step leader, we have seen, follows the path of least resistance through air, which is normally an insulator. How does the lightning rod help?

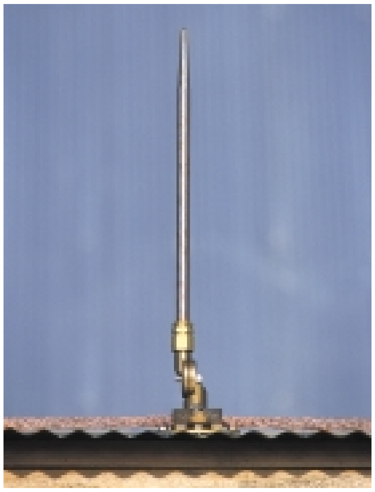

Figure 9
A long, thin conductor, pointed at the top, makes an effective lightning rod.

To answer, we first consider two conducting spheres of different radii connected by a long conducting wire (**Figure 10**). Since a conductor connects the two spheres, they must be at the same electric potential.

Therefore,

$$V_{\text{small}} = V_{\text{large}}$$

$$\frac{kq}{r} = \frac{kQ}{R}$$

$$\frac{q}{r} = \frac{Q}{R}$$

$$\frac{q}{Q} = \frac{r}{R}$$

The magnitude of the electric field near each sphere is given by the equations

$$\varepsilon_{\text{small}} = \frac{kq}{r^2} \quad \text{and} \quad \varepsilon_{\text{large}} = \frac{kQ}{R^2}$$

We use these equations to find the ratio of the magnitudes of the electric fields:

$$\frac{\varepsilon_{\text{small}}}{\varepsilon_{\text{large}}} = \frac{\left(\frac{kq}{r^2}\right)}{\left(\frac{kQ}{R^2}\right)} = \frac{q}{Q}\left(\frac{R^2}{r^2}\right) = \frac{r}{R}\left(\frac{R^2}{r^2}\right)$$

$$\frac{\varepsilon_{\text{small}}}{\varepsilon_{\text{large}}} = \frac{R}{r}$$

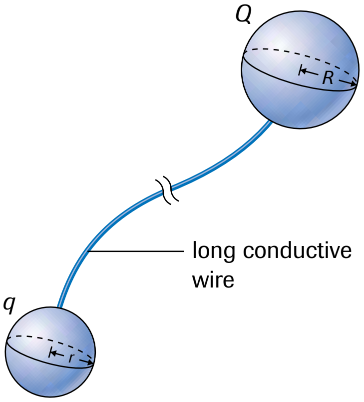

Figure 10
A long, thin conducting wire connecting two conducting spheres of different radii

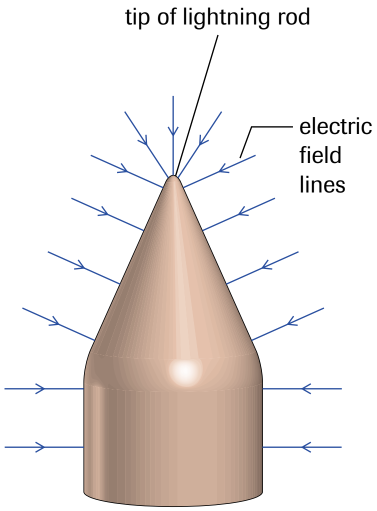

Figure 11
The tip of a lightning rod is small, creating a large electric field near its surface; this ionizes the surrounding air.

Since R is the radius of the larger sphere, the ratio is greater than 1, so $\varepsilon_{small} > \varepsilon_{large}$. We can increase the electric field near the smaller sphere by decreasing its size relative to the larger. The tip of a lightning rod has a very small radius of curvature in comparison with the adjoining rooftop surfaces (**Figure 11**). The electric field near the tip is correspondingly large, indeed large enough to ionize the surrounding air, changing the air from insulator to conductor and influencing the path of any nearby lightning. Lightning is thus induced to hit the rod and to pass safely along the grounding wire, without striking the adjoining rooftop.

Medical Applications of Electric Potential

The concept of electric potential is necessary for an understanding of the human nervous system and how it can transmit information in the form of electric signals throughout the body.

A nerve cell, or neuron, consists of a cell body with short extensions, or dendrites, and also a long stem, or axon, branching out into numerous nerve endings (**Figure 12**). The dendrites convert external stimuli into electrical signals that travel through the neuron most of the way through the long axon toward the nerve endings. These electrical signals must then cross a synapse (or gap) between the nerve endings and the next cell, whether neuron or muscle cell, in the transmission chain. A nerve consists of a bundle of axons.

The fluid within the nerve cell (the intracellular fluid) contains high concentrations of negatively charged proteins. The extracellular fluid, on the other hand, contains high concentrations of positive sodium ions (Na^+). The difference in concentrations is due to the selectively permeable membrane that surrounds the cell, causing a buildup of equal amounts of negative charge inside and positive charge outside the cell membrane (**Figure 13**). This charge separation gives rise to an electric potential difference across the membrane. A normal "resting" membrane electric potential difference (present when the cell is not sending a signal), between inside and outside, is typically –70 mV, negative because the inside of the cell is negative with respect to the outside.

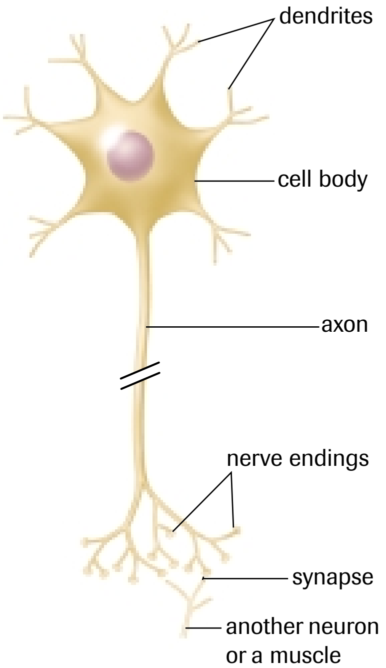

Figure 12
Typical structure of a neuron

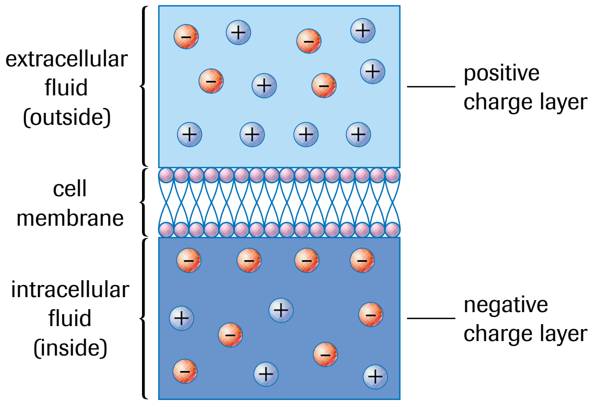

Figure 13
The buildup of equal but opposite charges on either side of the cell membrane causes an electric potential difference.

When exposed to a sufficiently strong stimulus at the right point on the neuron, "gates" open in the cell membrane, allowing the positively charged sodium ions to rush into the cell (**Figure 14**). The sodium ions enter the cell by diffusion, driven by the electrical attraction between positive and negative charges. Upon entry of the sodium ions,

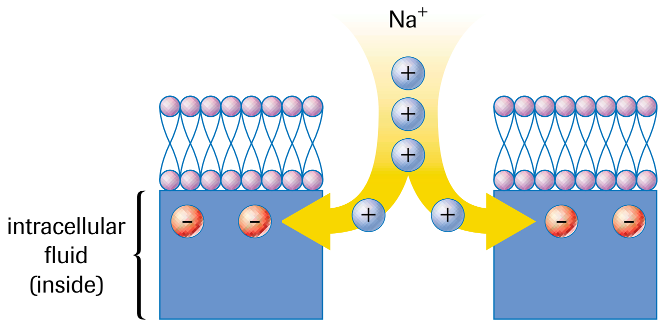

Figure 14
A strong enough stimulus can open "gates," allowing positively charged sodium ions to rush into the cell. The inrush causes the interior surface of the membrane to attain, momentarily, a higher potential than the exterior.

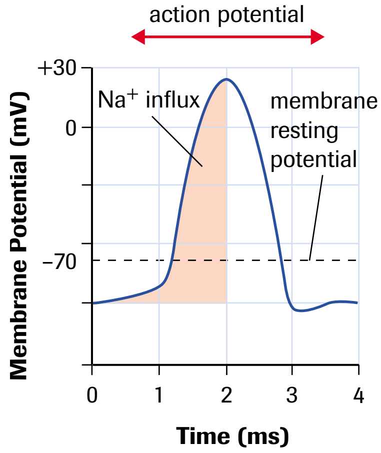

Figure 15
As the sodium ions rush in, the action potential starts. The electric potential difference across the membrane changes from −70 mV to +30 mV, then back to −70 mV.

the interior of the cell is momentarily positive, with the electric potential difference changing very rapidly from –70 mV to +30 mV. The gates then close and the electric potential difference quickly returns to normal. This cycle of potential changes, called the action potential, lasts only a few milliseconds. The cycle creates an electrical signal that travels down through the axon at about 50 m/s to the next neuron or muscle cell (**Figure 15**).

These changes in electric potential in neurons produce electric fields that have an effect on the electric potential differences measured at different points on the surface of the body ranging from 30 to 500 μV. The activity of the heart muscle causes such electric potential differences; measuring these changes is called electrocardiography. If the heart is healthy, its regular beating pattern will produce a predictable change in the electric potential difference between different points on the skin that doctors can use as a diagnostic tool. A graph of electric potential difference versus time between two points on the skin of a patient is called an electrocardiogram (EKG); the shape of the graph depends on how healthy the heart is and the placement of the two measuring points on a patient (**Figure 16**).

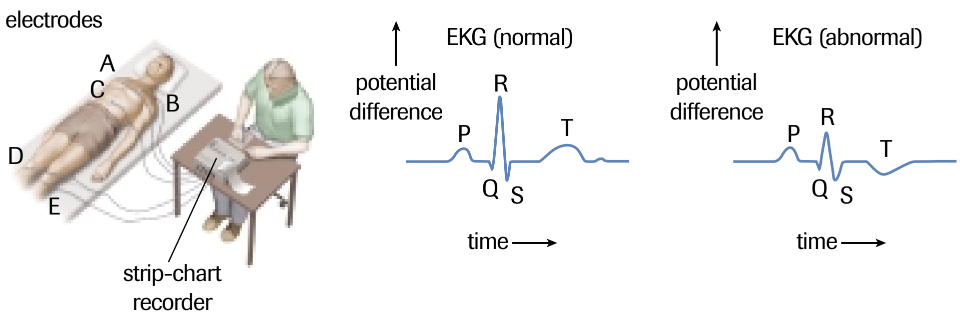

Figure 16
Electrocardiography measures the electric potential difference between any of the two points shown on the patient. The graphs represent normal and abnormal EKGs, with specific parts of a single beating cycle labelled.

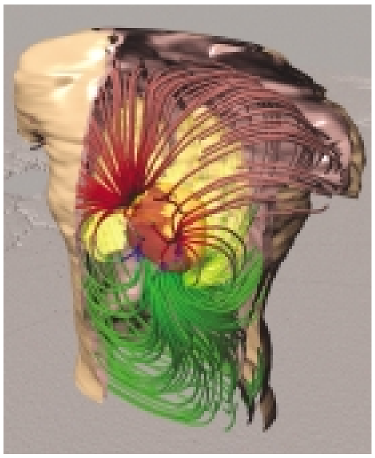

Figure 17
A map of potential differences over the skin caused by heart-muscle activity.

The main features of a normal electrocardiogram are labelled P, Q, R, S, and T in **Figure 16**. The first peak (P) indicates the activity of the atria in the upper portion of the heart. QRS shows the activity of the larger, lower ventricles. T indicates that the ventricles are preparing for the next cycle. **Figure 17** is a map of the potentials on the skin.

Answers

6. (b) 1.4×10^7 N/C
   (c) $+1.1 \times 10^{-20}$ J

Practice

Understanding Concepts

5. Thunderclouds develop a charge separation as they move through the atmosphere.
   (a) What causes the attraction between the electrons in the cloud and the ground?
   (b) What kind of charge will be on a lightning rod as a negatively charged cloud passes overhead? Explain your answer.
   (c) Explain why lightning is more likely to strike a lightning rod than other places nearby.

6. The electric potential difference between the inside and outside of a neuron cell membrane of thickness 5.0 nm is typically 0.070 V.
   (a) Explain why the inner and outer surfaces of the membrane can be thought of as oppositely charged parallel plates.
   (b) Calculate the magnitude of the electric field in the membrane.
   (c) Calculate the work you would have to do on a single sodium ion, of charge $+1.6 \times 10^{-19}$ C, to move it through the membrane from the region of lower potential into the region of higher potential.

SUMMARY Electric Potential

- The electric potential energy stored in the system of two charges q_1 and q_2 is $E_E = \frac{kq_1q_2}{r}$.
- The electric potential a distance r from a charge q is given by $V = \frac{kq}{r}$.
- The potential difference between two points in an electric field is given by the change in the electric potential energy of a positive charge as it moves from one point to another: $\Delta V = \frac{\Delta E_E}{q}$
- The magnitude of the electric field is the change in potential difference per unit radius: $\varepsilon = \frac{\Delta V}{r}$

Section 7.4 Questions

Understanding Concepts

1. The electric potential 0.35 m from a point charge is +110 V. Find the magnitude and sign of the electric charge.

2. Charge q_1 is 0.16 m from point A. Charge q_2 is 0.40 m from point A. The electric potential at A is zero. Calculate the ratio $\frac{q_1}{q_2}$ of the two charges.

3. Draw two equal positive point charges and connect them with a line.
   (a) Is there a point on the line at which the electric field is zero?
   (b) Is there a point on the line at which the electric potential is zero?
   (c) Explain the difference between the two answers.

4. Explain the difference between each of the following:
   (a) electric potential and electric field
   (b) electric potential and electric potential energy

5. The electric potential at a point is zero. Is it possible for the electric field at that point to be nonzero? If "yes," give an example. If "no," explain why not.

6. A particle moves from a region of low electric potential to a region of high electric potential. Is it possible for its electric potential energy to decrease? Explain your answer.

7. Two parallel plates are connected to a 120-V DC power supply and separated by an air gap. The largest electric field in air is 3.0×10^6 N/C. (When this "breakdown value" is exceeded, charge is transferred between the plates, reducing the separated charge and the field through sparks or arcing.) Calculate the smallest possible gap between the plates.

8. Three charges are placed at the corners of an equilateral triangle with sides of length 2.0 m, as shown in **Figure 18**.
(a) Calculate the total electric potential energy of the group of charges.
(b) Determine the electric potential at the midpoint of each side of the triangle.

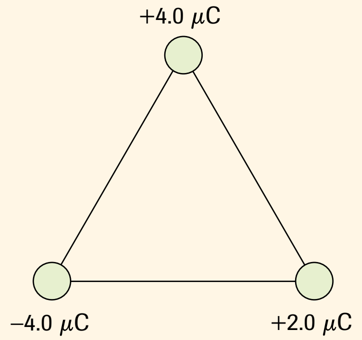

Figure 18

9. **Figure 19** shows a typical Van de Graaff generator with an aluminum sphere of radius 12 cm, producing an electric potential of 85 kV near its surface. The sphere is uniformly charged so we can assume that all the charge is concentrated at the centre. Notice that the voltmeter is connected to the ground, meaning Earth's electric potential is being set as zero.

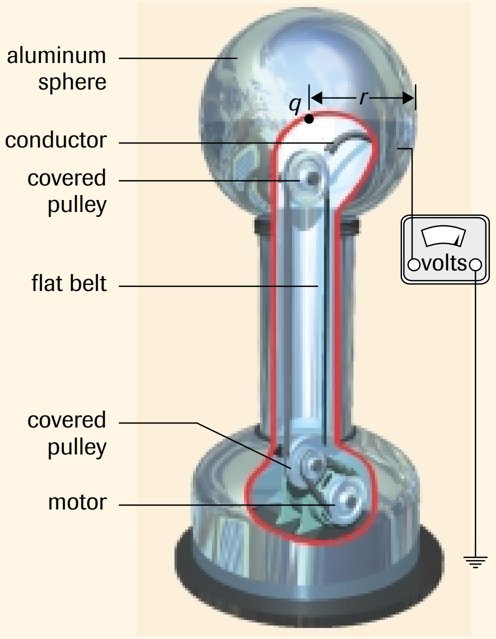

Figure 19
Measuring the electric potential difference near a Van de Graaff generator

(a) Calculate the charge on the sphere.
(b) Calculate the magnitude of the electric field near the surface of the sphere.
(c) Is there likely to be a discharge (a spark or arc) from the surface due to ionization of the air? Explain your answer.

Applying Inquiry Skills

10. Design an experiment to show that two conducting spheres connected by a long wire are at the same electric potential.

11. Researchers place two oppositely charged plates, a negatively charged sphere, and a positively charged sphere near three different lightning rods. They wait for a thunderstorm to pass overhead and monitor the situations by computer in a lab. Discuss what the scientists might observe about the charges and explain why it would happen.

Making Connections

12. Explain how a spark plug operates by examining **Figure 20** and discussing the following factors:
(a) the small gap (0.75 mm) between the two metal conductors
(b) the breakdown value (1.6×10^4 N/C) between the conductors
(c) the changes in the electric potential across the two conductors while the spark plug is operating

Figure 20
Typical spark plugs

13. Some researchers believe that lightning rods can actually prevent lightning from forming at all. Discuss how the ions formed near the tip of lightning rods might play a role in lightning prevention.